

# Green Growth or Grey Future? Evidence from Next 11 Countries

Gökay Canberk BULUŞ\* 

## ABSTRACT

This study provides a comprehensive analysis of the relationship between CO<sub>2</sub> emissions, per capita income (GDP), per capita renewable energy consumption, overall per capita energy use, and trade openness for the Next Eleven (N11) countries over the period 1986–2023, within the conceptual framework of the Environmental Kuznets Curve (EKC). By employing both static and dynamic panel data estimation techniques, the research captures not only the immediate but also the long-term interactions between economic growth, energy use, and environmental outcomes. The empirical results indicate that rising per capita income and increased reliance on conventional energy sources are significant drivers of CO<sub>2</sub> emissions in N11 countries, reflecting the environmental costs of rapid industrialization and economic expansion. In contrast, higher levels of renewable energy consumption are found to play a crucial role in reducing emissions, emphasizing the importance of transitioning towards sustainable energy systems. Additionally, the validation of the EKC hypothesis suggests a non-linear relationship between economic growth and environmental quality. These findings highlight the urgent need for N11 countries to adopt policies that accelerate investment in renewable energy infrastructure, enhance energy efficiency, and integrate environmental considerations into their growth strategies in order to mitigate pollution and support sustainable development.

**Keywords:** EKC, Renewable Energy, Next 11 Countries, Pooled Mean Group.

**JEL Classifications:** O13, F18

## Yeşil Büyüme mi, Gri Gelecek mi? Next 11 Ülkelerinden Bulgular

### ÖZ

Bu çalışma, Çevresel Kuznets Eğrisi (EKC) kavramsal çerçevesinde, 1986-2023 dönemi için Next Eleven (N11) ülkeleri için CO<sub>2</sub> emisyonları, kişi başına gelir (GSYİH), kişi başına yenilenebilir enerji tüketimi, toplam kişi başına enerji kullanımı ve ticaret açıklığı arasındaki ilişkiyi kapsamlı bir şekilde analiz etmektedir. Statik ve dinamik panel veri tahmin tekniklerini kullanarak, araştırma yalnızca ekonomik büyüme, enerji kullanımı ve çevresel sonuçlar arasındaki anlık etkileşimleri değil, aynı zamanda uzun vadeli etkileşimleri de ele almaktadır. Ampirik sonuçlar, kişi başına düşen gelirin artmasının ve geleneksel enerji kaynaklarına olan bağımlılığın artmasının, hızlı sanayileşme ve ekonomik genişlemenin çevresel maliyetlerini yansıtan, N11 ülkelerinde CO<sub>2</sub> emisyonlarının önemli itici güçleri olduğunu göstermektedir. Buna karşılık, yenilenebilir enerji tüketiminin yüksek seviyelerde olmasının emisyonların azaltılmasında önemli bir rol oynadığı ve sürdürülebilir enerji sistemlerine geçişin önemini vurguladığı görülmüştür. Ayrıca, EKC hipotezinin doğrulanması, ekonomik büyüme ile çevre kalitesi arasında doğrusal olmayan bir ilişki olduğunu göstermektedir. Bu bulgular, N11 ülkelerinin kirliliği azaltmak ve sürdürülebilir kalkınmayı desteklemek için yenilenebilir enerji altyapısına yatırımı hızlandıran, enerji verimliliğini artıran ve çevre hususlarını büyüme stratejilerine entegre eden politikalar benimsemelerinin acil bir ihtiyaç olduğunu vurgulamaktadır.

**Anahtar Kelimeler:** EKC, Yenilenebilir Enerji, Next 11 Ülkeleri, Havuzlanmış Ortalama Grup

**JEL Sınıflandırması:** O13, F18

### 1. Introduction

Sustainable development has increasingly become a priority in national policy agendas. However, the acceleration of industrial production, combined with rapid technological advances, has led to a sharp rise in environmental problems driven by human activities. The overexploitation of natural resources, particularly in highly industrialized regions, reflects this reality, making current environmental challenges the inevitable cost of being a production-oriented society. Yet, pursuing economic growth at the expense of severe environmental degradation is clearly unsustainable. To address this dilemma, the concept of “sustainable development” was introduced (Dincer & Rosen, 1999, p. 428; Omer, 2008, p. 2267). The idea first gained prominence with the Brundtland Report published by a United Nations (1987) sub-

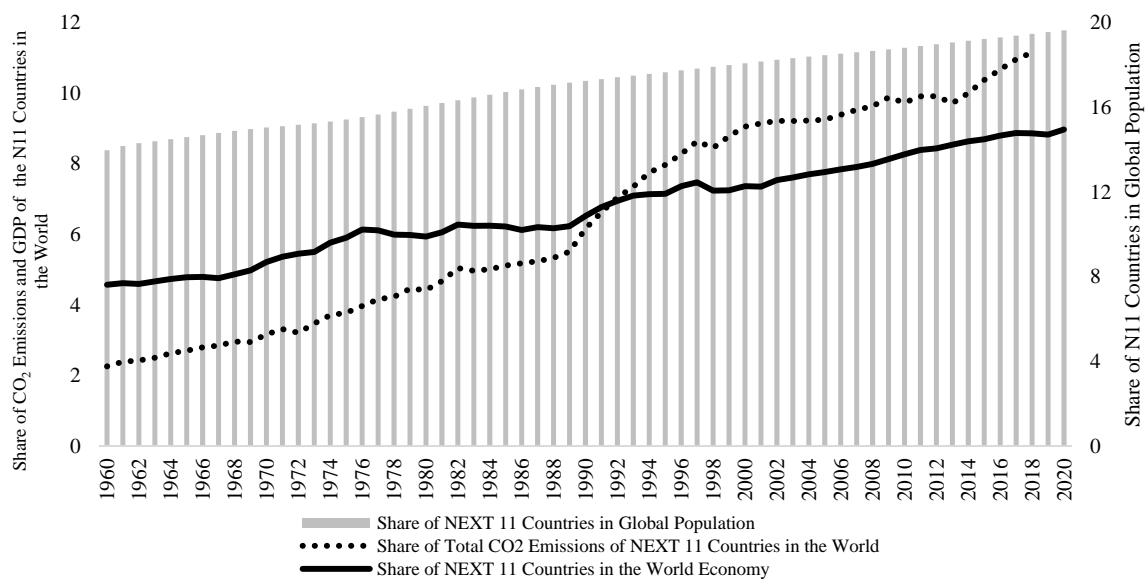
\* **Corresponding Author/Sorumlu Yazar**, Doç. Dr. Aksaray Üniversitesi, Aksaray, Türkiye/ Assoc. Prof. Dr., Aksaray University, Aksaray, Türkiye, gcbulus@aksaray.edu.tr  
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organization, which redefined economic development in terms of sustainability, emphasizing the need to meet present needs without compromising the ability of future generations to meet theirs. This approach was further reinforced by the Rio Declaration (Agenda 21) in 1992, and subsequently by Agenda 2030, adopted at the UN Sustainable Development Summit in 2015. Agenda 2030 builds upon the goals of Agenda 21, placing sustainability at the core of global development by underlining the interconnections between environmental, social, and economic dimensions (United Nations, 2024)

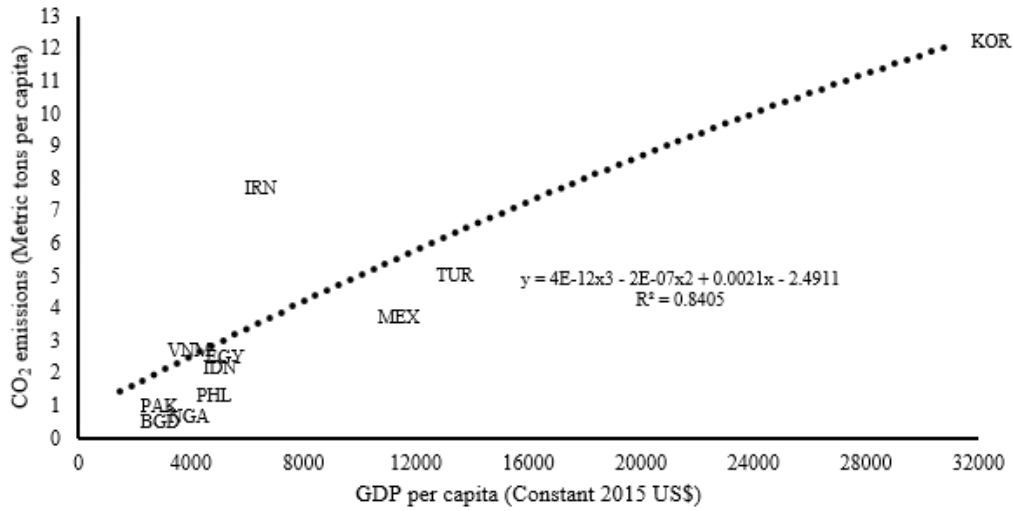
While major global economies have sought agreements and commitments to address environmental pollution, O'Neill et al. (2005, p. 3) identified a group of countries—referred to as the Next Eleven (N11)—as emerging economies with strong future growth potential. According to the authors, these countries possess high investment capacity and are expected to achieve rapid economic expansion. By 2050, the N11 are projected to account for a substantial share of both global population and production. However, their growing production and population levels also raise significant environmental concerns. Figure 1 illustrates the shares of GDP, total population, and CO<sub>2</sub> emissions of the N11 countries within the global economy between 1960 and 2020.



**Figure.1** N11 Countries in the World Economy  
(Source: <https://data.worldbank.org/> Accessed 11.01.2025)

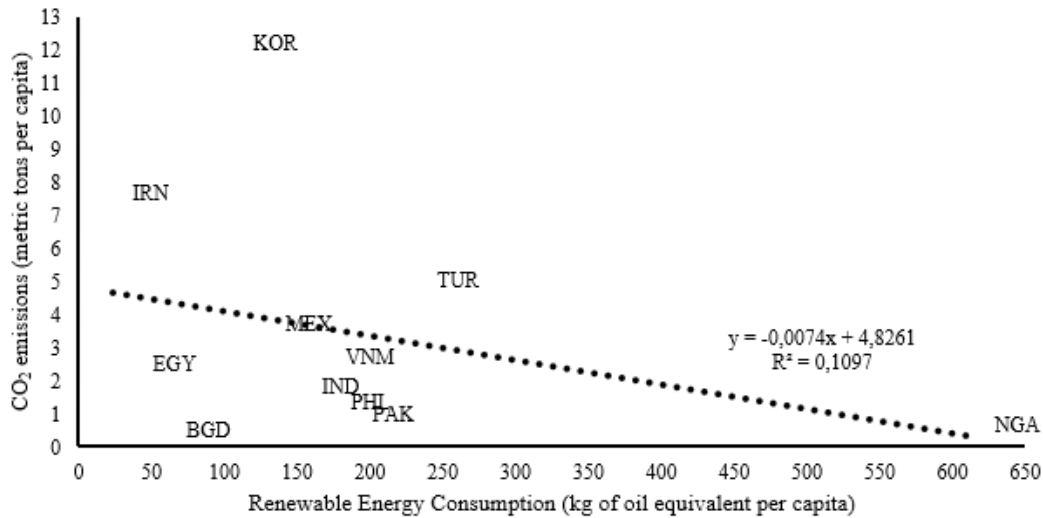
According to Figure 1, the share of N11 countries in the world population increased from 8% in the 1960s to nearly 20% in the 2020s. Similarly, their share of global GDP rose from 4.5% to about 7.5% over the same period. This expansion in both population and economic output has been accompanied by a notable rise in CO<sub>2</sub> emissions, with the group's share growing from 2% in the 1960s to almost 10% by 2020. These figures underscore the significant growth potential of the N11 countries within the global economy.

Figure 2 presents the scatter plot of per capita GDP and per capita CO<sub>2</sub> emissions for the N11 countries. The distribution of values does not appear to support the Environmental Kuznets Curve (EKC) hypothesis. As illustrated, South Korea records the highest levels of both per capita GDP and CO<sub>2</sub> emissions among the N11 countries. Given that the N11 are classified as rapidly growing economies, it is essential for them to expand the use of environmentally friendly energy sources in order to align with the Sustainable Development Goals (SDGs) of Agenda 2030.



**Figure.2** Per Capita Income and CO<sub>2</sub> Emissions in the N11  
 (Source: <https://data.worldbank.org/> Accessed 21.01.2025)

Figure 3 illustrates the scatterplot of per capita renewable energy consumption and CO<sub>2</sub> emissions in N11 countries. The graph indicates a negative relationship between renewable energy consumption and CO<sub>2</sub> emissions. Nevertheless, the overall use of renewable energy in these countries remains extremely limited. For instance, according to the OECD report, the share of renewable energy in total energy consumption was only 8% in the N11 countries in 2024.



**Figure 3.** Renewable Energy and CO<sub>2</sub> Emissions in the N11 Countries  
 (Source: <https://data.worldbank.org/> Accessed 08.02.2025)

The primary reason for selecting the N11 countries as a sample for this study is to analyze the balance between increasing global environmental pressures and economic growth objectives, and to assess the effectiveness of sustainable development policies in the context of developing countries. Examining the performance of these countries will provide insightful insights not only for the N11 group but also for other emerging economies with similar development dynamics. This study aims to make several significant contributions to the literature by comprehensively examining the dynamics of sustainable development in the N11 countries. First, it reveals the key determinants of sustainable development by analyzing the long-

term relationships among economic growth, energy use, renewable energy consumption, trade openness, and CO<sub>2</sub> emissions in the N11 countries. In this respect, the study simultaneously assesses not only environmental impacts but also the role of economic and trade factors on sustainability. Furthermore, by expanding the panel data specific to the N11 group to cover the period 1986–2023, this research utilizes a more up-to-date and comprehensive dataset. This allows for a clearer observation of the impacts of recent technological developments, energy transformation processes, and global environmental policies. Furthermore, the combined use of both static (pooled least squares, fixed effects, random effects, and Driscoll–Kraay) and dynamic panel (pooled mean group) methods in the study yields more robust and comparative empirical findings compared to previous studies. Finally, this study aims to shed light on the sustainable development policies of the N11 countries by testing the validity of the Environmental Kuznets Curve (EKC) hypothesis. The results are expected to guide the design of environmentally friendly energy strategies, carbon reduction policies, and green growth plans for both the N11 countries and similar emerging economies. The structure of the article is as follows: the next section provides a review of the relevant literature; Section 3 outlines the data and methodology; Section 4 reports the empirical findings; and Section 5 concludes with remarks and policy recommendations.

## 2. Literature

Sustainable economic growth constitutes a central objective of national economic policies. However, within carbon-based economic systems, environmental degradation emerges as a natural consequence of economic activities, with rising carbon emissions being the primary driver of global warming. Since environmental protection represents a global public good, numerous studies and international initiatives have sought to reduce and mitigate environmental degradation, particularly carbon emissions. Among these, the Intergovernmental Panel on Climate Change (IPCC) stands out as a major international effort, providing cutting-edge scientific insights into human-induced climate change. Growing concerns over climate change have also prompted economists to examine the impact of economic factors on environmental degradation. Grossman and Krueger (1991, p. 6) first evaluated the relationship between greenhouse gas emissions and economic growth through the EKC hypothesis. Over the last three decades, researchers have tested the validity of the EKC hypothesis and arrived at different conclusions. For instance, the following time series studies support the EKC hypothesis; Ang (2007, p. 4776) for France; Shahbaz et al. (2012, s. 2951) for Pakistan; Katircioglu (2014, p. 389) for Singapore; Ozatac et al. (2017, p. 16697) for Turkey; Rana and Sharma (2019, pp. 359-360) for India; Sarkodie and Ozturk (2020, p. 9) for Kenya; Alola and Ozturk (2021, p. 9) for United States; Bouyghrissi et al. (2022, p. 20761) for Morocco. However, the following time series studies do not support the EKC hypothesis; Day and Grafton (2003, p. 14) for Canada; Giovanis (2013, p. 609) for United Kingdom; Al-Mulali et al. (2015, p. 128) for Vietnam; He et al. (2017, p. 1726) for China; Hasanov et al. (2019, p. 30237) for Kazakhstan; Koc and Bulus (2020, p. 29049) for Korea; Yilanci and Pata (2020, p. 32690) for China; Özden and Beşe (2021, p. 2251) for Australia; Massagony and Budiono (2023, p. 26) for Indonesia; Pata et al. for Germany (2024, s. 162). In addition to extensive time series studies literature, a significant amount of linear and nonlinear panel data studies has been performed on the EKC hypothesis. For example, the following panel data studies support the EKC hypothesis; Grossman and Krueger (1991, p. 30) for 32 countries; Shafik and Bandyopadhyay (1992, p. 23) for 149 countries; Panayotou (1997, p. 482) for 30 countries; Farhani and Shahbaz (2014, p. 89) for MENA countries; Heidari et al. (2015, p. 788) for 5 Asian countries; Rafiq et al. (2016, p. 361) for 53 countries; Apergis and Ozturk (2015, p. 19) for 14 Asian countries; Sarkodie (2018, p. 22017) for 17 African countries; Balsalobre-Lorente et al. (2021, p. 3) for EU-5 countries; Nathaniel et al. (2021, p. 508) for G7 countries; Cetin et al. (2022, p. 34025) for 47 developing countries; Khalid et al. (2025, s. 7) for 11 high-income EU countries. On the other hand, the following panel data studies do not support the EKC hypothesis; Aslanidis and Iranzo (2009, p. 806) for 77 non-OECD countries; Jaunky (2011, p. 1234) for 36 developed countries; Wang (2012, p. 1543) for 98 countries; Ajmi et al. (2015, p. 634) for G7 countries; Antonakakis et al. (2017, p. 815) 106 countries; Destek and Sinha (2020, p. 13) for 24 OECD countries; Yilanci and Pata (2022, p. 1888) for G7 countries; Ciarlantini et al. (2023, p. 42911) for 5 European countries; Pradhan et al. (2022, p. 696) for BRICS countries; Barak et al. (2024, s. 13) for G-20.

**Table 1.** Selected Empirical EKC Studies on N11 Countries

Author(s)	Period	Methodology	Result
Mehmood and Rehman, (2025, s. 211)	1991-2022	GMM	Valid
Qamruzzaman et al. (2024, p. 26)	2004-2020	DSUR, CUP-FM, and CUP-BC	Valid
Zhu et al. (2024, p. 6)	1971-2022	CS-ARDL	Valid
Esmacili et al. (2023, p. 8)	1995-2010	Panel Quantile Regression	Valid
Shahbaz (2022, p. 84)	1972-2015	ARDL Bounds Testing	Mixed
Eregha et al. (2022, p. 1340)	1990-2017	CS-ARDL, CCEMG, AMG, FMOLS	Mixed
Kongbuamai et al. (2022, p. 11327)	1992-2015	Westerlund Cointegration, Dumitrescu-Hurlin Causality	Not Valid
Ampofo et al. (2021, p. 15)	1972-2013	Johansen Cointegration, NARDL	Mixed
Aslan et al. (2021, p. 7)	1980-2018	Panel VAR	Valid
Nathaniel et al. (2021, p. 507)	1990-2016	AMG	Valid
Selcuk et al. (2021, p. 55623)	1991-2019	CCEMG	Mixed
Sinha et al. (2020, p. 7)	1990-2017	Westerlund Cointegration, FMOLS, LSDV, Bai and Ng Estimator, GMM	Not Valid
Sinha et al. (2019, p. 1786)	1990-2017	Panel Causality, MG, AMG, CCEMG	Mixed
Sinha et al. (2017, p. 1224)	1990-2004	GMM	Not Valid
Esfahani and Rasoulinezhad (2016, p. 467)	1980-2013	DOLS, FMOLS	Valid

Table 1 provides a summary of recent empirical studies on the EKC for N11 countries. As shown, various modern panel and time series methods have been widely employed to test the validity of the EKC hypothesis in this context. Although the N11 are regarded as potential candidates for rapid economic growth, they remain highly heterogeneous in terms of industrialization levels and CO<sub>2</sub> emissions.

### 3. Data and Methodology

#### 3.1. Data

Overview of the dataset which is employed in the empirical analyses is explained in Table 2.

**Table 2.** Definition and Sources of the Data

Abbreviation	Variable	Unit	Source
CO <sub>2</sub>	Per capita CO <sub>2</sub> emissions	Metric tons per capita	WDI
Y	Per capita real GDP	US Dollars (2015, fixed)	WDI
Y <sup>2</sup>	Sq. of per capita real GDP	US Dollars (2015, fixed)	WDI
Eu	Per capita energy use	Kilograms of oil equivalent	OECD
Ren	Per capita renewable energy use	Kilograms of oil equivalent	OECD
Tr	Trade [(Exports+Imports)/GDP]	Percent	WDI

Table 2 provides the definitions, measurement units, and data sources of the variables employed in the analysis. The dependent variable is per capita CO<sub>2</sub> emissions (CO<sub>2</sub>), measured in metric tons per capita and obtained from the World Development Indicators (WDI). The core explanatory variable is per capita real GDP (Y), expressed in constant 2015 US dollars, along with its squared term (Y<sup>2</sup>) to capture potential nonlinearities such as the Environmental Kuznets Curve (EKC) effect. Energy-related variables include per capita energy use (Eu) and per capita renewable energy use (Ren), both measured in kilograms of oil equivalent and sourced from the OECD database. In addition, trade openness (Trade) is measured as the ratio of total exports and imports to GDP, expressed as a percentage, with data taken from WDI. Overall, the table shows that the dataset integrates economic, energy, and environmental dimensions, relying on internationally recognized sources (WDI, OECD). This combination allows for a comprehensive examination of the linkages between economic growth, energy consumption, trade, and CO<sub>2</sub> emissions in the N11 countries. The following sections present summary statistics and correlation coefficients to provide preliminary insights into the relationships among these variables. The summary statistics and the correlation coefficients between the variables are presented in Tables 3 and 4, respectively.

**Table 3.** Basic Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
CO <sub>2</sub>	418	2.78	2.90	0.10	12.57
Y	418	5015.51	6197.68	481.29	34121.02
Eu	418	1357.61	1268.04	109.64	6088.76
Ren	418	221.669	229.49	7.18	849.56
Tr	418	54.59	31.38	9.13	208.30

Table 3 presents the descriptive statistics for the variables over 1986–2023. Average per capita CO<sub>2</sub> emissions in the N11 countries are 2.78 metric tons, ranging from 0.10 to 12.57, indicating strong heterogeneity. Per capita GDP averages USD 5,016, with large disparities across countries (USD 481–34,121). Energy use per capita averages 1,358 kilograms of oil equivalent, while renewable energy consumption remains relatively low at 221.67 on average. Trade openness is 54.6% of GDP but varies widely (9.13–208.30%). Overall, the statistics reveal significant cross-country differences, underscoring the need for panel data methods to capture both temporal and cross-sectional dynamics.

**Table 4.** Correlation Coefficients

	CO <sub>2</sub>	Y	Eu	Ren	Trade
CO <sub>2</sub>	1				
Y	0.88	1			
Eu	0.87	0.78	1		
Ren	-0.36	-0.25	0.01	1	
Tr	0.20	0.20	0.14	-0.05	1

Table 4 reports the pairwise correlation coefficients among the variables. As expected, per capita CO<sub>2</sub> emissions (CO<sub>2</sub>) show a strong positive correlation with both per capita GDP (Y) (0.88) and per capita energy use (EU) (0.88), indicating that higher income levels and greater energy consumption are closely associated with higher emissions in the N11 countries. By contrast, renewable energy consumption (REN) is negatively correlated with CO<sub>2</sub> emissions (−0.36) and GDP (−0.25), suggesting that higher renewable energy use is linked to lower emissions and tends to be more prevalent in relatively less energy- and income-intensive settings.

### 3.2. Methodology

The dataset compiled for the analysis is structured as panel data, since it covers multiple countries (cross-sectional units) observed over multiple years (time dimension). The core principle of panel data analysis relies on the assumption that the relationships across individual units share identical parameters, commonly referred to as the pooling assumption (Asteriou & Hall, 2021). Under pooling, all units are combined into a single dataset, reducing the estimation to a common parameter. When the pooling assumption holds, panel data analysis provides substantial advantages over pure cross-sectional or time series methods. A standard linear panel data model is defined with N cross-sectional units and T time periods. A simple example with a single explanatory variable can be expressed as follows:

$$Y_{it} = \alpha + \beta X_{it} + \varepsilon_{it} \quad (1)$$

Here, Y is the dependent variable, X is the explanatory variable, i is the cross-sections (i=1,2,3,...), t is the time for each cross-section unit (t=1,2,3,...),  $\alpha$  is the common constant term for all units,  $\varepsilon$  is the error term. This study applies regression techniques designed to account for heterogeneity, in order to analyze the relationships between CO<sub>2</sub> emissions and their determinants across the N-11 countries. The regression model is specified as follows:

$$CO_{2it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Eu_{it} + \beta_4 Ren_{it} + \beta_5 Tr_{it} + u_{it} \quad (2)$$

Where  $CO_2$  denotes pollution emissions per capita,  $u_{it}$  are error terms. Explanatory variables are GDP per capita (Y), and Y square per capita  $Y_{it}^2$ , energy use (Eu) and trade openness (Tr). In this study, both static and dynamic panel estimation techniques are employed. The static analysis is conducted using the fixed-effects estimator with Driscoll–Kraay standard errors, which provide robustness against cross-

sectional dependence, heteroskedasticity, and autocorrelation. These estimates are therefore considered reliable and are taken into account when interpreting the empirical results. For the dynamic specification, the Pooled Mean Group (PMG) estimator is selected as the preferred method, given its suitability for capturing both short-run dynamics and long-run relationships across heterogeneous panels.

The PMG estimator is grounded in the Autoregressive Distributed Lag (ARDL) model, which was reparametrized as an error-correction model by Pesaran and Smith (1995, p. 92), Pesaran (1997, s. 185) and Pesaran et al. (1999, p. 630) as a new cointegration approach applicable when the dependent and independent variables are  $I(0)$ ,  $I(1)$ , or a mixture of both. In other words, the PMG/ARDL framework accommodates variables with mixed orders of integration. The panel ARDL model has become one of the most widely used methods for addressing cross-sectional heterogeneity. Within this framework, the PMG estimator employs the maximum likelihood procedure to estimate long-run coefficients, imposing homogeneity across cross-sectional units. Subsequently, it estimates the intercepts, short-run slope coefficients, and the error-correction mechanism separately for each unit, allowing them to vary across cross-sections while still using maximum likelihood. This dual feature makes the method particularly powerful, as it simultaneously captures both long-run and short-run dynamics, while also mitigating issues such as omitted variable bias and autocorrelation in the model (Odugbesan & Rjoub, 2019).

Pesaran et al. (1999, p. 631) assumed an ARDL  $(p, q, q, \dots, q)$  model for a given time periods  $(t = 1, 2, \dots, T)$  and groups  $(i = 1, 2, \dots, T)$ :

$$y_{it} = \sum_{j=1}^p \tau_{ij} y_{i,t-j} + \sum_{j=0}^q \delta'_{ij} x_{i,t-j} + \mu_i + u_{it} \quad (3)$$

In this equation,  $y_{it}$  denotes the dependent variable, while  $X_{it}$  is the  $k \times 1$  vector of explanatory variables,  $N_i$  is the group specific effects,  $\delta_{it}$  are the  $k \times 1$  coefficient vectors and  $\tau_{ij}$  are scalar coefficients of the lagged dependent variables. Furthermore,  $u_{it}$  is in  $I(0)$  process for all cross-sections if there is a long run relationship exists between the variables. Accordingly, Equation (3) is reformulated as an error correction model (ECM), wherein short-run dynamics are influenced by deviations from the long-run equilibrium. This specification is grounded in the expectation that cointegrated series respond to disequilibrium in the long run. In this context, Equation (3) is rewritten as follows:

$$\Delta y_{it} = \phi_i (y_{i,t-1} - \vartheta'_i X_{it}) + \sum_{j=1}^{p-1} \tau_{ij}^* \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta'_{ij} \Delta X_{i,t-j} + \mu_i + u_{it} \quad (4)$$

where  $\phi_i = -(1 - \sum_{j=1}^p \tau_{ij})$ ,  $\vartheta'_i = \sum_{j=0}^q \delta_{ij} / (1 - \sum_k \tau_{ik})$ ,  $\tau_{ij}^* = -\sum_{m=j+1}^p \tau_{im}$   $j = 1, 2, \dots, p-1$ , and  $\delta_{ij}^* = -\sum_{m=j+1}^q \delta_{im}$   $j = 1, 2, \dots, q-1$ . In addition,  $\phi_i$  represents the error-correcting speed of adjustment term.

#### 4. Empirical Results

Empirical analysis findings are included in this section under two subheadings: static analysis and dynamic analysis.

##### 4.1. Static Analysis

In this part of the analysis, different estimation techniques, including Pooled OLS (POLS), Fixed Effects (FE), Random Effects (RE), and Fixed Effects with Driscoll–Kraay standard errors, are applied to ensure robustness and account for potential econometric issues such as cross-sectional dependence, heteroskedasticity, and autocorrelation. By comparing these approaches, the analysis provides a comprehensive assessment of how economic growth, energy consumption, renewable energy use, and trade openness influence CO<sub>2</sub> emissions. The results obtained from these models are summarized below.

**Table 5.** Static Analysis Result

Dependent Variable: CO <sub>2</sub>	POLS	FE	RE	Driscoll-Kraay
Y	0.002 (0.001)***	0.002 (0.001)***	0.002 (0.001)***	0.001 (0.001)***
Y <sup>2</sup>	-5.220 (4.811)***	-3.960 (6.350)***	-3.980 (6.550)***	-3.960 (7.350)***
Eu	0.001 (0.004)***	0.001 (0.001)***	0.001 (0.001)***	0.002 (0.001)**
Ren	-0.003 (0.001)***	-0.002 (0.001)***	-0.003 (0.006)***	-0.001 (0.001)***
Tr	0.004 (0.009)***	0.008 (0.001)***	0.008 (0.001)***	0.008 (0.001)***
Cons.	0.344 (0.079)***	0.242 (0.216)	0.403 (0.249)	0.2242 (0.260)
Obs.	418	418	418	418

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

The empirical findings reported in Table 5 provide important insights into the determinants of CO<sub>2</sub> emissions in the N-11 countries. The coefficient of income (Y) is positive and statistically significant across all specifications, suggesting that economic growth contributes to higher CO<sub>2</sub> emissions. Conversely, the coefficient of the squared income term (Y<sup>2</sup>) is negative, supporting the Environmental Kuznets Curve (EKC) hypothesis. This implies that while emissions tend to rise during the early stages of economic development, they may eventually decline once a certain level of income is reached, reflecting a turning point in the growth–environment relationship. Energy consumption (Eu) exerts a positive and significant impact on CO<sub>2</sub> emissions, indicating that reliance on conventional energy sources remains a major driver of environmental degradation in the N-11 economies. In contrast, renewable energy consumption (Ren) shows a consistently negative and statistically significant effect, highlighting its critical role in reducing carbon emissions and mitigating environmental pressures. Furthermore, trade openness (Tr) is positively associated with CO<sub>2</sub> emissions, suggesting that increased integration into the global economy may exacerbate environmental challenges, possibly due to the expansion of energy-intensive production and trade-related activities. The robustness of these results is reinforced by the Driscoll–Kraay estimates, which correct for cross-sectional dependence, heteroskedasticity, and autocorrelation. Overall, the findings confirm the validity of the EKC hypothesis in the context of the N-11 countries while underscoring the importance of renewable energy adoption as a key policy tool for achieving sustainable growth.

#### 4.2. Robustness Check: Dynamic Analysis

Dynamic models have various advantages over static models in panel data analysis. First, dynamic models include past values of the dependent variable in the model, taking into account the effect of past behavior on current results. Thus, slow adjustment mechanisms observed in economic, financial, and social processes are represented more realistically. Static models, on the other hand, ignore this dependency and fail to capture transition processes (Seetanah, 2009). In addition, dynamic panel data methods can better capture heterogeneity and structural differences. In particular, methods such as Pooled Mean Group (PMG) allow long-term coefficients to be common to all units while allowing short-term coefficients to vary across units. This enables both theoretically consistent and empirically flexible results (Pesaran, Shin, & Smith, 1999, p. 629). The results of the dynamic panel data analysis using PMG analysis are presented in Table 6.

**Table 6.** Dynamic Analysis Result

Dependent Variable: CO <sub>2</sub>	PMG Analysis	
Error correction term	-0.241***	(-2.916)
Y	0.001***	(2.027)
Y <sup>2</sup>	-1.520***	(-2.335)
Eu	0.001***	(6.584)
Ren	-0.004***	(-7.848)
Tr	-0.001**	(-0.537)
Cons.	0.283**	(2.155)
Obs.	407	407

Note: \*, \*\*, \*\*\* denote 10%, 5% and 1% significance levels, respectively. The t-statistic values for the coefficients are shown in parentheses. The model established is defined as ARDL (1,1,1,1,1,1).

The results of the PMG analysis reveal important findings regarding the determinants of CO<sub>2</sub> emissions. First, the fact that the error correction term is negative and statistically significant (-0.241;  $p < 0.01$ ) indicates that there is a long-term equilibrium relationship and that CO<sub>2</sub> emissions return to equilibrium at a rate of approximately 24% each period. The income variable (Y) is positive and significant ( $p < 0.05$ ), while the square of income (Y<sup>2</sup>) is negative and significant ( $p < 0.05$ ). This result supports the environmental Kuznets curve (EKC) hypothesis, which suggests that economic growth increases emissions in the initial stages but has a reducing effect after a certain income level is reached. The energy consumption (Eu) variable is positive and highly significant ( $p < 0.01$ ), indicating that increases in energy use significantly increase CO<sub>2</sub> emissions. In contrast, the renewable energy usage (Ren) variable is negative and highly significant ( $p < 0.01$ ), indicating that renewable energy sources play a critical role in emission reduction. Although the coefficient of the trade openness (Tr) variable is negative, it is not statistically significant, meaning that trade openness does not have a significant effect on CO<sub>2</sub> emissions. The results of this study are similar to the results of the studies by Qamruzzaman et al. (2024, p. 26), Zhu et al. (2024, p. 6), Esmacili et al. (2023, p. 8) and Aslan et al. (2021, p. 7). Overall, the findings indicate that the relationship between economic growth and environmental sustainability is not linear, and that energy policies and renewable energy investments are decisive in emission reduction.

## 5. Conclusion

This study provides a comprehensive investigation into the nexus between CO<sub>2</sub> emissions, economic growth, energy consumption, renewable energy utilization, and trade openness in the Next Eleven (N11) economies over the period 1986–2023, employing the Environmental Kuznets Curve (EKC) framework as a theoretical foundation. The empirical evidence derived from both static (pooled least squares, fixed effects, random effects, and Driscoll–Kraay) and dynamic (PMG) panel estimation techniques indicates that economic expansion and reliance on conventional energy sources remain the predominant determinants of CO<sub>2</sub> emissions in these countries. Conversely, renewable energy consumption exhibits a statistically significant and negative relationship with emissions, highlighting its crucial role as an indispensable instrument for achieving long-term environmental sustainability. Furthermore, the empirical validation of the EKC hypothesis reaffirms the non-linear and transitional nature of the growth–environment relationship. Specifically, the early stages of industrialization and rapid economic expansion intensify environmental degradation, reflecting the carbon-intensive trajectory of initial development. However, as economies undergo structural transformation, technological innovation, and efficiency-oriented modernization at higher income levels, CO<sub>2</sub> emissions tend to decelerate and eventually decline. This dynamic pattern demonstrates that sustainable progress is achievable when growth is accompanied by innovation, clean energy transition, and institutional commitment to environmental stewardship.

N11 countries are considered as one of the important country groups due to their domestic and foreign investments, economic and political stability, education quality opportunities, trade openness and promising outlook on economic growth, as well as their population potential. Thanks to these features, they have the potential to be among the world's largest economies in the future. Findings from this research can undoubtedly guide policymakers in developing some policy recommendations for N11

countries. Accordingly, the pronounced contribution of fossil fuel-based energy consumption to environmental degradation necessitates a strategic and urgent transition toward low-carbon development pathways. This transition should encompass substantial public and private investment in renewable energy infrastructure, the establishment of fiscal and regulatory incentives to stimulate clean energy adoption, and the enhancement of energy efficiency standards across all sectors. In other words, tax breaks, low-interest green loans, subsidies, and investment incentives should be implemented to promote renewable energy technologies in the N11 countries. Integrating locally resourced resources, particularly solar, wind, and biomass, into regional development programs will support both energy supply security and employment. Moreover, the results highlight the critical importance of policy continuity and long-term commitment. The dynamic estimation results reveal that convergence towards a sustainable environmental trajectory is inherently gradual, implying that ad hoc or short-lived measures will be insufficient to produce lasting environmental improvements. Similarly, N11 countries should develop green bonds, sustainable development funds, and climate finance instruments to facilitate the financing of sustainable investments. Long-term investment flows can be generated for low-carbon projects through public-private partnerships. In addition, the pronounced heterogeneity among N11 economies—in terms of industrial maturity, resource endowments, and institutional capacities—necessitates a differentiated policy approach. While domestic policies must be tailored to national circumstances, they should also remain firmly aligned with international climate frameworks, including the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), to ensure coherence and global relevance.

In conclusion, sustainable growth in the N11 countries depends on balancing economic development with environmental protection. A policy framework that combines the promotion of renewable energy, improved energy efficiency, and stronger international cooperation provides the most effective means to achieve this goal. Such an approach can help decouple economic growth from environmental harm and enable the N11 economies to contribute meaningfully to global climate change mitigation, while ensuring their long-term economic and environmental commitments.

#### **Çıkar Çatışması Beyanı / Conflict of Interest**

Çalışmada herhangi bir kurum veya kişi ile çıkar çatışması bulunmamaktadır.  
There is no conflict of interest with any institution or person in the study.

#### **İntihal Politikası Beyanı / Plagiarism Policy**

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#### **Bilimsel Araştırma ve Yayın Etiği Beyanı / Scientific Research and Publication Ethics Statement**

Bu çalışmada Yükseköğretim Kurumları Bilimsel Araştırma ve Yayın Etiği Yönergesi kapsamında belirtilen kurallara uyulmuştur.  
In this study, the rules specified within the scope of the Higher Education Institutions Scientific Research and Publication Ethics Directive were followed.

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