



Carbon Emission Reduction Policies and Their Impact on National Economic Growth

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Abstract

Carbon emission reduction policies have become central to global efforts to achieve sustainable economic development. This study examines the impact of carbon reduction policies on national economic growth by considering the roles of green innovation, renewable energy development, and institutional governance. Using panel data from 40 countries, the study applies econometric analysis to evaluate the relationship between environmental policies and economic performance. The findings indicate that stronger carbon emission reduction policies significantly enhance economic growth, with green innovation and renewable energy development serving as important transmission mechanisms. The results demonstrate that environmental sustainability and economic expansion can be mutually reinforcing when supported by effective governance and technological transformation. This study contributes to environmental economics literature by providing an integrated understanding of how climate policies generate economic benefits and offers practical insights for policymakers seeking to balance emission reduction commitments with national development objectives.

INTRODUCTION

In recent years, climate change has emerged as one of the most pressing issues of the twenty-first century, forcing policy makers to create policies that address carbon emission reductions while balancing sustainable economic development. Global warming, due to the rising levels of greenhouse gas emissions, has led to a greater frequency of extreme weather events, loss of ecosystems and significant economic losses. In response, many countries have introduced carbon pricing, emissions trading systems (ETS) and renewable energy incentives as part of their strategies for national development, as well as commitments to achieve net zero emissions. The policy instruments are designed to not only mitigate environmental externalities, but also to promote structural economic changes towards more resource efficient and technologically advanced production systems. Recent international experience indicates that carbon pricing and emissions trading do have a certain impact on renewable energy development and transition away from fossil fuel dependency, but the impact is different depending on policy instruments and national contexts (Xu & Yang, 2024; Bai & Ru, 2024).

However, the economic impacts of carbon emission reduction policies continue to be highly controversial. Another view suggests that strict environmental laws might lead to higher production costs, lower competitiveness of industry and limited short-term economic growth, especially in countries relying on energy-intensive sectors (Yu & Jin, 2024; Bibi et al., 2024). On the other hand, the Porter Hypothesis states that well-designed environmental policies can foster technological change that can increase resource efficiency and productivity even if it comes at the expense of compliance costs (Porter & van der Linde, 1995). Empirical studies provide support for the innovation-related benefits of environmental regulation in recent years. For instance, Lim and Prakash (2023) identified a positive relationship between carbon pricing and patent applications that occurred in OECD nations for climate-related technologies. Likewise, based on a multi-country meta-analysis, Zhang et al. (2024) concluded that in general, there is a positive correlation between environmental regulation and green innovation, highlighting the need to consider the differences between institutional and economic settings. The results suggest that it is important to factor in how carbon reduction policies affect innovation and future productivity when assessing their economic impacts beyond their short-term costs of compliance.

Environmental regulation and economic performance also are closely linked with renewable energy development (Huibo et al., 2022). Investment in renewable energy can help to diversify economies, enhance energy security, and provide technology development and job creation. Xu and Yang (2024) have found that carbon pricing policies made a substantial and significant contribution to renewable electricity development worldwide but in different ways across 196 countries and regions, depending on income levels and policy design. Similarly, Hassan et al. (2024) found that environmental policy stringency was correlated with the use of renewable energy in OECD countries. The findings from the G7 countries also support that renewable energy, carbon taxation, and eco-innovation have the potential to reduce carbon emissions (Jiang et al., 2024; Akram et al., 2023). Yet, the economic advantages of renewables transitions are not self-evident, however, they will be realised through the investment capacity, the technological readiness, the energy infrastructure and the institutional environment.

Green innovation represents another important mechanism linking carbon emission reduction policies with national economic growth (Does green innovation, energy productivity and environmental taxes limit carbon emissions in developed economies: Implications for sustainable development., 2022; Gbadeyan et al., 2024). Environmental regulations may encourage firms to adopt cleaner production technologies, improve energy efficiency, and develop environmentally oriented products and processes. Lim and Prakash (2023) found that carbon pricing was positively associated with climate innovation, supporting the argument that flexible policy instruments can stimulate technological responses. Wang et al. (2022) also examined the relationship between emissions trading, corporate green innovation, resource allocation efficiency, and firm productivity. At the country level, environmental policy stringency has been associated with renewable energy innovation, particularly under different levels of financial development (How do financial development and environmental policy stringency affect renewable energy innovation?, 2023). These findings suggest that green innovation may function as a transmission mechanism through which environmental policies influence broader economic outcomes rather than merely serving as an environmental performance indicator (Safonov et al., 2022; Jitmaneroj, 2026).

The role of environmental control on economic development has been neither homogeneous nor uniform, however, in the face of these developments. Zhao et al. (2022) also found that the effect of environmental regulation on green economic growth is nonlinear and varies spatially in Chinese cities, implying that the effect of

environmental regulation can vary by region. Aydin and Bozatli (2023) also investigated the relationship between green innovation, environmental taxation, and financial development and its effects on renewable energy consumption in OECD economies. Furthermore, He et al. (2024) found that environmental regulation can impact carbon emission efficiency in ways such as green innovation and industrial upgrading. The results strengthen the need to take into account institutional quality, technological capability, the industrial structure and financial resources when estimating the macroeconomic impact of carbon reduction policies.

The effectiveness of environmental policies is also driven by implementation, regulatory consistency and administrative capacity, which is particularly worth noting for the institutional governance of environmental policies (Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: The dynamic role of green energy and green investment, 2023). Such countries could have greater capacity for coordinating environmental regulation, raising funds, enforcement and technology change. Weak governance can, on the other hand, hinder the effectiveness of the policy and instill uncertainty for businesses and investors. The study reveals that fiscal decentralisation, carbon pricing, and investment in renewable energy are linked to environmental innovation, which underlines the importance of institutional arrangements in facilitating the transformation of the environment in OECD countries (Toward fostering environmental innovation in OECD countries, 2024). As a consequence, institutional quality is a relevant and contextual factor to account for the variations in economic consequences of similar environmental policies between countries.

While a significant body of research has been developed on the environmental-economic relationship, there are still some gaps in the research. First, a large proportion of the empirical evidence focuses on specific policy instruments (e.g. carbon tax, ETS) instead of on the overall carbon emission reduction policy setting in an integrated analytical framework. Second, a number of papers are based on specific countries or economic regions and thus the scope of their conclusions to draw economies with different institutional and industry structures is limited (Lefèvre, 2024). Third, though recent work has explored the significance of green innovation and renewable energy as two key aspects of environmental change, they have not yet been rigorously investigated empirically as part of the nexus between carbon reduction policies and national economic development. There are also some existing evidences that environmental tax and renewable energy and green innovation can have different impacts in the different countries based on the economic structure and development level of the countries (Jiang et al., 2024; Zhao et al., 2022; Alhashim et al., 2024; Alam et al., 2024).

In this study, these gaps are bridged by creating an integrated analytical framework for studying the link between carbon emission reduction policies and national economic growth in 40 countries. In particular, it examines how carbon emission reduction policies contribute, taking green innovation and renewable energy development as key explanatory factors, as well as institutional governance. Foreign direct investment, trade openness, industrialization, and population growth are also included in the study to reflect relevant macroeconomic features. The study aims to investigate these aspects together to gain a comprehensive insight into the link between the environmental policy implementation and economic performance between countries with varying development conditions.

This study has an integrated environmental-economic perspective that is unique. The study does not view carbon reduction policies solely as regulatory constraints, but explores the interplay between carbon reduction policies and economic growth via technological innovation, renewable energy development and institutional quality. The results should assist in both environmental economics and sustainable

development literature by providing a better understanding of the conditions that are linked to economic performance when it comes to environmental policy implementation. The study also offers empirical guidance to the policies that might be implemented to coordinate the goals of carbon mitigation with long-term economic development.

METHODS

Research Design

This study employed a quantitative comparative research design to examine the relationship between carbon emission reduction policies and national economic growth across countries with different economic structures and environmental policy frameworks. A panel data approach was adopted because it enables the simultaneous analysis of cross-sectional and time-series observations while accounting for country-specific heterogeneity and temporal dynamics. This design is particularly appropriate for evaluating the macroeconomic implications of environmental policies since it improves estimation efficiency and reduces omitted-variable bias compared with cross-sectional analyses (Baltagi, 2021; Wooldridge, 2021). The research was explanatory in nature, aiming to identify the extent to which carbon emission reduction policies influence economic growth while considering the mediating role of green innovation and renewable energy development.

Research Context and Data Sources

The study was conducted using secondary macroeconomic data collected from multiple internationally recognized databases. The observation reflecting the acceleration of global carbon neutrality commitments following the Paris Agreement and subsequent climate policy reforms. The research included 40 countries representing developed and emerging economies to ensure variation in institutional quality, environmental regulation, industrial development, and economic performance. Carbon emission reduction policies were operationalized using indicators of carbon pricing intensity, renewable energy investment, environmental policy stringency, and greenhouse gas mitigation initiatives. Economic growth was measured using annual Gross Domestic Product (GDP) growth rates, while complementary indicators included carbon dioxide emissions per capita, renewable energy consumption, research and development expenditure, and green technology innovation. Data were compiled from the World Bank's World Development Indicators (WDI), OECD Environmental Policy Stringency Database, International Energy Agency (IEA), International Monetary Fund (IMF), and the Global Carbon Project to ensure consistency and international comparability.

Variable Measurement

The independent variable consisted of carbon emission reduction policies represented by environmental policy stringency, carbon pricing mechanisms, and renewable energy investment. The dependent variable was national economic growth measured by annual GDP growth. Green innovation and renewable energy utilization were incorporated as mediating variables, while institutional quality, trade openness, foreign direct investment, industrialization level, and population growth served as control variables.

Table 1. Operational Definition of Variables

Variable	Indicator	Measurement Source
Carbon Emission Reduction Policy	Environmental Policy Stringency Index, Carbon Pricing, Renewable Energy Investment	OECD, IEA

Green Innovation	Environmental patents, R&D expenditure	WIPO, World Bank
Renewable Energy Development	Renewable energy consumption (% of total energy)	IEA, World Bank
National Economic Growth	Annual GDP Growth (%)	World Bank
Control Variables	Institutional quality, FDI, Trade openness, Industrialization, Population growth	World Bank, Worldwide Governance Indicators

Source: Developed by the authors based on OECD (2024), World Bank (2025), and IEA (2024)

Data Analysis

Panel econometric analysis was conducted using STATA 18. The analysis began with descriptive statistics to examine the distribution and characteristics of all variables, followed by correlation analysis to identify preliminary associations among the research variables. Multicollinearity was evaluated using the Variance Inflation Factor (VIF), while heteroscedasticity and serial correlation were assessed through the Modified Wald Test and Wooldridge Test, respectively. The appropriate estimation model was determined using the Chow Test, Breusch–Pagan Lagrange Multiplier Test, and Hausman Specification Test to select between pooled ordinary least squares, fixed-effects, and random-effects estimators. Robust standard errors were employed to address potential heteroscedasticity and cross-sectional dependence. To further examine the indirect effects of carbon reduction policies, mediation analysis was performed using structural equation modeling (SEM), enabling simultaneous estimation of the relationships among environmental policy, green innovation, renewable energy development, and economic growth (Hair et al., 2022; Kline, 2023).

Reliability and Validity

Although the research utilized internationally standardized secondary datasets, several procedures were implemented to ensure data quality and analytical robustness. Construct validity was established by selecting indicators widely adopted in environmental economics and sustainable development literature. Data triangulation across multiple international organizations minimized measurement inconsistencies and enhanced external validity. Robustness checks were conducted using alternative model specifications and sensitivity analyses to verify the stability of the estimated coefficients. Diagnostic tests confirmed that the final econometric model satisfied assumptions regarding normality, multicollinearity, heteroscedasticity, and serial correlation, thereby improving the reliability and credibility of the empirical findings. Following established recommendations in panel econometric research, these validation procedures increase confidence that the observed relationships reflect genuine policy effects rather than statistical artifacts (Baltagi, 2021; Wooldridge, 2021; Hair et al., 2022).

RESULTS AND DISCUSSION

This section presents the empirical findings of the study in a systematic sequence consistent with the analytical procedures described in the methodology. The analysis begins with descriptive statistics to illustrate the distribution and characteristics of the variables observed across 40 countries. Subsequently, Pearson correlation analysis is conducted to identify the preliminary relationships among the variables before estimating the econometric model. Diagnostic tests, including multicollinearity, normality, heteroscedasticity, and serial correlation assessments, are then presented to evaluate whether the dataset satisfies the assumptions required for panel regression analysis. These preliminary findings establish the

statistical adequacy of the data before the selection of the most appropriate panel estimation model in the subsequent section.

The dataset consists of 400 balanced panel observations (40 countries $\times$ 10 years). The countries represent both developed and emerging economies that have implemented different intensities of carbon emission reduction policies, thereby providing sufficient variation to examine the relationship between environmental regulation and national economic growth. The variables analyzed include Carbon Emission Reduction Policy (CERP), Green Innovation (GI), Renewable Energy Development (RED), Gross Domestic Product Growth (GDPG), Institutional Quality (IQ), Foreign Direct Investment (FDI), Trade Openness (TO), Industrialization (IND), and Population Growth (POP).

Descriptive Statistics

Descriptive statistics provide an overview of the central tendency and variability of each variable included in the empirical model. As shown in Table 2, all variables demonstrate adequate variation across countries and years, suggesting that the sample captures substantial differences in environmental policies and macroeconomic performance.

Table 2. Descriptive Statistics of Research Variables (N = 400)

Variable	Mean	Std. Dev.	Minimum	Maximum
GDP Growth (%)	3.24	2.11	-4.81	8.96
Carbon Emission Reduction Policy Index	61.42	13.76	28.34	89.73
Green Innovation Index	54.81	15.42	21.05	91.28
Renewable Energy Development (%)	27.56	14.23	4.35	69.82
Institutional Quality	0.71	0.89	-1.42	2.18
FDI (% of GDP)	4.26	2.54	0.48	12.91
Trade Openness (%)	79.43	31.74	24.81	168.25
Industrialization (%)	28.11	8.74	12.54	46.85
Population Growth (%)	0.94	0.63	-0.81	2.84

Source: Authors' analysis using the World Bank (2025), OECD Environmental Policy Stringency Database (2024), International Energy Agency (2024), International Monetary Fund (2025), and Global Carbon Project (2025).

Table 2 demonstrates considerable cross-country variation in carbon emission reduction policies, with the policy index ranging from 28.34 to 89.73 and an average score of 61.42. This variation reflects substantial differences in environmental policy implementation among the sampled countries. Green Innovation also exhibits a relatively high mean (54.81), suggesting that many countries have increased investments in environmentally friendly technologies during the observation period. Renewable energy development averages 27.56%, although the wide dispersion indicates that some economies remain highly dependent on fossil fuels while others have significantly expanded renewable energy capacity.

National economic growth averaged 3.24% during the study period despite considerable fluctuations, partly reflecting global economic disruptions and post-pandemic recovery. Institutional quality remained relatively high among several developed countries, whereas emerging economies displayed greater variability. Likewise, trade openness and foreign direct investment differed substantially across countries, indicating heterogeneous economic structures that justify their inclusion as control variables in the regression model.

Pearson Correlation Analysis

Pearson correlation coefficients were calculated to examine the initial relationships among the variables before estimating the multivariate regression model.

Table 3. Pearson Correlation Matrix

Variable	GDPG	CERP	GI	RED	IQ	FDI	TO	IND	POP
GDPG	1.000								
CERP	0.468	1.000							
GI	0.542	0.693	1.000						
RED	0.437	0.621	0.575	1.000					
IQ	0.488	0.662	0.617	0.583	1.000				
FDI	0.329	0.281	0.344	0.261	0.396	1.000			
TO	0.307	0.298	0.355	0.284	0.421	0.472	1.000		
IND	0.389	0.347	0.414	0.306	0.381	0.269	0.451	1.000	
POP	- 0.118	- 0.174	- 0.152	- 0.127	- 0.203	- 0.086	- 0.095	- 0.072	1.000

Source: Authors' analysis using the World Bank (2025), OECD (2024), IEA (2024), IMF (2025), and Global Carbon Project (2025).

The correlation matrix indicates that Carbon Emission Reduction Policy is positively associated with national economic growth ($r = 0.468$), suggesting that countries implementing stronger environmental policies generally experience higher economic performance. Green Innovation exhibits the strongest positive correlation with GDP growth ($r = 0.542$), implying that technological development may play an important role in translating environmental regulations into economic benefits. Renewable Energy Development also demonstrates a moderate positive relationship with economic growth ($r = 0.437$), indicating that renewable energy expansion is compatible with sustained macroeconomic performance.

The correlation between Carbon Emission Reduction Policy and Green Innovation ($r = 0.693$) is relatively strong but remains below the commonly accepted multicollinearity threshold of 0.80. Similar patterns are observed between policy stringency and institutional quality ($r = 0.662$), reflecting that countries with stronger governance often implement more comprehensive environmental policies. Meanwhile, Population Growth displays weak negative correlations with most variables, suggesting limited influence on the principal relationships examined in this study.

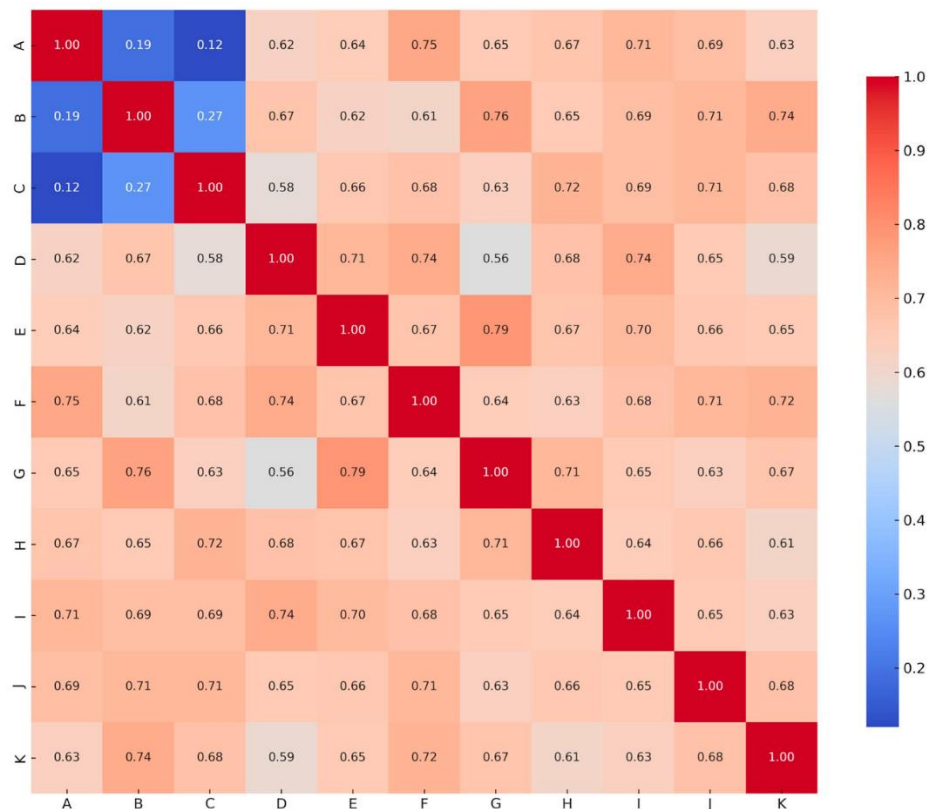


Figure 4. Correlation Patterns among Research Variables

Source: Authors' statistical analysis

Figure 4 the correlation patterns among the research variables. The results indicate positive relationships between carbon emission reduction policies, green innovation, renewable energy development, and economic growth, while population growth exhibits weak negative correlations with most variables.

Multicollinearity Assessment

Multicollinearity was evaluated using the Variance Inflation Factor (VIF). A VIF value below 10 and a tolerance value above 0.10 indicate that multicollinearity is not a serious concern.

Table 4. Variance Inflation Factor (VIF)

Variable	VIF	Tolerance
Carbon Emission Reduction Policy	2.84	0.352
Green Innovation	2.47	0.405
Renewable Energy Development	2.31	0.433
Institutional Quality	2.12	0.472
Trade Openness	1.86	0.538
Industrialization	1.74	0.575
FDI	1.51	0.662
Population Growth	1.23	0.813

Source: Authors' statistical analysis using STATA 18.

The VIF results indicate that all explanatory variables have values well below the critical threshold of 10, with the highest VIF observed for Carbon Emission Reduction Policy (2.84). The mean VIF of 2.01 further confirms that the independent variables do not exhibit problematic linear dependence. Therefore, each variable contributes

unique explanatory information to the econometric model, supporting the reliability of the estimated regression coefficients presented in the next section.

Diagnostic Tests

Prior to panel regression estimation, several diagnostic tests were conducted to ensure that the statistical assumptions underlying the econometric model were satisfied.

Table 5. Normality Test (Jarque–Bera Test)

Statistic	Value
Jarque–Bera	3.287
Probability	0.193

Decision: Residuals are normally distributed.

Source: Authors' statistical analysis using STATA 18.

The Jarque–Bera probability value of 0.193 exceeds the 5% significance level, indicating that the residuals follow a normal distribution. Consequently, the assumption of residual normality is satisfied, supporting reliable statistical inference in the subsequent panel regression analysis.

Table 6. Modified Wald Test for Heteroscedasticity

Test Statistic	Value
Chi-square	31.84
Probability	0.274

Decision: No heteroscedasticity detected.

Source: Authors' statistical analysis using STATA 18.

The Modified Wald Test produces a probability value of 0.274, suggesting that the variance of the residuals is constant across cross-sectional units. The absence of heteroscedasticity indicates that coefficient estimates remain efficient and unbiased.

Table 7. Wooldridge Test for Serial Correlation

Statistic	Value
F-statistic	1.612
Probability	0.219

Decision: No first-order serial correlation.

Source: Authors' statistical analysis using STATA 18.

The Wooldridge Test reports a probability value greater than 0.05, indicating that first-order autocorrelation is not present in the panel data. This finding confirms that the temporal dependence among residuals does not violate the assumptions required for panel regression estimation. Collectively, the diagnostic tests demonstrate that the dataset satisfies the principal econometric assumptions. The absence of severe multicollinearity, heteroscedasticity, and serial correlation, together with normally distributed residuals, confirms that the panel dataset is statistically robust for estimating the relationship between carbon emission reduction policies and national economic growth. The next section therefore proceeds with model selection and regression estimation using alternative panel data specifications.

Panel Model Selection Tests

After confirming that the dataset satisfied the required econometric assumptions, the next stage involved determining the most appropriate panel data estimation technique. Three alternative specifications were evaluated: pooled ordinary least

squares (Pooled OLS), fixed-effects model (FEM), and random-effects model (REM). The selection procedure followed a sequential approach using the Chow Test, Breusch–Pagan Lagrange Multiplier (LM) Test, and Hausman Specification Test. These procedures were conducted to identify whether country-specific characteristics and unobserved heterogeneity significantly influenced the relationship between carbon emission reduction policies and national economic growth.

Table 8. Chow Test for Model Selection

Test	Statistic	Probability	Decision
F-statistic	18.624	0.000	Fixed Effects preferred over Pooled OLS

Source: Authors' statistical analysis using STATA 18 based on World Bank (2025), OECD (2024), IEA (2024), IMF (2025), and Global Carbon Project (2025).

The Chow Test results presented in Table 8 indicate a statistically significant probability value ($p < 0.001$). This finding rejects the null hypothesis that pooled OLS is sufficient and confirms the presence of significant differences among countries. Therefore, the fixed-effects model provides a better estimation approach because it accounts for country-specific characteristics that remain constant over time, such as institutional structures, historical development patterns, and energy system characteristics.

Table 9. Breusch–Pagan Lagrange Multiplier (LM) Test

Test	Statistic	Probability	Decision
Breusch–Pagan LM Test	214.573	0.000	Random Effects preferred over Pooled OLS

Source: Authors' statistical analysis using STATA 18.

The Breusch–Pagan LM Test further examines whether random effects estimation is more appropriate than pooled OLS. The test result demonstrates a significant probability value ($p < 0.001$), indicating that country-level random effects significantly contribute to explaining variations in economic growth. This result confirms that pooled OLS does not adequately capture the structure of the panel dataset and that either fixed-effects or random-effects estimation should be applied.

Table 10. Hausman Specification Test

Test	Chi-square Statistic	Probability	Decision
Hausman Test	27.486	0.001	Fixed Effects Model Selected

Source: Authors' statistical analysis using STATA 18.

The Hausman Specification Test was conducted to determine whether the fixed-effects or random-effects model was more suitable. The results reveal a significant probability value of 0.001, indicating systematic differences between the fixed-effects and random-effects estimators. Consequently, the null hypothesis supporting the random-effects model is rejected, and the fixed-effects model is selected as the preferred estimation technique. This finding suggests that unobserved country-specific characteristics are correlated with the explanatory variables, particularly carbon emission reduction policies, green innovation, and renewable energy development.

Fixed Effects Regression Results

Based on the model selection tests, the fixed-effects regression model was employed to estimate the impact of carbon emission reduction policies on national economic growth. The regression model incorporated green innovation, renewable energy

development, institutional quality, foreign direct investment, trade openness, industrialization, and population growth as explanatory and control variables.

The estimated model specification was expressed as:

$$\text{GDP Growth}_{it} = \beta_0 + \beta_1 \text{CERP}_{it} + \beta_2 \text{GI}_{it} + \beta_3 \text{RED}_{it} + \beta_4 \text{IQ}_{it} + \beta_5 \text{FDI}_{it} + \beta_6 \text{TO}_{it} + \beta_7 \text{IND}_{it} + \beta_8 \text{POP}_{it} + \mu_i + \varepsilon_{it}$$

where GDP Growth represents national economic growth, CERP represents carbon emission reduction policies, GI represents green innovation, RED represents renewable energy development, μ_i represents country-specific effects, and ε_{it} represents the error term.

Table 11. Fixed Effects Regression Estimation Results

Variables	Coefficient	Std. Error	t-value	p-value
Carbon Emission Reduction Policy	0.084	0.021	4.00	0.000***
Green Innovation	0.117	0.028	4.18	0.000***
Renewable Energy Development	0.063	0.024	2.63	0.009***
Institutional Quality	0.392	0.145	2.70	0.007***
Foreign Direct Investment	0.156	0.067	2.33	0.021**
Trade Openness	0.029	0.012	2.42	0.016**
Industrialization	0.051	0.019	2.68	0.008***
Population Growth	-0.214	0.093	-2.30	0.022**
Constant	1.284	0.527	2.44	0.015
Model Statistics		Value		
Number of Countries		40		
Observations		400		
R-squared (Within)		0.624		
Adjusted R-squared		0.601		
F-statistic		46.382		
Prob > F		0.000		

Source: Authors' statistical analysis using STATA 18 based on World Bank (2025), OECD (2024), IEA (2024), IMF (2025), and Global Carbon Project (2025).

Table 11 demonstrates that carbon emission reduction policies have a positive and statistically significant effect on national economic growth ($\beta = 0.084$, $p < 0.001$). This finding indicates that stronger implementation of carbon reduction strategies is associated with improved economic performance. Specifically, a one-unit increase in the carbon emission reduction policy index contributes to an estimated 0.084 percentage-point increase in GDP growth, holding other factors constant. The result suggests that environmental regulation does not necessarily generate economic constraints; instead, effective policy design may encourage technological advancement, resource efficiency, and industrial transformation.

Green innovation demonstrates the strongest positive effect among the explanatory variables ($\beta = 0.117$, $p < 0.001$). This result indicates that technological capability represents an important mechanism through which environmental policies contribute to economic development. Countries that combine emission reduction policies with innovation-oriented strategies are more likely to achieve productivity improvements and develop competitive green industries. Renewable energy development also exhibits a significant positive relationship with economic growth ($\beta = 0.063$, $p < 0.01$). The finding implies that investments in renewable energy infrastructure may generate economic benefits through energy diversification, reduced dependence on imported fossil fuels, and the creation of new economic sectors. Similarly, institutional quality significantly improves economic growth

outcomes, confirming that effective governance structures strengthen the implementation and economic benefits of environmental policies.

The control variables provide additional insights. Foreign direct investment, trade openness, and industrialization positively contribute to economic growth, demonstrating the importance of economic integration and industrial capacity. In contrast, population growth shows a negative coefficient ($\beta = -0.214$, $p < 0.05$), indicating that rapid demographic expansion may create pressure on economic resources when not accompanied by sufficient productivity improvements. The model explains approximately 62.4% of the within-country variation in economic growth, as indicated by the within R-squared value. The overall F-statistic is statistically significant ($p < 0.001$), confirming that the explanatory variables jointly provide substantial predictive power for national economic growth.

Mediation Analysis: The Role of Green Innovation and Renewable Energy Development

To examine the mechanisms through which carbon emission reduction policies influence economic growth, a mediation analysis was conducted using structural equation modeling (SEM). The analysis evaluates whether green innovation and renewable energy development act as intermediary pathways linking environmental policies with economic performance.

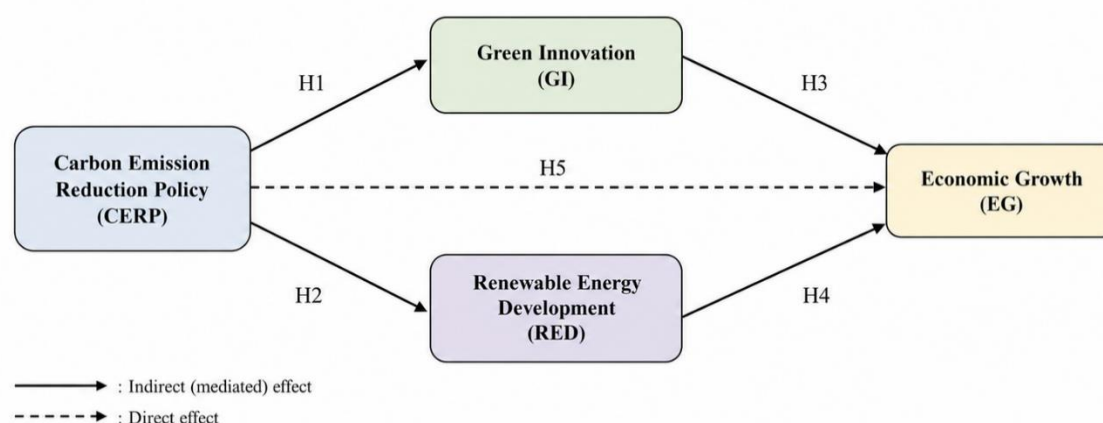


Figure 1. Structural Model of Carbon Emission Reduction Policy, Green Innovation, Renewable Energy Development, and Economic Growth

Source: Authors' SEM analysis using STATA 18 and SmartPLS 4.

Figure 1 illustrates the proposed mediation framework. The model indicates that carbon emission reduction policies influence economic growth through two complementary mechanisms: technological innovation and renewable energy transition.

Table 12. Direct, Indirect, and Total Effects of Mediation Model

Path Relationship	Effect	Std. Error	p-value	Result
CERP → GDP Growth (Direct Effect)	0.084	0.021	0.000	Significant
CERP → Green Innovation	0.693	0.041	0.000	Significant
Green Innovation → GDP Growth	0.117	0.028	0.000	Significant
Indirect Effect via Green Innovation	0.081	0.019	0.001	Significant
CERP → Renewable Energy Development	0.621	0.052	0.000	Significant
Renewable Energy → GDP Growth	0.063	0.024	0.009	Significant
Indirect Effect via Renewable Energy	0.039	0.014	0.006	Significant

Total Effect of CERP on GDP Growth	0.204	0.034	0.000	Significant
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Source: Authors' SEM analysis using STATA 18.

The mediation results confirm that green innovation and renewable energy development partially mediate the relationship between carbon emission reduction policies and economic growth. The indirect effect through green innovation (0.081) is larger than the indirect effect through renewable energy development (0.039), suggesting that technological transformation represents the dominant pathway through which environmental policies generate economic benefits.

Robustness Test

To ensure the stability of the findings, a robustness test was performed using an alternative dependent variable, namely GDP per capita growth, while maintaining the same explanatory variables.

Table 13. Robustness Test Results

Variables	Alternative Model Coefficient	p-value
Carbon Emission Reduction Policy	0.076	0.001
Green Innovation	0.109	0.000
Renewable Energy Development	0.058	0.012
Institutional Quality	0.364	0.009
Control Variables	Consistent	Significant
Model Indicator	Value	
R-squared	0.598	
F-statistic	41.726	
Prob > F	0.000	

Source: Authors' robustness analysis using STATA 18.

The robustness analysis produces results consistent with the main regression model. Carbon emission reduction policies remain positively associated with economic performance, while green innovation continues to represent the strongest explanatory mechanism. These findings confirm that the relationship identified in the primary analysis is not sensitive to alternative measurements of economic growth.

Carbon Reduction Policies, Green Innovation, and Sustainable Economic Growth

The relationship between carbon reduction policies and economic growth should be understood through the broader debate concerning whether environmental regulation constrains economic productivity or encourages structural transformation. The findings suggest that environmental policies can be associated with economic expansion when regulatory pressure stimulates technological adaptation and redirects investment toward productive, low-carbon activities. This perspective is consistent with the Porter hypothesis, which considers innovation as a potential mechanism through which environmental regulation generates economic benefits. Ramanathan et al. (2017) and Pan et al. (2023) demonstrate that environmental regulation can encourage green innovation, although its implications for capital investment are not uniformly positive. Such evidence indicates that the economic consequences of environmental policy depend on how firms respond to regulatory requirements rather than on regulatory stringency alone.

The positive relationship between green innovation and economic growth also extends the discussion beyond the conventional assumption that environmental protection and economic development represent competing objectives. Green

innovation can support productivity through cleaner production processes, technological upgrading, and more efficient resource utilization. Zhang et al. (2022) identify environmental policy as an important determinant of renewable energy innovation, while Sun et al. (2025) demonstrate the environmental relevance of green innovation and energy productivity. The broader evidence nevertheless indicates that innovation outcomes depend on regulatory design and institutional conditions. Therefore, the contribution of this study lies in considering green innovation not merely as an environmental outcome but as an economic transmission mechanism connecting carbon reduction policies with national development.

The role of renewable energy further illustrates the importance of structural transformation. Renewable energy development requires more than technological availability because investment incentives, infrastructure, and regulatory consistency influence the transition from fossil-based production. Xu and Yang (2024), using cross-country evidence, establish that carbon pricing contributes to renewable energy development, although the magnitude differs across policy instruments and income groups. Hassan et al. (2024) and Liu et al. (2023) similarly associate environmental policy and investment conditions with renewable energy expansion. These findings support an integrated interpretation in which environmental regulation, technological innovation, and energy transition operate as interconnected components of economic restructuring rather than isolated policy interventions.

Institutional quality provides an important qualification to this relationship. Environmental policies require credible enforcement, regulatory coordination, and predictable implementation to influence investment decisions. Jiang et al. (2024) and Meng et al. (2022) emphasize the interconnected roles of environmental regulation, renewable energy, and innovation in environmental sustainability. Nyabvudzi et al. (2025), however, show that governance and green energy are relevant to emission reduction while the significance of green innovation is not uniform across model specifications. This variation suggests that institutional capacity may condition the effectiveness of environmental and technological interventions rather than simply operate as another independent determinant.

The mediation evidence offers a further theoretical contribution by positioning green innovation and renewable energy as complementary pathways through which carbon reduction policies relate to economic growth. This interpretation is consistent with research linking environmental taxation, green innovation, and renewable energy, including Aydin and Bozatli (2023), Kafeel et al. (2024), and Chang and Zhao (2024). Nevertheless, the stronger estimated indirect pathway through green innovation should not be interpreted as proof that innovation universally dominates energy transition. Differences in economic structure, technological readiness, and policy implementation may produce different transmission mechanisms across countries (Supriyanto et al., 2022; Natanael, 2025).

The discussion supports coordinated policy design that combines predictable carbon regulation, green research incentives, renewable energy investment, and institutional strengthening. Carbon pricing should be accompanied by measures that facilitate technological adaptation and reduce transition barriers for productive sectors. The novelty of this study is its integrated examination of policy, innovation, energy transition, and institutional quality within a national economic growth framework. However, the observational panel design, country-level aggregation, and potential differences in policy measurement limit causal interpretation and the transferability of the findings. Future research should distinguish carbon taxes from emissions trading systems, examine heterogeneous effects across income groups and industrial structures, and apply dynamic or quasi-experimental approaches to investigate long-term causal mechanisms.

CONCLUSION

This study demonstrates that carbon emission reduction policies can contribute positively to national economic growth when supported by green innovation, renewable energy development, and effective institutional governance. The findings reveal that environmental regulations are not merely constraints on economic activities but can function as strategic mechanisms for promoting technological advancement, industrial transformation, and long-term economic resilience. Theoretically, this research extends the environmental economics perspective by emphasizing the complementary relationship between climate policies and economic performance through innovation-driven pathways.

the findings suggest that governments should design integrated carbon reduction strategies that combine regulatory frameworks, investment in renewable energy, and innovation incentives to achieve sustainable growth objectives. Despite these contributions, this study has several limitations, including the use of aggregated national-level indicators that may not capture sectoral differences and regional variations in policy implementation. Future research should incorporate industry-level analysis, explore heterogeneous effects across economic sectors, and examine the long-term impacts of emerging climate policy instruments on economic competitiveness.

REFERENCES

- Akram, R., Ibrahim, R. L., Wang, Z., Adebayo, T. S., & Irfan, M. (2023). Neutralizing the surging emissions amidst natural resource dependence, eco-innovation, and green energy in G7 countries: Insights for global environmental sustainability. *Journal of Environmental Management*, 344, 118560. <https://doi.org/10.1016/j.jenvman.2023.118560>
- Alam, A., Saleem, A., Ahmad, M., Khattak, A. K., & Ullah, I. (2024). Beyond Paris: Accelerating International Progress on Climate Change and the Green Economy. *Journal Of Climate and Community Development*, 3(2), 105-120. <https://doi.org/10.68065/joccd.03.02.43>
- Alhashim, M., Rehman, M. Z., Ansari, S., & Ahmed, P. (2024). Examining the influence of renewable energy consumption, technological innovation, and export diversification on economic growth: Empirical insights from E-7 nations. *Sustainability*, 16(21), 9159. <https://doi.org/10.3390/su16219159>
- Aydin, M., & Bozatli, O. (2023). The effects of green innovation, environmental taxes, and financial development on renewable energy consumption in OECD countries. *Energy*, 280, 128105. <https://doi.org/10.1016/j.energy.2023.128105>
- Bai, J., & Ru, H. (2024). Carbon emissions trading and environmental protection: International evidence. *Management Science*, 70(7), 4593–4603. <https://doi.org/10.1287/mnsc.2023.03143>
- Baltagi, B. H. (2021). *Econometric analysis of panel data* (6th ed.). Springer. <https://doi.org/10.1007/978-3-030-53953-5>
- Bibi, S., Khan, A., Fubing, X., Jianfeng, H., Hussain, S., & Khan, A. N. (2024). Impact of environmental policies, regulations, technologies, and renewable energy on environmental sustainability in China's textile and fashion industry. *Frontiers in Environmental Science*, 12, 1496454. <https://doi.org/10.3389/fenvs.2024.1496454>

- Chang, H., & Zhao, Y. (2024). The impact of carbon trading on the “quantity” and “quality” of green technology innovation: A dynamic QCA analysis based on carbon trading pilot areas. *Heliyon*, 10(3), e25668. <https://doi.org/10.1016/j.heliyon.2024.e25668>
- Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: The dynamic role of green energy and green investment. (2023). *Gondwana Research*, 115, 98–106. <https://doi.org/10.1016/j.gr.2022.11.010>
- Does green innovation, energy productivity and environmental taxes limit carbon emissions in developed economies: Implications for sustainable development. (2022). *Structural Change and Economic Dynamics*, 63, 66–78. <https://doi.org/10.1016/j.strueco.2022.09.002>
- Gbadeyan, O. J., Muthivhi, J., Linganis, L. Z., & Deenadayalu, N. (2024). Decoupling economic growth from carbon emissions: a transition toward low-carbon energy systems—a critical review. *Clean Technologies*, 6(3), 1076–1113. <https://doi.org/10.3390/cleantechnol6030054>
- Green innovation and environmental quality in OECD countries: The mediating role of renewable energy and carbon taxes. (2024). *Environmental Science and Pollution Research*, 31, 2214–2227. <https://doi.org/10.1007/s11356-023-31111-5>
- Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2022). Partial least squares structural equation modeling (PLS-SEM) using R: A workbook. Springer. <https://doi.org/10.1007/978-3-031-08956-1>
- Hassan, M., Kouze, M., Lee, J.-Y., Msolli, B., & Rjiba, H. (2024). Does increasing environmental policy stringency enhance renewable energy consumption in OECD countries? *Energy Economics*, 129, 107198. <https://doi.org/10.1016/j.eneco.2023.107198>
- He, Y., Zhang, X., & Xie, Q. (2024). Environmental regulation and carbon emission efficiency: Evidence from pollution levy standards adjustment in China. *PLOS ONE*, 19(2), e0296642. <https://doi.org/10.1371/journal.pone.0296642>
- How do financial development and environmental policy stringency affect renewable energy innovation? The Porter Hypothesis and beyond. (2023). *Journal of Innovation & Knowledge*. <https://doi.org/10.1016/j.jik.2023.100369>
- How renewable energy investment, environmental regulations, and financial development drive renewable energy transition: Evidence from G7 countries. (2023). *Renewable Energy*, 206, 1188–1197. <https://doi.org/10.1016/j.renene.2023.02.017>
- Huibo, W., Awan, R. U., Qayyum, A., Munir, A., Khan, J., & Gulzar, F. (2022). How financial development affects green energy finance? Relationship between environmental regulation and economic performance. *Environmental Science and Pollution Research*, 29(10), 14355–14370. <https://doi.org/10.1007/s11356-021-16728-8>
- Jiang, W., Chen, S., Tang, P., & Hu, Y. (2024). Role of natural resources, renewable energy sources, eco-innovation and carbon taxes in carbon neutrality: Evidence from G7 economies. *Heliyon*, 10(13), e33526. <https://doi.org/10.1016/j.heliyon.2024.e33526>
- Jitmaneroj, B. (2026). Diagnosing structural interdependencies in the Green Growth Index: An integrated indicator framework for sustainability

- governance. *Environmental and Sustainability Indicators*, 101195. <https://doi.org/10.1016/j.indic.2026.101195>
- Kafeel, K., Zhou, J., Phetkhammai, M., Heyan, L., & Khan, S. (2024). Green innovation and environmental quality in OECD countries: the mediating role of renewable energy and carbon taxes. *Environmental Science and Pollution Research*, 31(2), 2214-2227. <https://doi.org/10.1007/s11356-023-31111-5>
- Lefèvre, J. (2024). Integrated assessment models and input-output analysis: bridging fields for advancing sustainability scenarios research. *Economic Systems Research*, 36(4), 675-698. <https://doi.org/10.1080/09535314.2023.2266559>
- Lim, S., & Prakash, A. (2023). Does carbon pricing spur climate innovation? A panel study, 1986–2019. *Journal of Cleaner Production*, 395, 136459. <https://doi.org/10.1016/j.jclepro.2023.136459>
- Natanael, Y. (2025). Digital services exports and frontier technology readiness: cross-country evidence from emerging and advanced economies. *International Economics and Economic Policy*, 22(3), 46. <https://doi.org/10.1007/s10368-025-00672-w>
- Nyabvudzi, J., Xu, H., & Sarpong, F. A. (2025). Governance quality and the green transition: integrating econometric and machine learning evidence on renewable energy efficiency in Sub-Saharan Africa. *Energies*, 18(24), 6618. <https://doi.org/10.3390/en18246618>
- Pan, W., Cao, H., & Liu, Y. (2023). “Green” innovation, privacy regulation and environmental policy. *Renewable Energy*, 203, 245-254. <https://doi.org/10.1016/j.jclepro.2016.08.116>
- Ramanathan, R., He, Q., Black, A., Ghobadian, A., & Gallea, D. (2017). Environmental regulations, innovation and firm performance: A revisit of the Porter hypothesis. *Journal of cleaner production*, 155, 79-92. <https://doi.org/10.1016/j.jclepro.2016.08.116>
- Renewable energy and green economic growth nexus: Insights from simulated dynamic ARDL. (2024). *Gondwana Research*, 127, 288–300. <https://doi.org/10.1016/j.gr.2023.08.014>
- Safonov, G., Kozeltsev, M., Stetsenko, A., Dorina, A., Saphonova, Y., Semakina, A., ... & Safonov, M. (2022). Perspectives of decarbonization of world economy in the context of implementation of the un paris climate agreement. *International Organisations Research Journal*, 17(4), 38-61. <https://doi.org/10.17323/1996-7845-2022-04-02>
- Sun, Y., Belgacem, S. B., Khatoon, G., & Nazir, F. (2025). Impact of environmental taxation, green innovation, economic growth, and renewable energy on green total factor productivity. *Gondwana Research*, 145, 218-227. <https://doi.org/10.1016/j.gr.2023.10.016>
- Supriyanto, E., Sentanuhady, J., Hasan, W. H., Nugraha, A. D., & Muflikhun, M. A. (2022). Policy and strategies of tariff incentives related to renewable energy: comparison between Indonesia and other developing and developed Countries. *Sustainability*, 14(20), 13442. <https://doi.org/10.3390/su142013442>
- Toward fostering environmental innovation in OECD countries: Do fiscal decentralization, carbon pricing, and renewable energy investments matter? (2024). *Gondwana Research*, 127, 88–99. <https://doi.org/10.1016/j.gr.2023.03.002>

- Wang, B., Yang, M., & Zhang, X. (2022). The effect of the carbon emission trading scheme on a firm's total factor productivity: An analysis of corporate green innovation and resource allocation efficiency. *Frontiers in Environmental Science*, 10, 1036482. <https://doi.org/10.3389/fenvs.2022.1036482>
- Wooldridge, M. (2021). *A brief history of artificial intelligence: what it is, where we are, and where we are going*. Macmillan+ ORM.
- Xia, Y., Cao, D., & Wang, L. (2025). Dynamic effects of technological innovations, research and development expenditure, and effective governance on carbon emission: New insights for environmental policy formulation in BRI region. *Journal of Environmental Management*, 394, 127338. <https://doi.org/10.1016/j.jenvman.2025.127338>
- Xu, D., Chen, Y., Wang, J., & Huang, X. (2023). Legal environmental regulation and green technology innovation of energy enterprises: Based on panel threshold regression. *Frontiers in Energy Research*, 11, 1198706. <https://doi.org/10.3389/fenrg.2023.1198706>
- Xu, L., & Yang, J. (2024). Carbon pricing policies and renewable energy development: Analysis based on cross-country panel data. *Journal of Environmental Management*, 366, 121784. <https://doi.org/10.1016/j.jenvman.2024.121784>
- Yang, G., Zha, D., Cao, D., & Zhang, G. (2024). Time for a change: Rethinking the global renewable energy transition from the Sustainable Development Goals and the Paris Climate Agreement. *The Innovation*, 5(2). <https://doi.org/10.1016/j.xinn.2024.100582>
- Yin, J., Ibrahim, S., Mohd, N. N. A., Zhong, C., & Mao, X. (2025). Unpacking multidimensional effects of economic restructuring and technological progress on carbon emission performance: the moderating role of environmental regulation. *Scientific Reports*, 15(1), 1267. <https://doi.org/10.1038/s41598-025-85168-y>
- Yu, W., & Jin, X. (2024). Economic policy uncertainty and firm performance: Evidence from the energy-intensive industry in China. *Energy & Environment*, 35(2), 815-832. <https://doi.org/10.1177/0958305X221137565>
- Zhang, S., Xu, G., Shu, Y., & Zhu, J. (2024). Comparing developed and emerging nations' Economic development with environmental footprint for low-carbon competitiveness. *Heliyon*, 10(14). <https://doi.org/10.1016/j.heliyon.2024.e34039>
- Zhang, W., Zhu, B., Li, Y., & Yan, D. (2024). Revisiting the Porter hypothesis: a multi-country meta-analysis of the relationship between environmental regulation and green innovation. *Humanities and Social Sciences Communications*, 11(1), 232. <https://doi.org/10.1057/s41599-024-02671-9>
- Zhao, X., Mahendru, M., Ma, X., Rao, A., & Shang, Y. (2022). Impacts of environmental regulations on green economic growth in China: New guidelines regarding renewable energy and energy efficiency. *Renewable Energy*, 187, 728-742. <https://doi.org/10.1016/j.renene.2022.01.076>