Determinants of Carbon Intensity in Vietnam: Evidence from an ARDL Model

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ABSTRACT:

This study aims to examine the factors influencing the environmental performance of Vietnam's economy by analyzing the relationship among economic activity, energy transition, technological progress, and emissions per unit of output. Annual time-series data for the period 1990-2021 were collected from the World Bank's World Development Indicators and the annual reports of the Intellectual Property Office of Vietnam. The autoregressive distributed lag model is employed to investigate both the short-run and long-run effects among the research variables. The empirical results indicate the existence of a long-run cointegration relationship among the variables. The estimation results show that economic activity increases emissions per unit of output, reflecting the economy's relatively strong dependence on high-emission energy sources. In contrast, the expansion of clean energy use significantly reduces environmental pressure in both the short and long run. Meanwhile, the proxy for technological progress does not exhibit a statistically significant effect on the environmental indicator during the study period. In addition, the error correction coefficient is negative and statistically significant, confirming the existence of an adjustment mechanism toward long-run equilibrium after short-run shocks. Based on these empirical findings, the study proposes several policy implications to promote energy transition, improve the quality of economic growth, and support the achievement of sustainable development goals in Vietnam.

Keywords: greenhouse gas emissions; energy transition; green technology; sustainable development; cointegration **JEL Classification*:*** C22, O44, Q43, Q54, Q56.

INTRODUCTION

Climate change and environmental degradation have become major challenges to sustainable development worldwide. Among these challenges, greenhouse gas emissions, particularly carbon dioxide (CO_2), are widely recognized as the primary driver of global warming. For developing countries such as Vietnam, rapid economic growth is often accompanied by rising energy demand, which in turn increases carbon emissions and environmental pressure (Grossman & Krueger, 1995; Stern, 2004). Consequently, maintaining economic growth while simultaneously reducing carbon emissions has become an urgent priority in national development strategies.

In this context, renewable energy is widely regarded as an effective solution for reducing emissions and promoting green growth. According to OECD (2011), expanding the use of clean energy sources can reduce dependence on fossil fuels and enhance the environmental performance of an economy. A growing body of empirical evidence suggests that renewable energy plays a significant role in mitigating carbon emissions and improving environmental quality (Kirikkaleli & Adebayo, 2021; Mai et al., 2024).

In addition, innovation is considered an important driver of sustainable development. Technological advancements can improve energy efficiency, facilitate the development of cleaner production technologies, and contribute to long-term carbon emission reduction (Popp, 2010). However, empirical findings regarding the environmental effects of innovation remain inconclusive. While some studies argue that innovation contributes to environmental improvement, others suggest that the scale-expansion effect associated with technological development may increase carbon emissions, particularly during the early stages of technological progress (Chien et al., 2022; Pham et al., 2024).

Although extensive research has examined the relationships among economic growth, renewable energy, and innovation, most studies focus primarily on absolute CO_2 emissions. In contrast, carbon intensity, which measures emissions per unit of economic output, provides a more appropriate indicator for assessing the environmental efficiency of economic growth. Therefore, this study investigates the effects of economic growth, renewable energy, and innovation on carbon intensity in Vietnam during the period 1990–2021 using the Autoregressive Distributed Lag (ARDL) approach. The findings contribute to the existing literature on the determinants of carbon intensity and provide a scientific basis for formulating green growth policies and supporting Vietnam's commitment to achieving net-zero emissions.

Theoretical Background and Literature Review

The relationship among economic growth, renewable energy, innovation, and carbon intensity has attracted considerable attention in the sustainable development literature. According to environmental economics theory, economic expansion is often accompanied by increasing energy demand, production activities, and consumption, which may lead to higher greenhouse gas emissions when an economy relies heavily on fossil fuels (Pigou, 1920; Pearce & Turner, 1990). A substantial body of empirical research has similarly documented that economic growth tends to increase carbon emissions in developing economies. For example, Nguyen and Kakinaka (2019) and Le and Sarkodie (2020) reported that economic growth is one of the key drivers of long-term environmental pressure.

In contrast, green growth theory argues that economic development can be sustained while simultaneously reducing environmental degradation through the adoption of clean energy sources and more efficient resource utilization (OECD, 2011; Bowen & Hepburn, 2014). Renewable energy is regarded as a crucial factor in decreasing dependence on fossil fuels and enhancing environmental performance. Numerous empirical studies have demonstrated the beneficial role of renewable energy in mitigating carbon emissions and improving environmental quality (Apergis & Payne, 2014; Kirikkaleli & Adebayo, 2021). In the Vietnamese context, Mai et al. (2024) found that greater renewable energy consumption significantly contributes to carbon emission reduction.

Furthermore, the theory of environmentally oriented technological innovation suggests that scientific and technological progress can reduce environmental impacts by improving energy efficiency, facilitating the adoption of cleaner technologies, and optimizing production processes (Rennings, 2000; Popp, 2010). Ahmed et al. (2017) argued that technological innovation contributes to lowering carbon intensity in the long run, while Chien et al. (2022) provided evidence of the positive contribution of innovation to environmental quality in ASEAN countries. Nevertheless, recent studies indicate that the environmental effects of innovation are not always consistent, particularly when innovative activities are primarily directed toward expanding production capacity rather than developing green technologies (Pham et al., 2024).

Overall, previous studies suggest that economic growth tends to exert upward pressure on the environment, whereas renewable energy and innovation are generally viewed as important mechanisms for reducing carbon emissions and promoting sustainable development. However, most existing studies focus on absolute CO_2 emissions, while carbon intensity provides a more comprehensive measure of the environmental efficiency of economic growth. In addition, empirical evidence from Vietnam remains limited regarding the simultaneous effects of economic growth, renewable energy, and innovation on carbon intensity within a unified analytical framework. Therefore, this study seeks to fill this gap by providing further empirical evidence on the determinants of carbon intensity in Vietnam.

Research Model and Data

Drawing upon the theoretical foundations of environmental economics, green growth, and environmentally oriented technological innovation, this study employs a quantitative approach to examine the effects of economic growth, renewable energy, and innovation on carbon intensity in Vietnam. The selection of these variables is based on the premise that economic growth is a key driver of development but may simultaneously increase energy demand and carbon emissions. In contrast, renewable energy and innovation are expected to enhance resource-use efficiency, reduce dependence on fossil fuels, and improve environmental quality. By quantifying

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the impacts of these factors, the study provides empirical evidence to support policy formulation aimed at promoting green growth and sustainable development in Vietnam.

Building on the empirical studies of Ahmed et al. (2017), Nguyen and Kakinaka (2019), Le and Sarkodie (2020), and Chien et al. (2022), the following empirical model is specified:

$$CI_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 RPG_t + \alpha_3 LNPAR_t + \varepsilon_t$$

where (CI) denotes carbon intensity, measured as CO_2 emissions per unit of GDP and used as an indicator of the environmental efficiency of economic growth. Compared with absolute CO_2 emissions, carbon intensity provides a more comprehensive assessment of the environmental cost associated with economic output. (GDP) represents the economic growth rate and reflects the expansion of economic activity. (RPG) refers to the share of renewable energy consumption in total final energy consumption, capturing the degree of transition toward cleaner energy sources. (LNPAR) is the natural logarithm of the number of granted patents and serves as a proxy for innovation. Based on theoretical expectations, economic growth is anticipated to increase carbon intensity, whereas renewable energy and innovation are expected to reduce it.

The study utilizes annual time-series data for Vietnam covering the period from 1990 to 2021. This period was selected because it encompasses Vietnam's economic reform process, international integration, and structural transformation toward industrialization and modernization. These developments have been accompanied by significant changes in economic growth, energy demand, carbon emissions, and innovation activities. Moreover, the period witnessed the increasing adoption of renewable energy sources, providing a suitable context for examining the long-term interactions among economic, technological, and environmental factors.

The data were obtained from reliable and authoritative sources to ensure consistency and comparability over time. Specifically, data on carbon intensity, economic growth, and renewable energy were collected from the World Bank's World Development Indicators (WDI) database. Information on granted patents was obtained from the annual reports of the Intellectual Property Office of Vietnam. The use of these sources enhances the transparency, reliability, and comparability of the empirical analysis.

Given the relatively small sample size, additional control variables were not simultaneously incorporated into the baseline specification to avoid excessive parameterization and loss of degrees of freedom. The study therefore adopts a parsimonious model focusing on the three theoretically central determinants

Details regarding variable definitions, measurement methods, expected signs, and data sources are presented in Table 1.

Table 1. Description of Research Variables

Variables	Symbol	Measurement	Unit	Expected Sign	References
Carbon intensity	CI	CO_2 emissions per unit of GDP	kg CO_2/USD GDP		Mai et al. (2024)
Economic growth	GDP	Growth rate of gross domestic product	%	(+)	Nguyen & Kakinaka (2019); Le & Sarkodie (2020)
Renewable energy	RPG	Share of renewable energy consumption in total final energy consumption	%	(−)	Kirikkaleli & Adebayo (2021)
Innovation	LNPAR	Number of granted patents	Logarithmic scale	(−)	Chien et al. (2022); Pham et al. (2024)

Because the number of patents exhibits substantial variation and a strong upward trend over time, this variable is transformed into its natural logarithmic form before being included in the model. The logarithmic transformation helps reduce skewness, mitigate the influence of extreme values, and improve the reliability of the estimation results. In addition, the log-transformed specification allows the estimated coefficients to be interpreted in relative terms, thereby providing a clearer understanding of the relationship between innovation and carbon intensity.

Granted patents are employed as a proxy for innovation because they represent observable outputs of inventive activities and provide a relatively consistent annual time series for Vietnam over the study period. However, this indicator captures general innovative activity rather than specifically green innovation. Therefore, the estimated coefficient should be interpreted as the effect of broad technological innovation rather than environmentally oriented innovation. Alternative indicators such as R&D expenditure and green patents would be desirable for robustness analysis; however, consistent annual data covering the full study period are not available.

RESEARCH METHODOLOGY

This study employs a quantitative approach combining descriptive statistics and the Autoregressive Distributed Lag (ARDL) model to examine the effects of economic growth, renewable energy, and innovation on carbon intensity in Vietnam. Developed by Pesaran et al. (2001), the ARDL approach is particularly suitable for time-series data with relatively small sample sizes and variables integrated at different orders, namely I(0) and I(1). In addition, the method enables the simultaneous estimation of both short-run and long-run relationships among the variables.

To ensure the robustness and reliability of the empirical results, several diagnostic tests are conducted following model estimation. These include the Jarque–Bera test for residual normality, the Breusch–Godfrey LM test for serial correlation, the Heteroskedasticity test for variance stability, and the Ramsey RESET test for model specification. These diagnostic procedures help verify the validity of the estimated model and the reliability of the subsequent statistical inferences.

The ARDL approach is particularly appropriate for the present study for three reasons. First, the annual dataset covers the period 1990-2021 and therefore contains a relatively small number of observations. Second, the variables are expected to exhibit different orders of integration, I(0) and I(1), while none is I(2). Third, the ARDL framework enables the simultaneous examination of short-run dynamics and long-run relationships. To avoid over-parameterization given the limited sample size, a parsimonious specification with a restricted lag structure is adopted.

Research Results

The main characteristics of the dataset are presented in Table 2 through descriptive statistics and the correlation matrix of the study variables. The results indicate that carbon intensity (CI) has an average value of 0.2009 kg CO_2 per USD of GDP, while economic growth (GDP) records an average rate of 6.62%. The share of renewable energy consumption (RPG) averages 46.67%, although it exhibits considerable fluctuations throughout the study period. Innovation activity (LNPAR) also shows a substantial upward trend over time, reflecting the expansion of research activities and patent registrations in Vietnam.

Table 2. Descriptive Statistics and Correlation Matrix of Variables

Variables	CI	GDP	RPG	LNPAR
CI	1.00000			
GDP	-0.466928	1.00000		
RPG	-0.377001	0.405995	1.00000	
LNPAR	0.354069	-0.593945	0.617988	1.00000
Mean	0.200938	6.619063	46.67188	6.072854
Median	0.210000	6.740000	44.15000	6.572893
Maximum	0.300000	9.540000	75.90000	8.370779
Minimum	0.120000	2.550000	18.90000	2.639057

Regarding the correlation analysis, carbon intensity is negatively associated with economic growth ($r = -0.4669$) and renewable energy consumption ($r = -0.3770$), suggesting that higher economic growth and greater adoption

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of renewable energy may contribute to improved environmental performance. In contrast, innovation is positively correlated with carbon intensity (r = 0.3541), indicating that the environmental effects of innovative activities remain unclear during the study period. Furthermore, all absolute correlation coefficients are below 0.8, suggesting the absence of serious multicollinearity among the explanatory variables. Therefore, the selected variables are appropriate for inclusion in the ARDL model to further investigate the relationship between economic growth, renewable energy, innovation, and carbon intensity in Vietnam.

The lag selection results reported in Table 3 indicate that all criteria, including the Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan–Quinn Criterion (HQ), consistently identify a lag length of one as optimal, as indicated by the asterisks. This finding suggests that the model with one lag provides superior explanatory and predictive performance compared with alternative lag structures. The consistency across all selection criteria further confirms the reliability of the lag selection outcome. Accordingly, a lag length of one is adopted for the Bounds cointegration test and the subsequent ARDL estimation.

Table 3. Optimal Lag Length Selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-105.2094	NA	0.017064	7.280625	7.467451	7.340392
1	-9.071824	160.2293*	8.27e-	1.938122*	2.872253*	2.236958*
2	2.373485	16.02343	0.000119	2.241768	3.923205	2.779674

The results of the Augmented Dickey–Fuller (ADF) unit root test are presented in Table 4. The findings indicate that RPG is stationary at level, with a p-value of 0.0002, which is below the 5% significance level. In contrast, CI, GDP, and LNPAR are non-stationary at level, as their p-values exceed 0.05. However, after first differencing, all variables become stationary, with p-values lower than 0.05.

Table 4. Results of the ADF Unit Root Test

Variables	Level			First Difference		
	t-statistic	p-value	Conclusion	t-statistic	p-value	Conclusion
CI	1.838416	0.9818	Non-stationary	-4.115029	0.0002	Stationary
GDP	-0.704436	0.4034	Non-stationary	-4.459110	0.0001	Stationary
RPG	-4.054510	0.0002	Stationary	-3.171563	0.0025	Stationary
LNPAR	-1.401595	0.1462	Non-stationary	-7.908336	0.0000	Stationary

Specifically, the p-values of CI, GDP, and LNPAR after first differencing are 0.0002, 0.0001, and 0.0000, respectively, allowing the rejection of the null hypothesis of a unit root. Therefore, CI, GDP, and LNPAR are integrated of order one, I(1), whereas RPG is integrated of order zero, I(0). These findings indicate that the variables exhibit a mixed order of integration, comprising both I(0) and I(1) series, while no variable is integrated of order two, I(2).

Accordingly, the data satisfy the requirements for applying the ARDL approach and conducting the Bounds cointegration test, as recommended by Pesaran et al. (2001).

The results of the Bounds cointegration test are reported in Table 5. The calculated F-statistic is 6.413168, which exceeds the upper critical bound I(1) at all conventional significance levels, including 10%, 5%, 2.5%, and 1%.

Table 5. Bounds Test Results

F-Bounds Test		Null Hypothesis: No Levels Relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.413168	10%	2.72	3.77
k	3	5%	3.23	4.35

		2.5%	3.69	4.89
		1%	4.29	5.61

Specifically, even at the 1% significance level, the calculated F-statistic exceeds the upper critical bound I(1) value of 5.61. Therefore, the null hypothesis (H_0) of no cointegration among the variables is rejected. This result confirms the existence of a long-run equilibrium relationship among carbon intensity, economic growth, renewable energy, and innovation in Vietnam over the study period.

Accordingly, the ARDL framework is appropriate for estimating both the short-run and long-run effects of the explanatory variables. Moreover, the existence of cointegration permits further examination of the adjustment mechanism through the Error Correction Model (ECM).

The long-run estimation results reported in Table 6 indicate that both economic growth and renewable energy exert statistically significant effects on carbon intensity in Vietnam. Specifically, the coefficient of GDP is positive (0.000361) and statistically significant at the 5% level (p = 0.0496), suggesting that economic growth increases carbon intensity in the long run. This finding implies that Vietnam's economic expansion remains closely associated with higher energy consumption and carbon emissions.

Table 6. Long-Run Estimation Results				
Dependent Variable: CI				
Variables	Coefficient	Std. Error	t-Statistic	p-value
GDP	0.000361	0.000179	2.016121	0.0496
RPG	-0.003135	0.000794	-3.949163	0.0006
LNPAR	0.001459	0.009281	0.157263	0.8763

Conversely, renewable energy (RPG) has a negative coefficient (-0.003135) and is highly statistically significant (p = 0.0006), indicating that an increase in the share of renewable energy consumption contributes to a reduction in carbon intensity. This finding highlights the positive role of the energy transition process in improving the environmental performance of the economy.

Regarding innovation (LNPAR), the estimated coefficient is positive (0.001459) but statistically insignificant (p = 0.8763). Therefore, there is insufficient evidence to conclude that innovation exerts a significant effect on carbon intensity during the study period.

Overall, the long-run results indicate that economic growth increases carbon intensity, whereas renewable energy contributes to its reduction. Moreover, renewable energy appears to have a more pronounced and substantial impact on improving environmental performance than innovation in the Vietnamese context.

The short-run estimation results reported in Table 7 reveal that renewable energy continues to exert a significant effect on carbon intensity. Specifically, the first-differenced renewable energy variable, D(RPG), has a negative coefficient (-0.003603) and is statistically significant at the 1% level (p = 0.0000), indicating that an increase in the share of renewable energy consumption contributes to an immediate reduction in carbon intensity.

Table 7. Short-Run Estimation Results				
Dependent Variable: CI				
Variables	Coefficient	Std. Error	t-Statistic	p-value
D(RPG)	-0.003603	0.000634	-5.686080	0.0000
CointEq(-1)*	-0.309561	0.123030	-2.516146	0.0187

Furthermore, the error correction term, CointEq(-1), is negative (-0.309561) and statistically significant at the 5% level (p = 0.0187), which is consistent with theoretical expectations. This result confirms the existence of a long-run equilibrium relationship among the variables included in the model. It also indicates that when short-run shocks cause the system to deviate from its equilibrium path, approximately 30.96% of the disequilibrium is corrected within one year, enabling the system to gradually return to its long-run equilibrium state.

Overall, the short-run results highlight the important role of renewable energy in reducing carbon intensity in Vietnam. In addition, the significant error correction mechanism suggests that the system adjusts relatively quickly toward equilibrium following short-term disturbances.

The results of the post-estimation diagnostic tests are presented in Table 8 and indicate that the ARDL model satisfies the required econometric assumptions and exhibits a high degree of reliability. Specifically, the Jarque–Bera test yields a p-value of 0.14356, which is greater than 0.05, indicating that the residuals are normally distributed. Likewise, the Breusch–Godfrey LM test reports a p-value of 0.3731, confirming the absence of serial correlation in the residuals.

Table 8. Diagnostic Test Results

Diagnostic Test	p-value	Conclusion
Normality Test (Jarque–Bera)	0.14356	Residuals are normally distributed
Breusch–Godfrey LM Test	0.3731	No serial correlation
Heteroskedasticity Test	0.59791	Homoskedastic residuals
Ramsey RESET Test	0.2727	Model is correctly specified with no functional form misspecification

Regarding heteroskedasticity, the p-value of 0.59791 exceeds the 5% significance level, indicating that the residuals exhibit constant variance and that the model does not suffer from heteroskedasticity. Furthermore, the Ramsey RESET test yields a p-value of 0.2727, suggesting no evidence of functional form misspecification or omitted relevant variables.

Overall, all diagnostic tests produce satisfactory results, confirming that the model is appropriately specified and statistically reliable. Consequently, the estimated coefficients can be considered robust and suitable for analyzing and interpreting the effects of economic growth, renewable energy, and innovation on carbon intensity in Vietnam.

DISCUSSION

The findings indicate that economic growth exerts a positive and statistically significant effect on carbon intensity in Vietnam in the long run. This result is consistent with the arguments of environmental economics theory (Pigou, 1920; Pearce & Turner, 1990), which suggests that economic expansion is often accompanied by increased energy consumption and greenhouse gas emissions. In the Vietnamese context, economic growth over the past three decades has been largely driven by industrialization, manufacturing expansion, and increasing energy demand. Despite achieving relatively high growth rates, the country’s energy structure remains heavily dependent on fossil fuels, particularly coal and petroleum. Consequently, each additional unit of economic output is still associated with higher carbon emissions, leading to an increase in carbon intensity over time. This finding is consistent with the studies of Nguyen and Kakinaka (2019) and Le and Sarkodie (2020), which argue that economic growth in developing economies tends to impose significant environmental pressure when the pace of energy transition lags behind economic expansion.

In contrast, renewable energy is found to have a negative and statistically significant effect on carbon intensity in both the short and long run. This result supports the principles of green growth theory proposed by OECD (2011) and Bowen and Hepburn (2014), which emphasize that the substitution of fossil fuels with cleaner energy sources can decouple economic growth from environmental degradation. In recent years, Vietnam has experienced substantial growth in solar power, wind energy, and other renewable energy sources, contributing to a gradual reduction in dependence on carbon-intensive energy. As a result, the increasing share of renewable energy has enhanced environmental efficiency and reduced emissions per unit of economic output. This finding is in line with previous empirical evidence reported by Apergis and Payne (2014), Kirikkaleli and Adebayo

(2021), and Mai et al. (2024), all of whom highlight the effectiveness of renewable energy in mitigating carbon emissions and supporting sustainable development.

Regarding innovation, the estimated coefficient is positive but statistically insignificant, suggesting that innovation has not yet exerted a measurable influence on carbon intensity in Vietnam during the study period. This finding partially contrasts with the expectations of environmentally oriented technological innovation theory (Rennings, 2000; Popp, 2010), which argues that technological progress should improve energy efficiency and reduce environmental impacts. A plausible explanation is that the number of granted patents may not adequately capture the quality of innovation or the extent to which green technologies are adopted in production activities. Many patented inventions may be aimed primarily at improving productivity, expanding production capacity, or enhancing business performance rather than reducing carbon emissions. Furthermore, the time lag between research activities, patent registration, technology commercialization, and practical implementation may delay the environmental benefits of innovation. This result is consistent with the argument of Pham et al. (2024), who suggest that the environmental impact of innovation depends heavily on the technological orientation and development priorities of individual countries.

The short-run results further reveal that renewable energy is the only variable with a direct and significant effect on carbon intensity. In addition, the negative and statistically significant error correction term confirms the existence of a long-run equilibrium relationship among the variables. The estimated adjustment speed of approximately 30.96% per year indicates that shocks related to economic activity, energy use, or technological change can be absorbed relatively quickly, allowing the system to gradually return to its long-run equilibrium path. This finding reflects the stability of the relationship among economic growth, renewable energy, innovation, and carbon intensity in Vietnam.

Overall, the empirical evidence suggests that economic growth continues to exert pressure on environmental sustainability in Vietnam, whereas renewable energy plays a crucial role in reducing carbon intensity. By contrast, innovation has not yet demonstrated a significant contribution to environmental improvement. These findings imply that achieving green growth and the net-zero emissions target will require a stronger commitment to energy transition policies, accompanied by innovation strategies that prioritize the development and adoption of environmentally friendly technologies capable of reducing carbon emissions in the long term.

Policy Implications

The findings of this study indicate that economic growth continues to increase carbon intensity in Vietnam over the long run. Therefore, policymakers should promote a transition toward a growth model that emphasizes productivity improvements, technological advancement, and resource-use efficiency rather than relying primarily on the expansion of production scale. Environmental objectives, particularly carbon emission reduction targets, should be integrated into national socio-economic development strategies to ensure that economic growth is achieved in a sustainable manner. In addition, greater support should be directed toward high-technology and high-value-added industries that consume less energy and generate lower carbon emissions, thereby reducing dependence on carbon-intensive sectors.

The results also confirm that renewable energy plays a critical role in reducing carbon intensity in both the short and long run. Consequently, Vietnam should continue expanding investment in renewable energy sources, including solar, wind, biomass, and offshore renewable energy projects. To accelerate this transition, the government should further improve electricity pricing mechanisms, green financing programs, tax incentives, and investment support policies to encourage private-sector participation in clean energy development. Moreover, priority should be given to upgrading electricity transmission networks and energy infrastructure to enhance the integration and efficient utilization of renewable energy resources.

Another important implication concerns the restructuring of the national energy mix. According to the International Energy Agency (IEA, 2023), energy transition is a prerequisite for achieving long-term carbon neutrality goals. Therefore, Vietnam should establish a clear roadmap for gradually reducing the share of coal-fired power generation while increasing the contribution of renewable energy sources to the national energy

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portfolio. Such a strategy would help lower carbon emissions per unit of economic output and strengthen the country's commitment to sustainable development.

Although innovation was not found to have a statistically significant effect on carbon intensity, this does not imply that innovation is unimportant for environmental sustainability. Rather, the result suggests that current innovation activities may not yet be sufficiently oriented toward green technologies or effectively translated into environmental improvements. Because the innovation coefficient is statistically insignificant, the empirical results do not provide direct evidence that general innovation activities have reduced carbon intensity in Vietnam. Therefore, policy recommendations concerning innovation should be interpreted cautiously. Rather than expanding innovation support indiscriminately, policy efforts may focus on environmentally oriented R&D, green technologies, and the commercialization of low-carbon innovations.

In addition, stronger collaboration among universities, research institutions, and businesses is needed to accelerate the commercialization and diffusion of technological innovations. Facilitating technology transfer and the practical application of advanced technologies can improve energy efficiency, reduce resource consumption, and lower greenhouse gas emissions. Such collaboration is essential for ensuring that innovation contributes effectively to environmental improvement and sustainable economic development.

Beyond energy and technology policies, Vietnam should continue strengthening its environmental policy framework to promote green production and sustainable consumption patterns. Market-based instruments such as carbon taxes, emissions trading systems, carbon credit markets, and environmental standards can help internalize environmental costs and encourage firms to adopt cleaner production technologies. These measures would not only contribute to reducing carbon intensity but also enhance the international competitiveness of Vietnamese enterprises in an increasingly sustainability-oriented global economy.

Finally, international cooperation should be further expanded to facilitate access to financial resources, advanced technologies, and policy expertise necessary for the green transition. Effective utilization of support from international organizations, development partners, and climate finance initiatives can accelerate renewable energy deployment, strengthen innovation capacity, and support Vietnam's commitment to achieving net-zero emissions by 2050.

Limitations and Future Research Directions

Despite providing empirical evidence on the effects of economic growth, renewable energy, and innovation on carbon intensity in Vietnam, this study has several limitations that should be acknowledged.

First, the analysis focuses on three key explanatory variables: economic growth, renewable energy, and innovation. However, carbon intensity is also influenced by a variety of other factors, including energy structure, foreign direct investment (FDI), trade openness, urbanization, institutional quality, and financial development. The exclusion of these variables may limit the model's ability to fully capture the determinants of carbon intensity in Vietnam.

Second, innovation is measured using the number of granted patents. Although this indicator is widely employed in the literature, it may not adequately reflect the quality of innovation, the diffusion of technological knowledge, or the actual adoption of new technologies in production processes. Consequently, the environmental effects of innovation may not be fully captured by the measure used in this study.

Third, the study relies on annual time-series data for Vietnam covering the period 1990–2021. While this period encompasses significant economic and energy transitions, the findings may be influenced by country-specific characteristics, policy changes, structural transformations, and external economic shocks. Therefore, caution should be exercised when generalizing the results to other countries or regions.

Based on these limitations, several directions for future research can be proposed. Future studies may extend the analytical framework by incorporating additional control variables such as FDI, trade openness, urbanization, fossil fuel consumption, institutional quality, and financial development to provide a more comprehensive assessment of the determinants of carbon intensity. Moreover, alternative measures of innovation, including R&D expenditure, scientific publications, green patents, or the Global Innovation Index, may offer a more complete understanding of the relationship between technological progress and environmental performance.

Future research could also broaden the scope of analysis to ASEAN countries or other developing economies, allowing for cross-country comparisons and enhancing the external validity of the findings. In addition, alternative econometric techniques such as NARDL, FMOLS, DOLS, or VAR/VECM models may be employed to test the robustness of the results and to further explore the dynamic relationships among economic growth, energy transition, technological innovation, and carbon intensity over time.

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