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Achieving Carbon Neutrality Pledge through Clean Energy Transition: Linking the Role of Green Innovation and Environmental Policy in E7 Countries

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Abstract: Most countries, notably those that signed the Paris Climate Agreement, prioritize achieving the zero carbon or carbon neutrality aim. Unlike earlier studies, this one assesses the contribution of environmental policy, clean energy, green innovation, and renewable energy to the E7 economies' achievement of carbon neutrality goals from 1990 to 2019. Findings emanating from the study show that the EKC hypothesis is valid in E7 countries. Implying that emissions in the E7 countries increased with the kick-off of development but declined later due to possible potent environmental regulatory policies put in place. Similarly, across all models, renewable energy (REN), green innovations (GINNO), environmental tax (ETAX), and technological innovations (TECH) were found to exert a negative and significant impact on carbon emissions in the E7 countries both in the short and long run. On the other hand, economic expansion (GDP) positively impacts environmental deterioration. Furthermore, the country-specific result shows that, on average, Brazil, India, China, Russia, Mexico, and Indonesia have significant environmental policies aiding carbon abatement. Except for Brazil, Mexico, and Indonesia, the income growth in the rest of the countries does not follow the EKC proposition. Furthermore, the causality result revealed a unidirectional causal relationship between GDP, REN, and GINNO to CO_2 emission. No causality was found between ETAX with CO_2, while a bi-directional causality exists between technology and CO_2 emissions. Based on the finding, policymakers in the E7 countries should move away from fossil fuels because future electricity output will not be sufficient to reduce emissions considerably. Environmental regulations, encouraging technological innovation, adopting green and sustainable technology, and clean energy sources, among other things, demand radical and broad changes.

Keywords: CO_2 emissions; green technology; zero carbon; EKC; clean energy; E7 nations

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1. Introduction

Today, solving the environmental problem has grown as a significant topical issue facing the world, including global warming, environmental pollution, and climate change. These environmental issues are driven by the ever-increasing emission of greenhouse gases caused by the persistent burning of fossil fuels and the case of industrialization, which has a significant change in the world. As countries compete for the few available resources, an abundance of energy is required to harness these resources to their optimal use fully. The process, over time, has led to an increase in carbon emissions. However, as countries search for alternative means of tapping these resources, global environmental experts have continued to press home the importance of achieving carbon neutrality through clean energy means other than fossil fuels. To achieve this target, the united nation organizes an annual climate change conference to address some of the general issues affecting the environment. For countries to achieve carbon neutrality, certain pledges and commitments must be made; thus, one of the pledges at the recent climate change conference known as COP26 focused on attaining a net zero carbon before 2050.

With the growing space of greenhouse gas emissions, recent studies by Hossain et al. [1] prove that a sound fiscal policy such as environmental tax will serve as a good instrument in achieving carbon neutrality. Globally, there is a need to revamp and modernize the current tax systems to address pressing global environmental and economic issues that are ever increasingly clear. These issues include changing technology, shifting demographics, growing inequality, and the triple environmental crises of biodiversity loss, climate change, and excessive resource consumption [2,3]. It is time for environmental taxes and carbon pricing policies to take the lead. As we move toward a climate-neutral economy, their importance and significance will only grow. However, these economic tools must adhere to the idea of "getting the prices right," following the polluter pays principle to promote the sustainability transition. Policy discussions should no longer focus on how environmental levies, particularly carbon pricing systems, generate income [4].

There is constant discussion about whether economic growth can be maintained while combating climate change and maintaining broader environmental standards. There are many different opinions, from the viewpoint that environmental constraints do not constrain economic growth to that sustained economic growth is incompatible with environmental constraints [5]. It is clear from previous studies [6–8] that economic growth plays a potential role in the environment. However, recent studies have shown that economic growth can double, referred to as the environmental Kuznets curve (EKC). In EKC theory, there is an inverse U-shaped relationship between environmental deterioration and per-capita income (Please see Figure 1). This has been interpreted to mean that economic growth will gradually mitigate the negative effects of its early stages on the environment [9]. In recent years, recent literature on this subject has increased. Growth and emissions can be uncoupled by switching from fossil energy to low-carbon renewable resources, which can help maintain current or even increased production levels while lowering emissions [10–13].

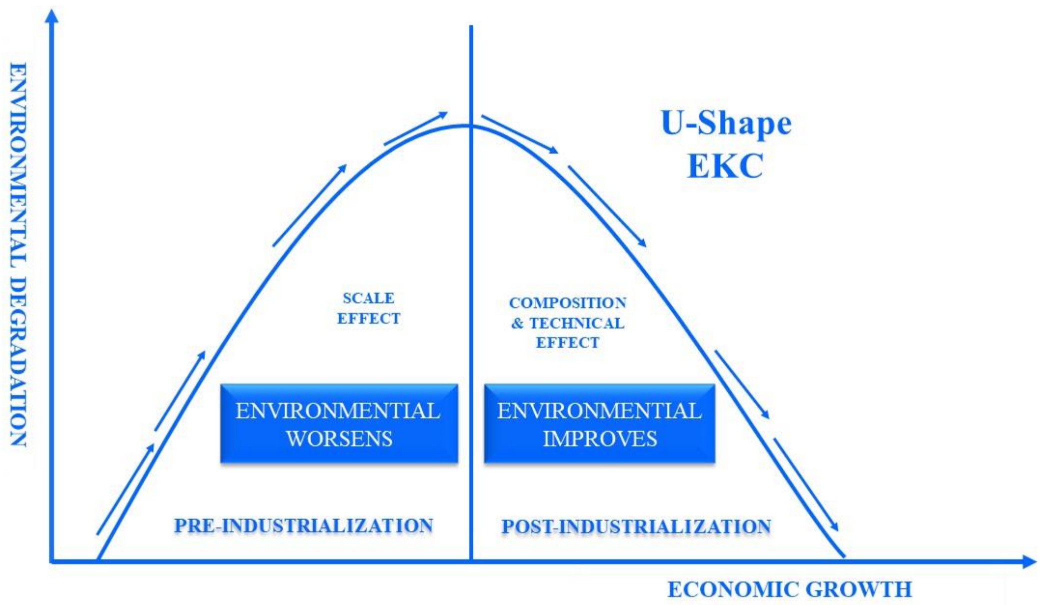

Figure 1. EKC with U-shape, source: author's own illustration.

Numerous studies highlight the crucial and essential function of green energy from renewable resources, including wind, solar energy, biofuel, waves, tides, and geothermal heat, to slow down environmental deterioration over the previous few decades [14]. They also describe the advantages of using eco-friendly green energy sources to reduce CO_2 emissions. Similarly, Kirikkalli and Sowah [15] recognized the benefits of using green energy to help development in economic and environmental spheres. There are many advantages to meeting energy needs with natural renewable energy sources, including reducing imported non-renewable energy sources. Although the use of renewable energy is on the rise, consumption of these resources is still constrained due to their generally high cost and other technical issues in many nations [16]. Innovative, environmentally friendly green technology can significantly contribute to the fight against all environmental pollution-related problems. Innovation in green technology has been employed to revitalize the ecosystem [17]. Green technology is a viable solution for eliminating carbon emissions by incorporating environmentally friendly technologies into current operations to achieve maximum growth at the lowest possible cost to the environment [18]. To achieve carbon neutrality, the intergovernmental panel on climate change (IPCC) also stressed the need to cut and phase out fossil fuel use, utilize more renewable energy, and increase energy efficiency in its special report on global warming of 1.5 °C. The panel also stressed the significance of implementing these measures in cities to attain carbon neutrality [19]. Additionally, it is necessary to encourage carbon reduction or absorption in terrestrial and aquatic ecosystems to attain net-zero carbon emissions and environmental sustainability [20].

The choice of the E7 is driven by the expansion of the global economy, which has afforded newly industrialized nations the potential future that might transform the global economy and make it even more resilient and vibrant. Any emerging country's growth trajectory can be predicted using financial, economic, and demographic factors. There is still a long way to go before the emerging seven countries become a global powerhouse, navigating other economies through the geopolitical seas and choppy economic dividends in the future. This is because several internal and external complexities and policies affect people in these nations. Due to their fast-rising rates of energy consumption and the effects of the accompanying CO_2 emissions, developing economies like the E7 continue to be particularly vulnerable to threats coming from climate change [21]. Figure 2 shows that China has the highest CO_2 emissions among the E7 nations, whereas Turkey has the lowest.

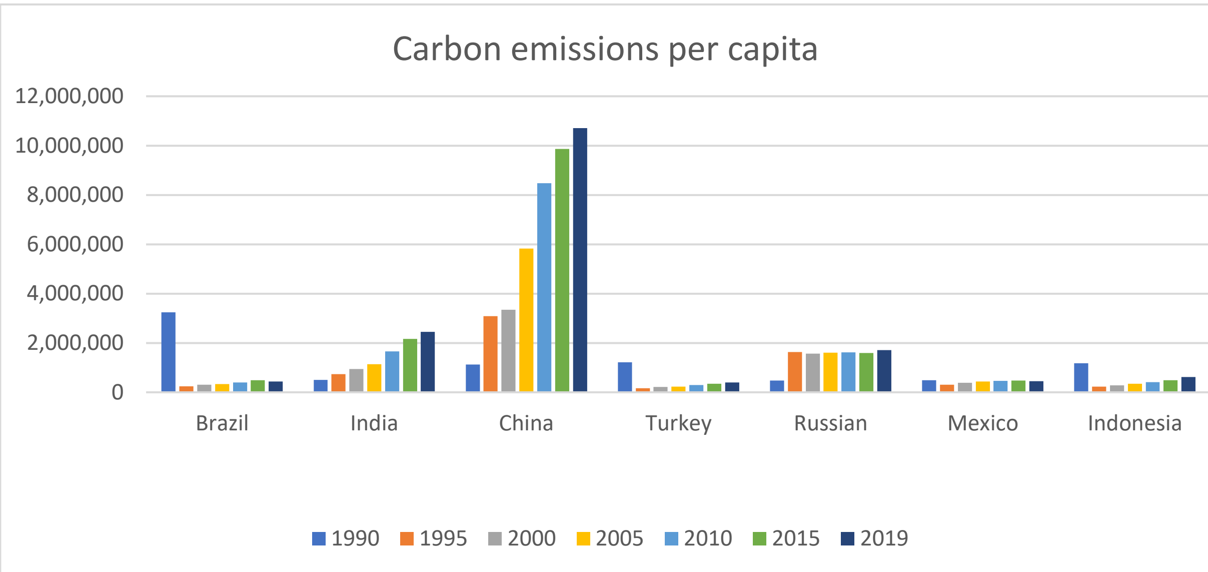

Figure 2. CO_2 emissions (metric tons per capita) in E-7 nations over the test period.

This study investigates the dynamic linkage between clean energy, green technology, environmental policy in the form of taxes and technological innovation, and carbon emission in emerging 7 countries. These countries include China, Turkey, India, Russia, Brazil, Indonesia, and Mexico. Other study objectives include investigating green innovation, clean energy, and environmental policy. Secondly, the study examines if technological innovation helps carbon neutrality accomplish its goal. The third goal is to determine whether green innovation aids in achieving carbon neutrality goals—since most nations are protective of green innovation. The study's final objective is to investigate the validity of EKC in E7 to carbon neutrality.

This study considers new econometric issues as a part of nation-specific traits such as cross-sectional dependencies, endogeneity, and multicollinearity. To address the problems of slope heterogeneity and cross-sectional dependencies, we employ the second-generation panel unit root, Westerlund, panel cointegration test, dynamic common correlated effect mean group (DCEMG) estimators, and augmented mean group (AMG) estimators, and Dumitrescu and Hurlin (D-H) non-causality test.

The structure of this study is as follows. The research and econometric approaches are discussed, followed by a review of the relevant literature on the topic. The section on the empirical results and discussion of outcomes contains the study's findings. The summary of the conclusions and the implementation of the policies make up the closing section.

2. Literature Review

This study is associated with four spectra of literature. First is the one that deals with the nexus between renewable energy and CO_2 emissions; second, the association between technology innovation, green innovation, and environmental degradation; third, the relationship between environment tax and environmental contamination and fourth, the investigations between economic growth and environment in light of the EKC hypothesis. The most recent literature on the subject is presented in Table 1.

Table 1. Previous related studies.

Authors	Countries	Period	Methods	Findings
(A) Renewable Energy-Environment Nexus				
Qayyum et al. [22]	India	1980–2019	FMOLS, DOLS	REN $\rightarrow_{(-)}$ CO2
Usman et al. [23]	South Asia nations	1995–2017	FMOLS, DOLS	REN $\rightarrow_{(-)}$ CO2
Zhang et al. [24]	Top remittance-receiving nations	1990–2018	CUP-FM, CUP-BC	REN $\rightarrow_{(-)}$ CO2
Wan et al. [25]	India	1990–2018	VECM, ARDL	REN $\rightarrow_{(-)}$ EF
Rehman et al. [26]	Pakistan	1975–2019	ARDL model	REN $\rightarrow_{(-)}$ CO2
Sheraz et al. [27]	64 BRI countries	2003–2019	Second-generation approach	REN $\rightarrow_{(-)}$ CO2
Sun et al. [28]	MENA region	1991–2019	Second-generation approach	REN $\rightarrow_{(-)}$ CO2
Raihan and Tuspekova [29]	Malaysia	1990–2019	DOLS	REN $\rightarrow_{(-)}$ CO2
Khan et al. [30]	4 East Asian economies	1997–2020	PMG	REN $\rightarrow_{(-)}$ CO2
Khan et al. [31]	Global economies	2002–2019	Second-generation approach	REN $\rightarrow_{(-)}$ CO2
Yunzhao, [32]	E-7 nations	1985–2018	CUP-FM, CUP-BC	REN $\rightarrow_{(-)}$ CO2
(B) Technology Innovation–Green Innovation-Environment Nexus				
Jahanger et al. [33]	73 Developing nations	1990–2016	PMG approach	TECH $\rightarrow_{(-)}$ EF
Yang et al. [34]	BICS nations	1990–2016	Second-generation approach	TECH $\rightarrow_{(-)}$ EF
Lin and Ma, [35]	China	2006–2017	Quantile regression	TECH $\rightarrow_{(-)}$ CO2
Ma et al. [36]	China	2006–2017	Second-generation approach	TECH $\rightarrow_{(-)}$ CO2
Abid et al. [37]	G8 nations	1990–2019	FMOLS	TECH $\rightarrow_{(-)}$ CO2
Obobisa et al. [38]	25 African countries	2000–2018	CCEMG, AMG	TECH $\rightarrow_{(-)}$ CO2
Chishti and Sinha, [39]	BRICS nations	1990–2019	CCEMG, AMG	TECH $\rightarrow_{(-)}$ CO2
Usman and Hammar, [40]	APEC nations	1990–2017	CCEMG, AMG	TECH $\rightarrow_{(+)}$ EF
Adebayo et al. [41]	BRICS nations	1990–2017	Quantile regression	TECH $\rightarrow_{(+)}$ EF
Xu et al. [42]	China	2007–2013	Spatial econometric model	GINNO $\rightarrow_{(-)}$ CO2
Razzaq et al. [43]	Top 10 GDP countries	1995–2018	MMQR approach	GINNO $\rightarrow_{(-)}$ CO2
Meng et al. [44]	BRICST	1995–2020	CS-ARDL	GINNO $\rightarrow_{(-)}$ CO2
Liu et al. [45]	China	2000–2019	Fixed effect regression	GINNO $\rightarrow_{(-)}$ CO2
Koseoglu et al. [46]	Top 20 green innovator countries	1993–2016	Second-generation approach	GINNO $\rightarrow_{(-)}$ CO2
Latief et al. [47]	Mediterranean countries	2001–2016	Quantile regression, GMM	GINNO $\rightarrow_{(-)}$ CO2

Table 1. *Cont.*

Authors	Countries	Period	Methods	Findings
(C) Environment Tax-Environment Nexus				
Doğan et al. [48]	G7 nations	1994–2014	Second-generation approach	ETAX $\rightarrow_{(-)}$ CO2
Yunzhao, [49]	E-7 nations	1995–2018	CUP-FM, CUP-BC	ETAX $\rightarrow_{(+)}$ CO2
Dogan et al. [50]	25 nations	1994–2018	Quantile regression	ETAX $\rightarrow_{(-)}$ CO2
Hao et al. [51]	G7 nations	1991–2017	CS-ARDL	ETAX $\rightarrow_{(-)}$ CO2
Khan et al. [52]	19 EU nations	1990–2019	MMQR approach	ETAX $\rightarrow_{(-)}$ CO2
Safi et al. [53]	G7 nations	1990–2019	Second-generation approach	ETAX $\rightarrow_{(-)}$ CO2
Ma et al. [54]	China	1995–2019	Second-generation approach	ETAX $\rightarrow_{(-)}$ CO2
Hsu et al. [55]	China	1990–2019	QARDL approach	ETAX $\rightarrow_{(-)}$ CO2
(D) Economic Growth-Environment Nexus				
Usman and Jahanger [56]	93 Nations	1990–2016	Quantile regression	(U)EKC
Jahanger, [57]	78 Nations	1990–2016	GMM approach	(U)EKC
Li et al. [58]	MINT nations	2000–2020	FMOLS, DOLS approaches	(U)EKC
Koc and Bulus, [59]	Korea nation	1971–2017	ARDL	(N)EKC
MassagonyandBudiono, [60]	Indonesia	1970–2019	FMOLS, DOLS	(NO)EKC
Pata and Aydin, [61]	Top six hydropower energy-consuming nations	1965–2016	Fourier Bootstrap ARDL procedure	(NO)EKC
Jahanger et al. [62]	78 Nations	1990–2016	2SLS approach	(U)EKC
Li et al. [63]	89 OBOR nations	1995–2017	Second-generation approach	(U)EKC
Maranzano et al. [64]	17 OECD nations	1950–2015	2SLS regression	(U)EKC
Jahanger et al. [65]	Malaysia	1965–2018	QARDL approach	(U)EKC
Boubelloutaand Kusch-Brandt, [66]	30 European countries	2008–2018	Panel quantile regression	(N)EKC
Balsalobre-Lorente et al. [67]	PIIGS countries	1990–2019	DOLS	(U)EKC

Notes: +, − correspondingly indicate positive, negative.

The first group of studies in part (A) focuses on the association between renewable energy use and environmental degradation. Many scholars and policymakers argue that Increases in renewable energy utilization decrease environmental contamination. Qayyum et al. [22] reveal that REN decreased pollution in India's economy from 1980–2019 by employing FMOLS regression. Moreover, Usman et al. [23] analyze the association between environmental contamination and REG for South Asian nations by applying the FMOLS and the DOLS from 1995–2017 and conclude that REN decreases emissions. For the case of top remittance-receiving nations, Zhang et al. [24] find that REN leads to environmental upgrades using the CUP-FM and CUP-BC models from 1990–2018. The study of Wan et al. [25] reaches the same conclusion for India's economy using the VECM and ARDL models from 1990–2018. In addition, Rehman et al. [26] scrutinize the long relationship between REN and environmental contamination in Pakistan over the period 1975–2019 using the ARDL model and indicate that REN minimizes pollution. Some other researchers also reach the same conclusion, such as Sheraz et al. [27] for 64 BRICS nations, Sun et al. [28] for the MENA region, Raihan and Tuspekova [29] for Malaysia's economy, Khan et al. [30] for 4 East Asian economies, Khan et al. [31] for global sample data and Yunzhao [32] for E-7 nations.

Second, technological innovation (TECH) and green innovation (GINNO) have been key to SDGs without compromising on the environment. From the theoretical viewpoint, the ecological modernization theory holds that human-induced environmental contamination can be counteracted by increasing resource efficiency by developing green technology and innovation. Most scholars believe that TECH helps reduce environmental contamination and improve environmental excellence. For example, for the case of 73 developing nations, Jahanger et al. [33] find that TECH leads to environmental enhancements by using the PMG model from 1990–2016. Moreover, Yang et al. [34] investigate the impacts of TECH and the environment on BRICS nations over the period 1990-2016 using the second-generation model and show that renewable TECH mitigates environmental contamination. Other scholars also reach the same finding, for instance, Lin and Ma [35]; Ma et al. [36] in the case of China; Abid et al. [37] G8 nations; Obobisa et al. [38], 25 African countries; Chishti and Sinha [39] BRICS nations, etc. Other scholars believe that TECH may be demeaning environmental excellence, for example, Usman and Hammar [40] in the case of APEC nation. Many scholars also believe that GINNO helps reduce environmental contamination [41–47].

Third, many scholars and policymakers argue that an environmental tax is important to minimize environmental contamination. Such as, Doğan et al. [48] G7 nations, Yunzhao [49] E-7 nations; Dogan et al. [50] 25 nations; Hao et al. [51] G7 nations; Khan et al. [52] 19 EU nations; Safi et al. [53] G7 nations; Ma et al. [54] and Hsu et al. [55] in case of China. Fourth, in the literature on the environment, almost no subject confines the scholar's notice more than the GDP-pollution nexus. The EKC is perhaps the hypothesis that received considerable debate and controversy. The world is currently confronted by two key challenges; attaining maximum GDP and protecting the environment. Part (D) in Table 1 presents studies that examine the relationship between GDP and environmental contamination. One group of researchers, such as Usman and Jahanger [56] 93 global nations; Jahanger [57] and Jahanger et al. [62] 78 developing nations; Li et al. [58] MINT nations; Li et al. [63] 89 OBOR nations; Maranzano et al. [64] 17 OECD nations; Jahanger et al. [65] Malaysia; Balsalobre-Lorente et al. [67] in case of PIIGS countries. On the contrary, the EKC is examined but not supported for Indonesia [60] and; Top six hydropower energy-consuming nations [61].

The study provides an inclusive review of existing studies, such as the nexus between renewable energy use, technological innovation, green innovation, environment tax, economic growth, and environment (as present in Table 1). Still, none of them have explored renewable energy use, technological innovation, Green innovation, environment tax, and environment in the EKC hypothesis framework, especially in the context of E-7 nations. Hence, the primary purpose of our current paper is to curtail the research gap in the extant literature.

3. Methodology and Data

3.1. Theoretical Motivation

This section describes the theoretical framework by which environmental policies such as tax, renewable energy, and green innovation influence the carbon neutrality target. First, environmental policies, interpreted as environmental taxes, are applied to the economy and the environment. One way to lower carbon emissions is to implement environmental taxes, such as carbon taxes; according to Alola et al. [68] and Gulati and Gholami [69], environmental-related taxes specifically decreased gasoline sales, petrol sales, and natural gas use, which in turn decreased carbon emissions [70] and carbon emissions. But according to the decision-makers, environmental taxes can negatively affect the economy [49]. Green innovation aids in the restructuring of the industrial sector. In the transition phase, the production of industries would switch from low value-added to high value-added, further supporting the nation's economy [71]. The environmental Kuznets curve (EKC) hypothesis, the "pollute now and grow later" tenet, and the "carbon curse theory" are among the theories that explain the factors influencing environmental quality. According to Friedrichs and Inderwildi's [72] primer on the carbon curse idea, nations with a large fossil fuel industry tend to have high carbon intensity levels. The modeling strategy from the existing literature is expanded upon in this study by Qui et al. [73]; Okere et al. [74]; Alola et al. [68]. According to the notion of growth-induced EKC, GDP per capita has a significant impact on carbon emissions [74–76].

3.2. Data Description

Our study uses annual and balanced data from the estimated dataset from 1990 to 2019 in E7 countries (China, Turkey, India, Russia, Brazil, Indonesia, and Mexico, please see Figure 3 for the geographical coverage of E7 nations). Following the COP26 pledge, E7 countries' commitment to achieving a net zero aim by 2050 plays a significant role in selecting countries. The empirical specification used in this study, which is based on an existing empirical model, serves as the foundation and analysis for the investigation. The summary of the data is presented in Table 2 below.

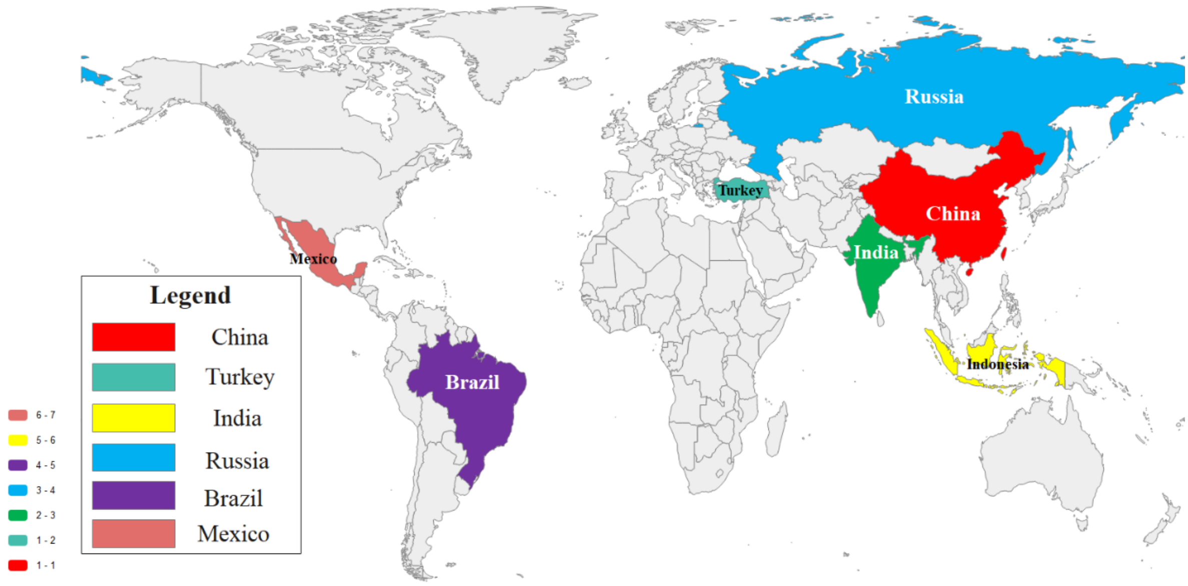

Figure 3. Geographical coverage of E7 nations.

Table 2. Description of Variables.

Variables	Symbol	Unit of Measurement	Sources
Carbon emissions	CO_2	Kiloton (kt)	[75] WDI 2021
GDP per capita	GDP	In constant 2010 USD	[75] WDI 2021
GDP^2	GDP^2	GDP Squared	Author's computation
Renewable energy	REN	Metric tons	[75] WDI 2021
Technology innovation	TECH	Patent of resident	[75] WDI 2021
Environment tax	ETAX	% of GDP	[76] OECD 2021
Green innovations	GINNO	Environmental patents and technologies	[76] OECD 2021

Author's computation.

3.3. Model Specification

Based on the aforementioned theoretical framework, this study uses three primary independent variables that potentially affect CO_2 emissions: environmental policy, renewable energy, and green innovation. The theoretical framework also suggests the significance of GDP in reducing carbon emissions. Therefore, the environmental Kuznets curve in E7 countries was verified in this study using the GDP (i.e., GDP^2) square term. In addition, the theoretical idea also highlights the significance of researching and developing renewable energy and technology as a crucial element to consider for reducing CO_2 emissions. The general expression of the model is provided as follows:

$$CO_{2.it} = f\left(GDP_{it}, GDP_{it}^2, REN_{it}, TECH_{it}, ETAX_{it,} GINNO_{it}\right) \quad (1)$$

GDP represents the gross domestic product, GDP^2 is the square of GDP, REN is renewable energy, TECH represents technology innovation, ETAX represents environmental tax/policy, and GINNO represents green innovation. The letters "i"and "t" in the subscript stand for the cross-section and the time or year, respectively. In terms of estimations, we used a precise general strategy to gradually examine each independent variable's impact on CO_2 emissions. As a result, we develop five models using the regression form for each method from Equation (1), which are listed as follows:

- **Model-1**

$$CO_{2,it} = \alpha_{it} + \beta_{1it}GDP_{it} + \beta_{2it}GDP_{it}^2 + \mu_{it} \quad (2)$$

Model-1 uses the square of economic growth and two independent variables to represent economic growth to confirm EKC.

- **Model-2**

$$CO_{2,it} = \alpha_{it} + \beta_{1it}GDP_{it} + \beta_{2it}GDP_{it}^2 + \beta_{3it}REN_{it} + \mu_{it} \quad (3)$$

To determine the renewable energy effect on carbon emissions and economic growth, Model-2 is also included in addition to Model-1.

- **Model-3**

$$CO_{2,it} = \alpha_{it} + \beta_{1it}GDP_{it} + \beta_{2it}GDP_{it}^2 + \beta_{3it}REN_{it} + \beta_{4it}GINNO_{it} + \mu_{it} \quad (4)$$

The green innovation is added as an independent variable to Model-2 in a specific to a general method, forming Model-3.

- **Model-4**

$$CO_{2,it} = \alpha_{it} + \beta_{1it}GDP_{it} + \beta_{2it}GDP_{it}^2 + \beta_{3it}REN_{it} + \beta_{4it}GINNO_{it} + \beta_{5it}ETAX_{it,} + \mu_{it} \quad (5)$$

Model-4 is developed as an extension to Model-3 using an exogenous environmental tax variable that affects CO_2 emissions.

- **Model-5**

$$CO_{2,it} = \alpha_{it} + \beta_{1it}GDP_{it} + \beta_{2it}GDP_{it}^2 + \beta_{3it}REN_{it} + \beta_{4it}GINNO_{it} + \beta_{5it}ETAX_{it,} + \beta_{5it}TECH_{it} + \mu_{it} \quad (6)$$

To determine technology's effect on CO_2 emissions, it is included in the final model as an independent variable.

3.4. Econometric Approaches

3.4.1. Cross-Section Dependence and Slope Heterogeneity

We check the panel data's cross-section dependence and slope heterogeneity as the first steps in our research. Countries on the panel may resemble one another in certain ways while differing in others. In contrast, homogeneous economic characteristics in the econometric analysis may result in skewed results, particularly in panel estimations. Therefore, the concerned set of countries must be homogeneous (i.e., E7 economies). In this context, we used the slope coefficient homogeneity (SCH) test proposed by Pesaran and Yamagata [77] while considering coefficients parallel to the null hypothesis. The general Equations (7) and (8) for the earlier tests are as follows:

$$\hat{\Delta}_{SCH} = (N)^{1/2}(2K)^{-\frac{1}{2}}\left(\frac{1}{N}S - K\right) \quad (7)$$

$$\hat{\Delta}_{SCH} = (N)^{1/2}\left(\frac{2K(T-K-1)}{T+1}\right)^{-1/2}\left(\frac{1}{N}S - K\right) \quad (8)$$

To examine cross-section reliance among the E7 nations, we used the Pesaran (2004) cross-section dependence (CD) test. The relevant test is presented as Equation (9) in its general form, with the independence of the cross-sections serving as the null hypothesis.

$$\begin{gathered} CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\beta}_{ik}\right) \sim N(0,1)i,k \\ CSD = (1, 2 \ldots\ldots\ldots\ldots 20 \ldots\ldots N) \end{gathered} \quad (9)$$

3.4.2. Panel Unit Root

We next proceeded to examine the unit root or stationarity in the chosen panel after the results for cross-section dependence and heterogeneity. Dealing with data that includes cross sections and time series simultaneously requires constant attention. To address the problem of the heterogeneous panel and resolve the cross-section dependence issue between the units, we employed the panel unit root test, such as IPS "(2003)" proposed by I'm et al. [78] and CIPS (2007) produced by Pesaran, [79]. The null hypothesis for these tests was that the unit root did not exist in the data. The following is the equation for the CADF and CIPS:

$$\Delta y_{it} = \alpha_i + \pi_i y_{i,t-1} + \varphi_i \, \overline{y}_{t-1} + \sum_{l=0}^{p} \varnothing_{il} \Delta\overline{y}_{t-1} + \sum_{l=1}^{p} \gamma_{il} \Delta\overline{y}_{i,\,t-1} + \in_{it} \quad (10)$$

In Equation (10), $\overline{y}_{t-1}$ and $\Delta\overline{y}_{t-1}$ are averages for the lagged and first differences of each cross-section series. The CIPS is estimated as follows;

$$\text{CIPS} = \frac{1}{N}\sum_{i=1}^{N} \text{CADF}_i \quad (11)$$

3.4.3. Panel Cointegration Test

The Westerlund [80] method is used in this study's cointegration approach to shed light on the cointegration of the variables. The estimation's error rectification method (ECM) is presented as follows:

$$\Delta X_{i,t} = \alpha_i^{\prime}\delta_i + \beta_i\left(Y_{i,t-1} - \theta_i^{\prime} X_{i,t-1}\right) + \sum_{j=1}^{q} \beta_{i,j}\Delta Y_{i,t-j} + \sum_{j=0}^{q} \varphi_{i,j}\Delta X_{i,t-j} + \varepsilon_{i,t} \quad (12)$$

where: The adjustment coefficient I show the term for the error coefficient and the rate of correction in the direction of equilibrium. The dependent and independent variables are $Y_{i,t}$ and $X_{i,t}$, respectively, and the difference operator is Equation (12) above predicts four separate tests from the estimate.

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N} \frac{\theta_i}{S.E(\hat{\theta}_I)} \quad (13)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N} \frac{T\theta_i}{\theta_I^{\prime}(1)} \quad (14)$$

$$P_\tau = \frac{1}{N}\sum_{i=1}^{N} \frac{\theta_i}{S.E(\hat{\theta}_I)} \quad (15)$$

$$P_a = T\hat{\theta} \quad (16)$$

H1: I 0 for at least I is the alternative to the non-cointegration hypothesis that exits in at someone of the cross-sections (H.O.: I = 0 for all values of I. However, panel statistics (Pt and Pa) combine data from all cross-sectional units to predict the null hypothesis (H.O.: I = 0) for all values of I against the alternative (H1: I = 0) for all I and provide a method for determining whether cointegration exists across the entire panel.

3.5. Dynamic Common Correlated Effects (DCCE)

Chudik and Pesaran, [81] created this method to address the issue of cross-sectional dependence. It effectively estimates both short- and long-run outcomes for heterogeneous data panels. It is based on the guidelines for PMG estimation developed by Pesaran et al. (1999) and M.G. estimation developed by Pesaran and Smith [82]. The common correlated effects (CCE) method was introduced by Pesaran [83], then carefully implemented by Sharma et al. [84], Chaudhry et al. [85], and Ali et al. [86].

The DCCE can be written as follows.

$$Y_{it} = \beta_i Y_{it-1} + \delta_i X_{it} + \sum_{P=0}^{P_r} \gamma_{xip} X_{t-p} + \sum_{P=0}^{P_r} \gamma_{xip} X_{t-p} + \varepsilon_{it} \quad (17)$$

The lag between the time it takes for carbon emission to reach its long-term equilibrium has been accounted for in the model by adding a one-period lag. Where the variables Y_{it} and Y_{t-1} stand for the parameter and the lag used to act as an independent variable. A vector of explanatory variables, X_{it} and two unobserved factors, X_{ip} and Y_{iP}, are present. The cross-sectional mean lags are represented by pt and it, and the set of cross-sectional and time dimensions are represented by t and the random error term. Using the AMG estimator from Eberhardt and Bond [87], a thorough investigation is conducted to address the problem of cross-sectional dependence via the common dynamic interplay.

Lastly, we used the Granger causality heterogeneous panel test created by Dumitrescu Urlin [88] to determine whether there was a causal relationship between all the variables under investigation. This test is effective when the time series and cross-sections are not parallel (i.e., T = N). Additionally, this method effectively handles the panel data's cross-section dependency and heterogeneity. The causality of D.H. is expressed as:

$$Y_{it} = \vartheta_i + \sum_{k-1}^{k} \varnothing_{ik} Y_{i,t-k} + \sum_{k-1}^{k} \delta_{ik} X_{i,t-k} + \varepsilon_{it} \tag{18}$$

where the coefficients of $Y_{i,t-k}$, and $X_{i,t-k}$ the Ho is δ_{ik}, and $\varnothing_{ik}$: i1 = . . . =: $\delta_{ik} = 0, \forall_i = 1$, . . . , N is compared to the opposing hypothesis H1: δ_{ik} and $\varnothing_{ik}$: i1 = . . . =: $\delta_{ik} = 0, \forall_i = 1$, . . . , N_1 with $\delta_{ik} \neq$ or . . . $\delta_{ik} \neq 0\forall = N_1 + 1, \ldots, N$.

Table 3 describes the nomenclature of the dataset used in the current study, the correlation between the explanatory interest variables and the dependent variable, and the slope heterogeneity test. As revealed in Table 1, carbon dioxide emissions (LNCO2) show variation across the E7 countries; this is indicated by the maximum and minimum values of 16.186 and 11.843, although the variation is not extremely wide. This implies that some E7 countries emit more CO_2 than others, and comparing the maximum and minimum values with the mean value (13.496) gives the impression that most countries fall within the minimum emission boundary, with fewer countries having high emissions. Again, this later outcome may also arise because some countries experienced higher emission rates during certain periods and lower during other periods. A further comparison of the mean and median values (13.065) suggests no reasonable growth in $LNCO_2$ within the sample periods. The GDP per capita (LNGDP) followed the line of LNCO2 as it shows variations in maximum and minimum values of 30.291 and 26.321 but not at extremes with a mean value (27.697) less than the maximum value but above the minimum value. In comparing the mean value (27.697) and the median value (27.619), there seems to be noticeable growth in LNGDP within the sample period. Thus, the E7 country seems to have a steady LNGDP over the sample period, implying a stable economy. The summary statistics of the concerned variables from1990 to 2019 through plot-boxes are shown (see Figure 4).

Furthermore, the rest of the interest variables followed a similar trend as $LNCO_2$ and LNGDP when the interest statistics were compared. The only exception is green innovation (LNGINNO) and environmental tax (ETAX), which have negative minimum values. This implies that some of the sampled E7 countries are still backward in terms of green technology innovations, which are key for environmental management and tax. Possibly they are yet to institute any tax to control environmental degradation. Overall, the data in the Table 2 reveals that the E7 countries have a good structure economy with a good policy framework that is effective and favors every member country.

Furthermore, Table 3 shows the correlation matrix of the interest variable, which is used to check if a good relationship exists between the variables and the dependent variable (LNCO2). It further gives us some insight into the presence of outliers in the model, which, if present, will amount to the problem of multi-collinearity. As revealed by the correlation matrix, a strong positive relationship exists between LNGDP and LNTECH with the dependent variable (LNCO2), while LNGINNO has a weak positive relationship with LNCO2. Furthermore, the dependent variable (LNCO2) has a weak negative relationship with LNREN and ETAX. This significant relationship is within the acceptable range, which permits the investigation of the impact relationship between the dependent and explanatory variables. Similarly, this study does not find any multi-collinearity issues in the model that could result in an illogical regression since the correlation between the various explanatory variables is within the acceptable range. We can then proceed to carry out the rest of the diagnostics tests.

Table 3. Descriptive and Correlation Matrix.

	LNCO2	LNGDP	LNREN	LNGINNO	ETAX	LNTECH
Mean	13.496	27.697	2.9531	1.2495	1.4065	8.1384
Median	13.065	27.619	3.1789	1.3558	1.2173	8.1017
Maximum	16.186	30.291	4.0716	2.6630	4.3564	14.147
Minimum	11.843	26.321	1.1568	−2.5257	−1.7614	3.3672
Std. Dev.	1.1076	0.7976	0.8903	0.9583	0.9880	2.1931
Skewness	0.7334	1.0909	−0.6698	−1.3196	0.3780	0.4426
Kurtosis	2.6323	4.6338	2.3276	5.4530	4.0367	3.2609
Jarque-Bera	20.010	65.013	19.659	113.60	11.799	7.3101
Correlation Matrix						
CO_2	1					
GDP	0.8453	1				
REN	−0.3262	−0.0828	1			
GINNO	0.1139	−0.1584	−0.1193	1		
ETAX	−0.1697	−0.3407	−0.2077	0.3324	1	
TECH	0.8887	0.8744	−0.3848	−0.0863	−0.0567	1
Slope Heterogeneity Test						
($\widetilde{\Delta}$ **test**)	21.19	19.09	20.31	15.90	10.55	9.63
($\widetilde{\Delta}_{adj}$)	23.22	20.12	22.25	17.78	12.48	11.77

The last phase of Table 3 shows the results of the Pesaran and Yamagata [77] Delta tilde and its adjusted counterpart used to check slope heterogeneity. The null hypothesis is normally positive about a homogeneous slope in the panel dataset, whereas the alternative hypothesis is positive about a heterogeneous slope in the panel dataset. From the result at the base of Table 3, we find that the null hypothesis is rejected at 0.05, implying that the slope of the panel dataset is heterogeneous.

The result of the Pesaran CD tests for cross-sectional dependence for each of the variables is presented in Table 4 alongside the unit root tests of CIPS and CADF. The rationale for the cross-sectional dependence test is to check the presence of correlation in the panel. When correlation exists between the cross-sectional entities in a panel, be it countries, states, or firms, such a relationship entails that a shock in one cross-sectional unit will be transmitted to one or more other units in the cross-section. Such an econometrics problem could render the estimated model results unsuitable for policy and forecasting purposes. More so, cross-sectional dependence renders the first-generation unit root and cointegration tests undesirable. Therefore, addressing such issues of cross-sectional dependence will warrant using second generational unit root tests of CIPS and CADF and Westerlund cointegration test. Other estimation techniques that could efficiently correct such problems of cross-sectional dependence were also used. The first column in Table 4 shows the results of the cross-sectional dependence test of Pesaran CD, which reveals the presence of significant cross-sectional dependence. As a result, the second-generation unit root and cointegration tests were used, and the result was presented in the subsequent columns. Accordingly, we find a significant unit root result across the entire variable in the study at first difference. This is true for the CIPS as well as the CADF. At levels I(0), only LNGINNO has significant stationary status from the CADF test; the rest are insignificant except at the first difference I(0). The above outcome from the unit-roots has validated the conformity of the dataset to the prescriptions of econometrics theory.

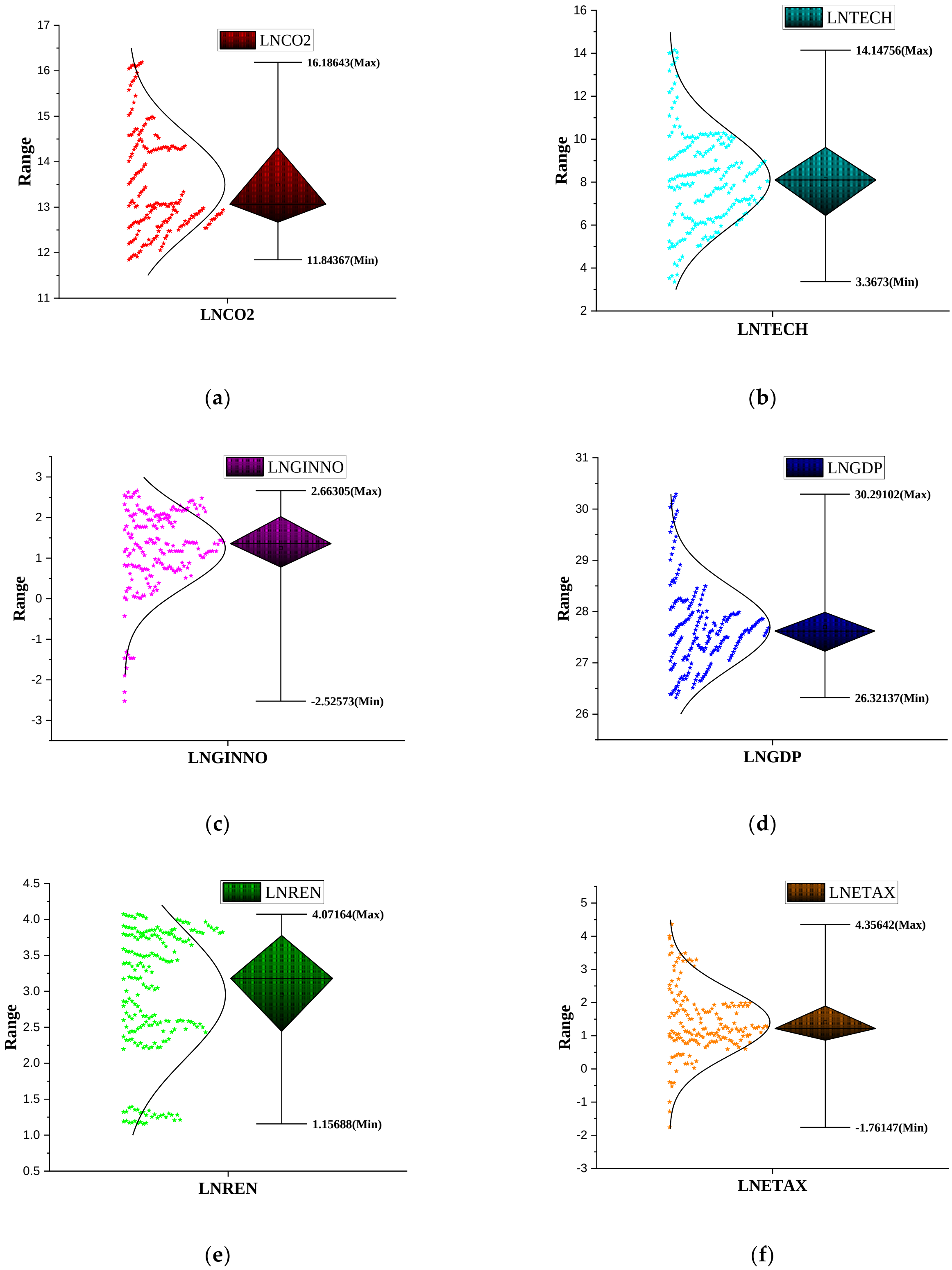

Figure 4. Box plot summary for the investigated variables: (**a**) LNCO2; (**b**) LNTECH; (**c**) LNGINNO; (**d**) LNGDP; (**e**) LNREN; (**f**) LNETAX.

Table 4. Cross-section dependency test and second-generation unit test.

	CD Test	CIPS Level	First Diff	Results	CADF Level	First Diff	Results
GDP	23.14 ***	−0.783	−3.325 ***	1 (1)	17.683	35.256 ***	1 (1)
REN	17.19 ***	1.417	−5.783 ***	1 (1)	11.466	62.270 ***	1 (1)
GINNO	14.38 ***	−0.216 *	−5.307 ***	1 (0)	16.745 **	57.490 ***	1 (0)
ETAX	8.23 ***	0.157	−5.082 ***	1 (1)	17.601	53.020 ***	1 (1)
TECH	19.13 ***	−0.563	−4.289 ***	1 (1)	14.523	44.448 ***	1 (1)

Note: ***, **and * denote statistical significance at 1%, 5% and 10% levels, respectively.

Table 5 presents the Westerlund cointegration test for the various models. The Westerlund cointegration test is a second-generation test that is often used when the first-generation unit root tests such as Pedroni, Kao, and others are no longer suitable as a result of certain econometrics issues such as cross-sectional dependence in the dataset, which raises the possibility of having a spurious regression outcome. The presence of a heterogeneous slope in the panel dataset is another reason for using the Westerlund cointegration test. These twin econometrics issues are very much present in the current study, thereby justifying the use of the Westerlund cointegration test. As indicated by the result, a significant long-run relationship is observed across the different models at the 0.05 conventional significant levels. This implies that a long relationship exists between each model's dependent and explanatory variables, thus validating the estimation of long-run impacts in the current study.

Table 5. Westerlund cointegration results.

Models	G_τ	G_α	P_τ	P_α
Model 1	−0.140 (0.445)	0.171 (0.568)	−0.769 ** (0.049	−1.660 ** (0.032)
Model 2	−3.238 ** (0.011)	−3.250 ** (0.035)	−3.563 (0.345)	−4.234 *** (0.000)
Model 3	−1.232 (0.874)	−5.278 *** (0.000)	−2.295 (0.345)	−2.121 (0.347)
Model 4	−1.847 (0.876)	−7.672 *** (0.000)	−4.721 *** (0.000)	−7.184 *** (0.000)
Model 5	−9.237 *** (0.000)	−3.944 *** (0.003)	−6.324 *** (0.000)	−4.323 ** (0.023)

Note: *** and ** denote statistical significance at 1%, 5% and 10% levels, respectively.

The short run and long run of the dynamic common correlated effect regression result, which is used to investigate the role of clean energy transition in achieving the carbon neutrality pledge in the E7 countries, are presented in Table 6. The result shows that the initial GDP (LNGDP) has a positive and significant impact on CO_2 emissions (LNCO$_2$) in both the short and long run. Implying that the initial economic growth level brought environmental degradation in the E7 countries. This is in line with economic postulations and several research findings. Similarly, the second level of GDP (LNGDPSQ) has a negative and significant impact on LNCO$_2$ in the E7 countries both in the short and long run, indicating that the high environmental deteriorations experienced at the initial growth in the economy aroused the need for environmental sustainability in the E7 countries. This led to adopting green technology in production and economic processes while also establishing the necessary environmental laws and regulations to curb LNCO$_2$. This outcome is true across the various specifications. According to the coefficient values, the long-run impact of LNGDP and LNGDPSQ is stronger than the short-run impact in some specifications. This confirms the existence of an inverted U-shaped curve in the E7 countries, according to the Kuznets hypothesis (EKC). As expected, the ECM value is negative and significant, indicating that 41% of the disequilibrium in the current period will be corrected in the next period, all this being equal. This outcome is in line with the findings from Alola et al. [68] for E.U. countries; Gyamfi et al. [89], who found an inverted U-shaped EKC in the long run rather than the investigated N-shaped curve in the E7 countries, while Kilinc-Ata and Likhachev [90], found same for Russia.

Table 6. Dynamic common correlation effect by (Chudik and Pesaran (2015)).

Variables	Model-1 Coefficients (Std. Errors)	Model-2 Coefficients (Std. Errors)	Model-3 Coefficients (Std. Errors)	Model-4 Coefficients (Std. Errors)	Model-5 Coefficients (Std. Errors)
Short Run ΔGDP	2.090 *** (1.508)	3.341 *** (10.924)	1.277 *** (10.872)	10.590 *** (7.853)	6.672 *** (6.684)
ΔGDPSQ	−0.033 *** (0.274)	−0.056 ** (0.199)	−0.018 ** (0.198)	−0.190 ** (0.141) **	−0.120 *** (0.120)
ΔREN	-	−0.433 *** (0.107)	−0.421 *** (0.093)	−0.465 ** (0.139)	−0.554 *** (0.122)
ΔGINNO	-	-	−0.007 *** (0.010)	−0.007 *** (0.023)	−0.002 *** (0.012)
ΔETAX	-	-	-	−0.022 *** (0.017)	−0.060 *** (0.054)
ΔTECH	-	-	-	-	−0.014 ** (0.041)
ECM(-1)	−0.417 *** (0.000)	−0.662 *** (0.000)	−0.687 *** (0.000)	−0.7834 *** (0.000)	−0.9723 *** (0.000)
Long-Run					
GDP	20.440 *** (28.138)	0.619 *** (17.30)	3.695 ** (1.697)	7.544 *** (6.864)	6.827 *** (6.251)
GDPSQ	0.3932 ** (0.514)	−0.017 ** (0.316)	−0.073 ** (0.073)	−0.135 ** (0.124)	−0.122 *** (0.113)
REN	-	−0.642 *** (0.145)	−0.618 * (0.142)	−0.516 ** (0.163)	−0.580 *** (0.154)
GINNO	-	-	−0.009 *** (0.014)	−0.006 *** (0.023)	−0.001 *** (0.013)
ETAX	-	-	-	−0.018 *** (0.014)	−0.043 *** (0.037)
TECH	-	-	-	-	−0.004 *** (0.154)

Note: ***, **and * denote statistical significance at 1%, 5% and 10% levels, respectively.

Renewable energy (LNREN) negatively and significantly impacts LNCO2 in the E7 countries. By implication, renewable energy plays an important role in meeting the carbon neutrality plan in the E7 countries. Accordingly, renewable energy use has the potential to cut LNCO2 in the E7 countries to the tune of 0.433% for every one-unit increase. This further strengthens the finding from the EKC assessment, where it is revealed that the significant mitigation of environmental degradations at the second phase of economic growth (LNGDPSQ) was a result of various environmentally-friendly measures, which included energy transition and enactment of environmental laws and regulations. This outcome is generally true across all the specifications, both for the short and long run. The only exception is in the third specification, where the long run is significant at 10% and not at the conventional 5% level. According to Gyamfi et al. [89], who had a similar finding for the E7 countries, investment in and increase in the share of renewable energy consumption will help mitigate environmental degradation and, in turn, improve the quality of the environment in the growing efforts in the block.

The study results further show that green innovation (LNGINNO) will significantly promote the achievement of carbon neutrality in the E7 countries, just as indicated across the various specifications for the short and long run. It is argued that poor environmental quality can potentially deplete income (GDP) in the E7 countries. Thus, in agreement with Wu et al. [91], this study holds that green innovation, which could assume the form of green financing and technology or is called eco-friendly innovations, is very potent in environmental sustainability in the E7 countries. Thus, the role of green innovation, according to these findings, goes beyond the short run; it is a major player in achieving carbon neutrality in the E7 countries.

Similarly, the study found that environmental tax (ETAX) significantly promotes environmental sustainability in the E7 countries. This is true for the long and short runs of the various model specifications. Thus, the role of ETAX in achieving carbon neutrality in the E7 countries goes beyond the short run but extends to the long run. According to the premium times, the E7 countries significantly cut CO_2 emissions in 2013 by 1.7%. This effort has not been sustained, and ETAX has gradually grown to become one of the potent instruments for achieving this. Generally, there seems to be an insignificant number of studies that have sought to investigate the role of ETAX in promoting environmental sustainability in the E7 countries. This agrees with Doğan et al. [48], who found that ETAX significantly influences carbon reduction in the E7 countries. Thus, the current study touches on the significant role ETAX plays in achieving carbon neutrality in the short and long run. Others like Doğan et al. [48]; Hao et al. [51]; Safi et al. [53], who assessed the G7 countries, found a similar outcome: that an ETAX effectively reduces emissions and that strict environmental regulations will compel firms to transit from primitive to cleaner production methods.

Furthermore, the study found that across all specifications, in both the short and long run that technological innovation (LNTECH). This finding agrees with Cao [92], who opined that technological innovations (LNTECH) are significant in cutting the level of CO_2 emission in the E7 countries. The E7 countries are fast expanding the level of trade connectedness with the rest of the world in terms of trade (globalization). This has undoubtedly scaled up economic complexity in these countries, which is the bedrock of technological innovation. We agree with Jahanger [57] and Usman et al. [93] that globalization significantly predicts the environment quality in the E7 countries.

Furthermore, model 1 shows evidence of market failure; this is indicated by the coefficient value of 0.41, which is less than the 50% range required for effective market convergence towards long-run equilibrium. The rest of the specifications (models) having an ECM value that is above 50% is an indication that there are no issues of market failure as indicated by the coefficient values and, as such, implies that the market will converge towards the long run equilibrium, ceteris paribus.

The country-specific augmented mean group estimator results in Table 7, used for robustness check, show that Brazil, Mexico, and the Indonesian economy assumed the EKC pattern of inverted U-shaped nature. According to the results, India and China showed signs of an inverted U-shaped curve, only that one of the income variables falls below the acceptable significant level in each case. The case of Russia is positive and insignificant at all levels. Thus, the existing environmental policy in India, China, Turkey, and Russia has not impacted the country's efforts to achieve carbon neutrality. The reason for this may not far fetch as most of these countries still depend on coal and fossil fuel to drive their industrial sector.

Table 7. Country-specific augmented mean group estimator (Bond and Eberhardt, 2009; Eberhardt and Teal, 2010) robustness results.

	Brazil	India	China	Turkey	Russia	Mexico	Indonesia
GDP	46.786 ***	3.469 *	3.531 **	0.716 *	6.450	22.877 **	23.595 ***
GDPSQ	−0.820 ***	−0.063 **	−0.042	0.214 *	0.120	−0.406 **	−0.440 ***
REN	−1.310 ***	−0.514 **	−0.933 ***	−0.338 ***	−0.176	−0.455 ***	−0.589 ***
GINNO	0.003 ***	0.005	0.062 *	−0.088 *	−0.031 **	1.510 ***	−0.026 *
ETAX	−0.061 *	−0.131 *	0.042 ***	−0.012	−0.014 **	−0.016 **	−0.009
TECH	−0.135 **	−0.561 **	−0.028 **	−0.019	0.029 **	−0.026 *	0.031 ***

Note: ***, **and * denote statistical significance at 1%, 5% and 10% levels, respectively.

Similarly, the result shows that renewable energy (REN) promotes environmental sustainability in all E7 countries except Russia. This shows that the countries are positive about adopting renewable energy except for Russia. Furthermore, green innovation (LNGINNO) significantly deteriorates Brazil's environmental quality but promotes environmental sustainability in Russia and Mexico. At the conventional level, LNGINNO has no significant impact on LNCO2 in India, China, Turkey, and Indonesia. This gives the impression that most of these countries with insignificant results are slow in the move towards green financing and adopting eco-friendly technologies in their productive and other sectors, which are key to decarbonizing the various sectors and promoting carbon neutrality. More so, the result shows that environmental tax (ETAX) in China, Russia, and Mexico effectively contributes to environmental sustainability while suggesting that the case of Brazil, India, Turkey, and Indonesia are not so effective in promoting significant environmental sustainability. Hence, the ETAX in these countries may need to be reviewed. Technological innovation (LNTECH) in Brazil, India, and China are potently promoting environmental sustainability, thereby facilitating the achievement of carbon neutrality. The conventional LNTECH in Turkey and Mexico does not influence environmental sustainability. For Russia and Indonesia, LNTECH contributes to the deterioration of environmental quality. A key implication for LNTECH across the individual countries with positive or insignificant results is that some measure of trade restriction is still active in their trade activities with many of the countries of the world. This would have impeded the rate of globalization in these countries and deprived them of the opportunity for economic complexity, especially in producing economic goods. More so, it is likely that these countries are giving greater attention to military hardware or goods production; hence LNTECH is tilting towards this end.

The study further presents an additional test to validate the existence of a causal relationship among the variables of interest in this study. The outcome of the D-H panel causality test is presented in Table 8. Accordingly, there is significant unidirectional causality which flows from income (LNGDP) and income squared (LNGDPSQ) to CO_2 emissions (LNCO2). This outcome agrees with the findings from the regression estimates. It implies that every effort to increase income in the E7 countries will contribute to the growth of carbon emissions which will, in turn, require the introduction of certain environmental measures to help curb the problem. Similarly, a unidirectional causality was observed for renewable energy (LNREN) and green innovation (LNGINNO) with LNCO2, and this causality was found to run from LNREN and LNGINNO to LNCO2, respectively. This implies that renewable energy and green innovations significantly contribute to environmental sustainability in the E7 countries, which agrees with the main regression findings. While there seems to be no significant causality between environmental tax (ETAX) and LNCO2 in the E7 countries, running either from ETAX to LNCO2 or from LNCO2 to ETAX, which contradicts the finding from the regression estimate, the reason remains uncertain. Finally, significant bidirectional causality was observed between technological innovations (LNTECH) and LNCO2. This shows that agreement that LNTECH makes a significant contribution to the promotion of carbon neutrality targets in the E7 countries. Our empirical results are consistent with some previous studies [94–115] in the case of different single and panel nations.

Table 8. D.H. Causality Results.

Null Hypothesis	W-Stat.	Z-Bar	*p*-Value	Decision
lnGDP → lnCO2	2.69080	2.60408	0.0092	Unidirectional
LnCO2 → lnGDP	5.84892	7.72021	1.0914	
GDPSQ → lnCO2	2.58149	2.42700	0.0152	Unidirectional
lnCO2 → GDPSQ	6.02637	8.00768	1.0915	
lnREN → lnCO2	3.82300	−0.42173	0.0032	Unidirectional
lnCO2 → lnREN	1.54586	0.74929	0.4537	
lnGINNO → lnCO2	4.66219	0.93774	0.0084	Unidirectional
lnCO2 → lnGINNO	2.11776	1.67577	0.0938	
lnETAX → lnCO2	0.89258	−0.34357	0.7312	No causality
lnCO2 → lnETAX	1.99181	1.31307	0.1892	
InTech → lnCO2	3.55697	3.98887	0.0005	Bidirectional
lnCO2 → lnTECH	6.02898	7.97860	0.0005	

4. Conclusions and Policy Implications

4.1. Concluding Remarks

The present study aims to investigate the dynamic linkage between clean energy, green technology, environmental policy in the form of taxes and technological innovation, and carbon emission in the emerging 7 countries, including China, Turkey, India, Russia, Brazil, Indonesia, and Mexico from 1990–2019. The study employed the dynamic common correlated effects (DCCE) approach to cointegration to unravel the specific effect of the short and long-run coefficients of the studied variables. Moreover, the study utilized the Granger causality test to unravel the direction of causal flow among the variables. Findings from the study demonstrated that renewable energy use, environmental tax, and technology innovation reduced environmental degradation. Furthermore, The inverted U-shape EKC has been found for the E-7 nations. Furthermore, unidirectional causal relationships between technology and CO_2 emissions and relationships between economic growth, renewable energy, green innovation, and environmental legislation.

4.2. Policy Recommendation and Directions for Further Research

In assessing the role of energy transition in achieving the carbon neutrality pledge in the seven most emerging countries, this study has found that significant U-shaped EKC exists in the sampled countries, implying that the current carbon abatement policy measures have been effective in the E7 countries. Hence, it is ideal to ensure the sustenance of these policies because they effectively combat GHG emissions in the E7. Any deviation from this current state resulting from further negligence of environmental sustainability will plunge the E7 into deeper environmental deterioration. This is possibly the case being described as technological obsolesces (where scale effect outweighs technological effects), which ensues when technological innovations reach their climax without further technological innovations. Furthermore, the outcome from the study indicates that the short-run and long-run environmental sustainability in the E7 countries, just as the U-shaped EKC depict, is tied to the adoption of renewable energy in the production process, green innovations which takes the form of eco-friendly investment, environmental tax and technological innovation which assumes the form of innovations that improves the environment via GHG emission reduction. Thus, pointing to the tremendous relevance of these environmental mitigation measures in achieving carbon neutrality in the E7 countries. The E7 countries are encouraged to scale up environmental policy touching these investigated areas through continuous revisions of this policy to meet the changing times and trade policies. It is advised that more investment and innovation in the E7 countries should target environmental mitigation. Overall, there is reason to think that combating climate change and promoting economic growth are not mutually exclusive goals. The recession that followed the global financial disaster caused emissions to fall, correlated with a decline in economic activity. However, it is questionable if the promising trends observed to date in some nations will continue. Furthermore, to policymakers in E7 countries, a shift away from fossil fuels in the production of power will not be enough to reduce emissions in the future significantly. Radical and extensive adjustments are required. Furthermore, there is a need for the E7 countries to transform their industries into a green economy, which is the best way to combat the environmental challenges emanating from economic growth. In the manufacturing process, sustainability refers to the creation of products that are produced in an economically sensible way. These products are created in an environmentally conscious way and in the most efficient manner. This production method supports the safety of employees, communities, and products. Thus, the focus should be on innovation-driven sustainable industrialization.

The study suffers from a set of conventional limitations. First, the period and the number of countries limit the study to 2019. Second, future studies can also include an interactive term for environmental tax and foreign direct investment along with the pollution haven/halo hypothesis. As a limitation, the present study results are limited to E7 countries. Future studies might use recent years' data and social and economic variables such as different aspects of financial development and globalization. Future scholars might apply sophisticated econometric models such as time series, wavelet coherence, quantile based ARDL, and panel models such as CS-ARDL and quantile-based GMM models to replicate the model presented in the study.

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Abbreviations

ARDL autoregressive distributed lag, **GMM** generalized methods of moments, **OECD** Organisation for Economic Co-operation and Development, **OBOR** One Belt and One Road, **CS-ARDL** cross-sectional autoregressive distributed lag, **QARDL** quantile nonlinear autoregressive distributed, **FMOLS** fully modified ordinary least square, **DOLS** dynamic least square, **PMG** pooled mean group, **CO_2** carbon emission, **CCEMG** common correlated effects mean group., **BRICS** Brazil, Russia, India, China, and South Africa, **MMQR** Method of Moments Quantile regression, **AMG** augmented mean group, **Cup-FM** continuously updated full modified, **Cup-BC** continuously updated bias-corrected, **EU** stands for European Union, **2SLS** Two-Stage least squares, **PIIGS** Portugal, Ireland, Greece, and Spain, **MINT** Mexico, Indonesia, Nigeria, and Turkey, **APEC** Asia-Pacific Economic Cooperation.

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