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Energy Transition, Energy Intensity, Economic Growth, and Financial Development: Their Interrelationship and Impact Toward Vietnam's Carbon Neutrality Target

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Abstract: To respond to global climate change, promote climate governance, and develop a master plan for sustainable development, carbon neutrality has become a common goal and vision of both developed and developing countries. In view of this objective, the interaction among energy transition, energy intensity, economic growth, and financial development is considered an important tool to harmonize economic development and environmental governance. This study aims to investigate the impacts of these four variables on Vietnam's carbon neutrality objective during the period of 1995–2022. The Johansen cointegration analysis and a Vector Error Correction Model (VECM) were employed to disentangle short- and long-run relationships among the variables; the results of these analyses revealed asymmetric temporal effects. Energy transition and economic growth were found to increase CO_2 emissions in both the short and long run, hence suggesting that expansion of renewable energy could not effectively substitute fossil fuels and that economic growth remains energy intensive. In contrast, energy intensity and financial development reduced CO_2 emissions in the short run but contributed to rising emissions in the long run. This indicates the presence of rebound effects and scale-driven financial expansion without green investment target. It was concluded that Vietnam should plan and implement appropriate low carbon-intensive policies to achieve its carbon neutrality objective in the years ahead.

Keywords: Energy transition; Energy intensity; Economic growth; Financial development; Carbon neutrality; Vietnam

1. Introduction

Climate change is increasingly becoming a structural constraint on global economic development, compelling countries to realign their growth models toward low-carbon pathways. The Paris Agreement established a temperature-based climate governance framework, which requires countries to limit the increase in global average temperature to below 2 °C and to pursue efforts to restrict it to 1.5 °C relative to pre-industrial levels (UNFCCC, 2015). These targets could be achieved via executing deep decarbonization, the long-term process of reducing greenhouse gases in a scalable way, across energy systems and economic structures (IPCC, 2022).

In this context, Vietnam is officially committed to achieving net-zero emissions by 2050 at the 26th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). This commitment was formally documented in UNFCCC records and has been institutionalized in national policy instruments, including Vietnam's updated Nationally Determined Contribution (NDC) and the National Strategy on Climate Change to 2050 (NSCC) issued by the Government of Vietnam (Government of Vietnam, 2022; MONRE, 2022). According to these official documents, Vietnam aims to achieve net-zero emissions by 2050 through energy transition, economic restructuring, and the development of green finance.

As a rapidly growing economy with increasing energy demand, Vietnam faces significant challenges in balancing economic growth with its commitment to decarbonization. The national energy mix remains heavily reliant on fossil fuels, while ongoing industrialization and urbanization continue to exert pressure on the energy system. Therefore, identifying and quantifying the impact of key economic and structural determinants on Vietnam's decarbonization pathway is of considerable academic and policy relevance.

More importantly, in this study, carbon neutrality is operationalized through the dynamics of CO_2 emissions and it serves as a proxy indicator for progress toward the net-zero target. Strictly speaking, carbon neutrality refers to a net balance between greenhouse gas emissions and removals within a defined period. However, consistent and reliable national-level data on carbon sinks, sequestration capacity, and offset mechanisms remain limited and subject to measurement uncertainty. Reductions in CO_2 emissions are interpreted as a measurable and policy-relevant indicator of progress along the decarbonization pathway toward carbon neutrality, rather than a direct measurement of the net-zero state itself.

In the context of structural drivers shaping the decarbonization pathway, this study focused on four key determinants, i.e., energy transition, energy intensity, economic growth, and financial development, thereby contributing across three dimensions: theoretical, empirical, and policy.

From a theoretical perspective, the study developed an integrated analytical framework that simultaneously examined the roles of energy transition and energy efficiency in relation to economic growth and financial development. This approach extended existing literature, which largely analyzed these factors in isolation. In particular, the study contributes to the ongoing debate on the validity of the Environmental Kuznets Curve (EKC) by providing new evidence from a rapidly industrializing emerging economy, where the income–environment relationship remains inconclusive (Grossman & Krueger, 1995; Shahbaz et al., 2013; Stern, 2004).

From an empirical perspective, the study highlighted the central role of energy transition, in which increasing the share of renewable energy is widely recognized as a prerequisite for reducing CO_2 emissions (Balsalobre-Lorente et al., 2018; Danish & Ulucak, 2020). Meanwhile, improvements in energy intensity are associated with technological progress and structural transformation toward less carbon-intensive economic activities. Furthermore, the analysis provided nuanced evidence on the dual role of financial development: While a well-developed financial system could mobilize capital for projects related to renewable energy and green innovation (Tamazian et al., 2009; Zhang, 2011), it may also increase emissions through the expansion of energy-intensive production and consumption driven by scale effects (Sadorsky, 2010; Shahbaz et al., 2016).

From a policy perspective, the findings offered important implications for designing development strategies aligned with the net-zero emissions target. Specifically, the results underscored the need to accelerate renewable energy deployment, improve energy efficiency, and strategically direct financial development toward supporting green investments rather than reinforcing carbon-intensive activities. In addition, the study suggested that economic growth policies should be cautiously calibrated across different developmental stages to mitigate environmental degradation, particularly in economies undergoing rapid industrialization.

Since previous studies focused on examining energy transition, energy intensity, economic growth, or financial development on an individual basis, an integrated analytical framework is required to simultaneously evaluate these four determinants in constructing Vietnam's decarbonization pathway, as defined in official national policy documents. To address the identified gap, the present study investigated the impact of energy transition, energy intensity, economic growth, and financial development on the progress of Vietnam toward carbon neutrality. Consistent with the above conceptual clarification, CO_2 emissions were employed as a proxy indicator in the development of decarbonization pathway, to reflect measurable changes in emission dynamics relative to the net-zero commitment outlined in the National Strategy on Climate Change to 2050.

This empirical analysis, while undergoing the above operationalization, was structured upon the following research questions:

(1) Does energy transition significantly reduce CO_2 emissions and thereby contributing to progress toward Vietnam's net-zero commitment?

(2) How does energy intensity influence Vietnam's CO_2 emissions dynamics and its decarbonization pathway?

(3) What is the relationship between economic growth and CO_2 emissions in Vietnam? Does the EKC hypothesis hold?

(4) Does financial development accelerate or hinder Vietnam's advancement toward carbon neutrality as reflected in the trend of CO_2 emissions?

By explicitly linking these questions to Vietnam's policy-defined net-zero objective, the present study provided an integrated framework for evaluating the structural drivers of the country's decarbonization pathway while maintaining conceptual consistency between carbon neutrality as a net-balance target and CO_2 emissions as an observable proxy indicator.

2. Literature Review

2.1. The Relationship Between Energy Transition and Carbon Neutrality

Carbon neutrality refers to a state in which the total amount of CO_2 emitted into the atmosphere is offset by an equivalent amount of CO_2 either absorbed or removed. While carbon neutrality focuses primarily on reducing and removing CO_2 emissions, the broader "net zero" objective targets all greenhouse gases across all sectors of the economy. To achieve either goal would require a major and rapid transformation of the entire economic system. In this connection, energy transition specifically from fossil fuel-based consumption to renewable energy sources, plays a pivotal role.

The energy transition is commonly understood as the transformation from conventional energy sources such as fossil fuels toward cleaner and more sustainable alternatives (Ialnazov & Keeley, 2020; Ozturk & Acaravci, 2013). This process entails not only the replacement of polluting energy plants but also improvements in technology, regulatory frameworks, energy infrastructure, and consumption behavior (Sgouridis & Csala, 2014). By reducing dependence on fossil fuels, energy transition conserves natural resources, mitigates environmental degradation, and ultimately supports the goal of carbon neutrality.

Energy consumption has long been recognized as the most significant contributor to greenhouse gas emissions. Numerous studies documented the adverse environmental effects of fossil fuel-based energy sources, particularly oil and coal (Bandyopadhyay et al., 2022). Aller et al. (2021), while adopting Bayesian Model Averaging (BMA) across 92 countries, concluded that fossil fuel consumption consistently exhibited the highest posterior inclusion probabilities in explaining CO_2 emissions. These findings implied that the use of fossil fuels had a statistically significant impact on emissions in all tested model specifications.

In contrast, a growing body of literature emphasized the positive role of renewable energy in mitigating environmental degradation (Kirikkaleli et al., 2023). Scholars generally concurred that transitioning from fossil fuels to renewable energy is essential to reducing CO_2 emissions. Consequently, energy transition is widely viewed as a prerequisite toward achieving carbon neutrality.

The relationship between energy transition and the target of carbon neutrality has been examined in various empirical studies. Some have provided evidence that shifting from fossil fuel energy to renewable energy contributes to the attainment of national carbon neutrality goals. For instance, Long et al. (2015) investigated the relationships between the consumption of renewable energy and non-renewable energy and CO_2 emissions in China from 1995 to 2012. The results indicated that renewable energy played a crucial role in curbing rising carbon emissions in the country. Similarly, Yao et al. (2019) examined the impact of renewable energy consumption on CO_2 emissions across 17 developed and developing countries between 1990 and 2014. Their findings confirmed the significant role of renewable energy in controlling carbon output. In a more recent study, Yeboah et al. (2024) have explored the role of renewable energy in CO_2 mitigation in Africa and confirmed the positive effect of renewables in reducing carbon emissions.

Contrasting evidence has been given by Bilgili et al. (2016), whose work used fully modified ordinary least squares (FM-OLS) and dynamic ordinary least squares (DOLS) techniques to discover that renewable energy consumption actually increased CO_2 emissions in 17 countries under the Organisation for Economic Co-operation and Development (OECD) during the period 1977–2010. Their findings suggested that the deployment of renewable energy might not always contribute to emission reduction. Consistent results were reported by Al-Mulali et al. (2016), who applied the Generalized Method of Moments (GMM) to a panel of 58 developed and developing countries between 1980 and 2009. Their study found that renewable energy consumption negatively affected environmental quality. Using the econometric techniques of FM-OLS and DOLS, Jebli & Youssef (2017) examined the effect of renewable energy on CO_2 emissions in five North African countries from 1980 to 2011. Their results indicated that the assumed environmental benefits of renewables might not materialize under certain structural conditions. Most recently, Hasanov et al. (2023) have assessed the impact of renewable energy on CO_2 emissions in Azerbaijan from 1991 to 2019 and found that CO2 was found to be negatively affected by renewable energy consumption.

2.2. The Relationship Between Energy Intensity and Carbon Neutrality

Closely linked to energy transition is the concept of energy intensity, which serves as an indicator of a country's energy efficiency. According to Daniel et al. (2019), energy intensity was typically measured as the ratio of energy use (or supply) to gross domestic product (GDP). This metric reflects how effectively an economy converts energy into monetary output. A lower energy intensity indicates reduced energy consumption per unit of economic output, which is often associated with lower greenhouse gas emissions, especially when fossil fuels dominate the energy mix. As such, reducing energy intensity is considered a core strategy for reaching carbon neutrality.

Numerous empirical studies demonstrated that high energy intensity contributed to increased CO_2 emissions, thereby hindering progress toward carbon neutrality. Lin & Moubarak (2013) demonstrate that industrial activity is the leading force explaining emission increase while energy intensity is the major contributor to the emission mitigation.

Similarly, Lin et al. (2016) identified both energy structure and energy intensity as primary drivers of carbon emissions across African countries. They emphasized the need for African economies to enhance energy efficiency to alleviate environmental degradation. In the case of the United States, Danish et al. (2020) used an Autoregressive Distributed Lag (ARDL) model to investigate the nexus between energy intensity and CO_2 emissions during the period 1985–2017. His findings confirmed that higher energy intensity led to higher emissions.

Rahman et al. (2022), in analyzing 25 emerging economies from 1990 to 2018, found that energy intensity had a statistically significant positive effect on CO_2 emissions in the long run. These results were supported by Peng et al. (2024), who employed the Logarithmic Mean Divisia Index (LMDI) method to decompose carbon emissions across South American countries from 2010 to 2020. The study highlighted that rising energy intensity significantly contributed to increased CO_2 emissions in Brazil and Ecuador, while in Argentina, increased carbon intensity emerged as the main driver of emissions growth.

However, some empirical evidence contradicted this general trend. For instance, using an ARDL model, Du et al. (2019) reported that a 1% increase in energy intensity led to an 83.9% reduction in CO_2 emissions in Uganda during the 1990–2014 period. The author recommended that, in the context of Uganda, increased energy intensity could support long-term emission reductions, provided that thorough institutional and policy reforms were implemented. In addition, Ortega-Ruiz et al. (2020) found that energy intensity made the largest contribution to reducing CO_2 emissions in India, thus underscoring the impacts of context-specific energy intensity. These divergent findings highlight the importance of considering national circumstances, patterns of energy consumption, and institutional frameworks when assessing the role of energy intensity in achieving carbon neutrality.

2.3. The Relationship Between Economic Growth and Carbon Neutrality

From a macroeconomic perspective, Mankiw (2012) defined economic growth as the change in an economy's output level over time and analyzed the direction and causes of output variation across both the short- and long-term horizons. The relationship between economic growth and CO_2 emissions is often examined through the lens of the EKC hypothesis. This hypothesis posits that in the early stages of development, economic growth leads to rising emissions due to industrialization. However, along with the rise of income level, societies begin to prioritize environmental protection and result in the decline of emissions. Thus, the EKC framework links economic growth to environmental quality in a non-linear manner.

A number of empirical studies suggested that economic growth contributed to increased CO_2 emissions, thereby posing significant challenges to achieving carbon neutrality. For instance, Ortega-Ruiz et al. (2020) concluded that economic growth was the primary contributor to CO_2 emissions in India. Similarly, Kouyakhi (2022), while analyzing 30-year emissions data from 12 Middle Eastern countries, identified economic growth as the main driving force behind rising carbon emissions in the region.

In a comparative analysis of the 6 largest CO_2-emitting countries from 1990 to 2018, Ortega-Ruiz et al. (2022) found that economic growth had the strongest impact on emissions increase across the sample. In the context of Vietnam, Hung et al. (2022) employed a quantile-on-quantile regression approach to assess the relationship between economic growth and CO_2 emissions from 1990 to 2020. Their results confirmed a strong positive correlation between GDP growth and emissions.

In agreement with these findings, Bui et al. (2023) further demonstrated that foreign direct investment (FDI), economic growth, and urbanization all contributed to increased carbon emissions in Vietnam. Similarly, Luo & Zhao (2025) identified economic growth as one of the key drivers of rising carbon emissions among Regional Comprehensive Economic Partnership (RCEP) member countries. These studies reinforced the widely held view that economic expansion, particularly in developing and emerging economies, remained carbon intensive.

However, some research challenged the assumption of a uniform relationship between economic growth and emissions. Using a Panel Smooth Transition Regression (PSTR) model, Aslanidis & Iranzo (2009) found no evidence from the EKC in a sample of 77 non-OECD countries from 1971 to 1997. These results, along with findings by Li et al. (2016), underscored the inconsistency and context-specific nature of the relationship between economic growth and environmental degradation.

2.4. The Relationship Between Financial Development and Carbon Neutrality

Financial development is a multi-dimensional process including financial institutions and financial markets. Financial institutions include banks, insurance companies, and other institutions whereas financial markets involve the stock market and the bond market. According to the World Bank (2018), financial development is the process by which financial institutions and markets improve in quality, depth, accessibility, and efficiency in providing financial services. To reflect the diversity of financial development advocated by the World Bank, Sahay et al. (2015) applied Principal Component Analysis (PCA) to construct financial development indices across different dimensions based on the depth, accessibility, and efficiency of financial institutions and financial markets. A developed financial system could enhance savings, promote investment, and improve productivity, thereby contributing to long-term economic growth. If aligned with environmental goals, financial development may also support the transition to a low-carbon economy.

Several empirical studies showed that financial development could contribute to CO_2 emissions reduction and supported the achievement of carbon neutrality. Al-Mulali et al. (2015), in their study of 129 countries from 1980 to 2011, concluded that financial development had a negative impact on CO_2 emissions in both the short and long run, thus implying its potential to improve environmental quality. Using panel data for 30 provinces in China during 1997–2011 and applying the STIRPAT model, Xiong & Qi (2018) discovered that financial development was associated with a reduction in carbon emissions per capita. Similarly, Mardani et al. (2019) reviewed the relevant evidence for Saudi Arabia, Qatar, Bahrain, and Oman during 1980–2011 and reported that, in Oman and Bahrain, financial development played a significant role in reducing CO_2 emissions.

In contrast, other studies found that financial development might exacerbate carbon emissions. Sehrawat et al. (2015), investigating the impact of financial development, economic growth, and energy consumption on environmental degradation in India from 1971 to 2011, concluded that financial development had a positive and significant effect on environmental degradation. Batool et al. (2022) analyzed the relationship between information and communication technology (ICT), renewable energy, financial development, and CO_2 emissions in developing countries across East and South Asia. Their results indicated that in the long run, financial development increased CO_2 emissions, primarily through its effect on economic growth and rising energy consumption.

Moreover, some studies reported nil statistically significant relationship between financial development and environmental outcomes. For example, Ozturk & Acaravci (2013), as well as Omri et al. (2015), found inconclusive or insignificant effects in their cross-country analyses, hence suggesting that the link between finance and emissions might be context-dependent.

In summary, existing empirical evidence on the impact of energy transition, energy intensity, economic growth, and financial development on carbon neutrality, both globally and in the case of Vietnam, remains inconclusive and sometimes contradictory. Future research is required to carefully analyze and evaluate how these factors influence the capacity of Vietnam to meet its carbon neutrality goals. Such research should account for the country's structural conditions, institutional context, and priorities of development.

3. Methodology

3.1. Specification of the Model

The empirical model was structured to assess the dynamic interrelationship between the logarithm of CO_2 emissions (LCO_2) and four explanatory variables: logarithm of renewable energy share (LGE), energy efficiency measured as GDP per unit of energy use (LEE), economic growth proxied by GDP per capita (LEG), and financial development represented by domestic credit to the private sector (LFD). The general functional form of the model is as follows:

$$\mathrm{LCO_2}_t = \alpha + \sum_{i=1}^{k} \beta \mathrm{LGE}_{t-i} + \sum_{i=1}^{k} \beta \mathrm{LEE}_{t-i} + \sum_{i=1}^{k} \beta \mathrm{LEG}_{t-i} + \sum_{i=1}^{k} \beta \mathrm{LFD}_{t-i} + \varepsilon_t$$

Regarding the data, the dataset employed in this study was compiled from reputable databases. The details are presented in Table 1.

Table 1. Variables used in the model

Name of Variable	Description	Source
LCO_2	Logarithm of total CO_2 emissions (tonnes)	Our World in Data
LGE	Logarithm of renewable energy consumption (% of total primary energy)	Our World in Data
LEE	Logarithm of GDP per unit of energy use (PPP dollars per kg of oil equivalent)	World Bank Development Indicators
LEG	Logarithm of GDP per capita (current US dollars)	World Bank Development Indicators
LFD	Logarithm of domestic credit to the private sector (% of GDP)	World Bank Development Indicators

3.2. Estimation Procedure

This study employed the Johansen cointegration test and the VECM to examine both the short-run and long-run effects of energy transition, energy intensity, economic growth, and financial development on CO_2 emissions in Vietnam over the period 1995–2022. The process of estimation consists of the following steps:

Step 1: Descriptive Statistics: Compute basic statistical indicators for each variable to understand distributional characteristics.

Step 2: Unit Root Testing: Apply the Augmented Dickey-Fuller test (ADF), Phillips–Perron Test (PP), Kwiatkowski–Phillips–Schmidt–Shin test (KPSS) to determine the order of integration for each time series.

Step 3: Cointegration Testing: Use the Johansen trace and maximum eigenvalue tests to verify the existence of long-run equilibrium relationships among variables.

Step 4: Lag Selection: Determine the optimal lag length for the VECM model using Akaike information criterion (AIC) and other selection metrics.

Step 5: Model Estimation: Estimate the VECM model to quantify both short-run dynamics and long-run relationships.

Step 6: Diagnostic Checking: Assess model robustness via residual autocorrelation tests, heteroskedasticity tests, and model stability analysis.

Step 7: Analysis Forecasting: Conduct impulse response functions and variance decomposition to evaluate the effect of variables over time.

4. Data Analysis

4.1. Descriptive Statistics

Table 2 reports the descriptive statistics of the variables used in the model, including LCO_2, LEE, LEG, LFD, and LGE. The mean values of these variables are 2.086, 0.940, 3.058, 1.789, and 1.292, respectively, while the medians are close to the corresponding means, indicating relatively stable distributions. The standard deviations range from 0.080 to 0.399, suggesting a moderate level of dispersion across the variables.

Table 2. Descriptive statistics of variables used in the model

Statistic	LCO_2	LEE	LEG	LFD	LGE
Mean	2.085765	0.939381	3.057645	1.789004	1.292387
Median	2.123973	0.920021	3.077220	1.896204	1.293947
Maximum	2.546621	1.131616	3.614516	2.100067	1.439299
Minimum	1.535903	0.782572	2.459095	1.266812	1.108793
Std. Dev.	0.307340	0.102689	0.398882	0.267105	0.079874
Skewness	-0.137750	0.269781	-0.087909	-0.834866	-0.321754
Kurtosis	1.919575	1.789405	1.419568	2.405401	2.504961
Jarque-Bera	1.450421	2.049447	2.950124	3.665146	0.769029
Probability	0.484223	0.358896	0.228764	0.160001	0.680781
Sum	58.40142	26.30267	85.61405	50.09211	36.18682
Sum Sq. Dev.	2.550365	0.284717	4.295885	1.926320	0.172257

The skewness coefficients indicate that most variables are slightly negatively skewed (LCO_2, LEG, LFD, and LGE), whereas LEE exhibits mild positive skewness. Kurtosis values are all below 3, implying relatively platykurtic distributions compared with the normal distribution. Furthermore, the Jarque–Bera test probabilities are greater than 0.05 for all variables, indicating that the null hypothesis of normal distribution cannot be rejected. Overall, the variables display moderate variability and are suitable for subsequent regression analysis.

4.2. Unit Root Test of Data Series

According to the ADF test results presented in Table 3, LGE, LEE, and LFD became stationary after first differencing, whereas LCO_2 and LEG required second differencing under the ADF criterion. These mixed outcomes were examined further using the PP and KPSS tests. The PP and KPSS tests were then conducted and yielded the following results.

Table 4 presents the results of the ADF, PP, and KPSS unit root tests. The findings revealed some degree of inconsistency across the three tests. Specifically, the ADF test suggested that LCO_2 and LEG might be integrated of order two, whereas the PP test indicated that all variables were integrated of order one. The KPSS results further suggested that most variables were at most I(1), although LGE and LEG appeared stationary at level under that specification.

Such divergence across unit root tests is not uncommon, particularly in small samples, as these tests are known to be sensitive to lag selection, deterministic components, and finite-sample properties. In particular, the ADF test may exhibit relatively low power in distinguishing between highly persistent I(1) processes and I(2) behavior, especially when the underlying series are subject to structural changes or strong persistence. Therefore, the indication of possible I(2) integration for LCO_2 and LEG is interpreted with caution rather than as conclusive evidence.

Considering the combined evidence, the PP test consistently classified all variables as I(1), while the KPSS results did not provide strong support for integration beyond order one. Accordingly, for empirical implementation, the variables were treated as predominantly I(1). On this basis, the Johansen cointegration test was employed to examine the existence of long-run relationships among the variables, followed by the estimation of the VECM to capture both long-run equilibrium and short-run dynamics.

It should be noted, however, that the standard Johansen–VECM framework was formally derived under the assumption that variables were integrated of order one. Given the mixed unit root evidence, particularly the possible I(2) indication from the ADF test, the results of the cointegration and VECM analysis should be interpreted as conditional and indicative rather than definitive evidence of a stable long-run equilibrium relationship. This limitation is explicitly acknowledged, and the findings are discussed with appropriate caution.

Table 3. Results of the Augmented Dickey-Fuller (ADF) test

Series	Original Series		1st Difference		2nd Difference		Result
	t-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	
LCO_2	-2.602438	0.2821	-3.244939	0.0286	-6.251805	0.0000	I(2)
LGE	-2.955778	0.0527	-4.639040	0.0012			I(1)
LEE	-2.497883	0.3264	-4.170651	0.0037			I(1)
LEG	-2.464999	0.3405	-2.049890	0.2652	-9.081414	0.0000	I(2)
LFD	-1.236147	0.8821	-4.254554	0.0028			I(1)

Table 4. Results of Augmented Dickey-Fuller test (ADF), Phillips–Perron Test (PP), Kwiatkowski–Phillips–Schmidt–Shin test (KPSS) tests

Series	ADF	PP	KPSS
LCO_2	I(2)	I(1)	I(1)
LGE	I(1)	I(1)	I(0)
LEE	I(1)	I(1)	I(1)
LEG	I(2)	I(1)	I(0)
LFD	I(1)	I(1)	I(1)

4.3. Johansen Cointegration Test and Long-Run Relationship

The results in Table 5 indicate the existence of at least two cointegrating equations in the long-run relationship among the variables. Table 5 also presents the normalized coefficients of the single cointegrating equation, as suggested by the Johansen methodology.

Table 5. Results of the Johansen cointegration test

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.****
None *	0.869947	120.0604	79.34145	0.0000
At most 1 *	0.729360	67.02519	55.24578	0.0033
At most 2	0.487037	33.04411	35.01090	0.0801
At most 3	0.412066	15.68776	18.39771	0.1150
At most 4	0.069688	1.878115	3.841466	0.1705
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	**Eigenvalue**	**Max-Eigen Statistic**	**0.05 Critical Value**	**Prob.****
None *	0.869947	53.03522	37.16359	0.0004
At most 1 *	0.729360	33.98108	30.81507	0.0198
At most 2	0.487037	17.35636	24.25202	0.3119
At most 3	0.412066	13.80964	17.14769	0.1436
At most 4	0.069688	1.878115	3.841466	0.1705

Note: Trace test indicates 2 cointegrating eqn(s) at the 0.05 level; max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level; *denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis (1999) *p*-values.

Table 6. Normalized cointegrating coefficients

LCO_2	LGE***	LEE***	LEG***	LFD**
1.000000	0.392678	0.677378	0.076106	0.018878
	(0.02022)	(0.07335)	(0.01694)	(0.01606)

Note: *** denotes significance at the 1% level; ** denotes significance at the 5% level. Standard errors were reported in ( ).

The long-run relationship among the variables is described by the following equation, and the estimation results are reported in Table 6.

$$LCO_2 = 0.392678 \times LGE + 0.677378 \times LEE + 0.076106 \times LEG + 0.018878 \times LFD + \varepsilon$$

with the long-run adjustment coefficient: $D(LCO_2) = 0.772325$

The results indicated that, in the long run, all four explanatory variables were statistically significant. Energy transition, energy intensity, economic growth, and financial development were positively associated with CO_2 emissions in Vietnam. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality rather than a direct measure of it, these findings suggested that increases in these factors were associated with higher emission levels, which might reflect potential challenges along the decarbonization pathway. These results are broadly consistent with previous empirical studies, including those by Batool et al. (2022), Hung et al. (2022), Jebli & Youssef (2017), Luo & Zhao (2025), and Peng et al. (2024).

Besides, the value of LCO_2 was currently above its long-run equilibrium level, hence suggesting a short-term deviation from the equilibrium path. Given that CO_2 emissions were used as a proxy indicator of progress toward carbon neutrality, this deviation might reflect a temporary imbalance in the decarbonization trajectory. In the subsequent period, LCO_2 is expected to be adjusted by approximately 0.772325 of the deviation toward its long-run equilibrium.

4.4. Optimal Lag Selection

This study determined the optimal lag length for the model using the vector autoregression lag order selection criteria, to be applied to five differenced variables: $D(LCO_2)$, D(LGE), D(LEE), D(LEG), and D(LFD). The results in Table 7 indicated that the optimal lag length for the variables in the VECM model, as determined by the AIC and other selection criteria, was lag 3.

Table 7. Optimal lag selection based on the vector autoregression lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	258.0461	NA*	4.78e-16	-21.08717	-20.84175*	-21.02206
1	280.7063	33.99039	6.13e-16	-20.89220	-19.41963	-20.50152
2	311.8031	33.68816	5.05e-16	-21.40026	-18.70055	-20.68403
3	361.9326	33.41963	1.71e-16*	-23.49438*	-19.56753	-22.45259*

Note: Lag—lag order; LogL—log-likelihood; LR—likelihood ratio; FPE—final prediction error; AIC—Akaike information criterion; SC—Schwarz criterion; HQ—Hannan–Quinn criterion.

4.5. Estimation of the Vector Error Correction Model

The estimation results of the VECM model in Table 8 confirmed the existence of a cointegrating vector, thus indicating a short-run equilibrium relationship among the variables. This relationship is expressed as follows:

$$LCO_2 = 0.006524 + 2.232531 \times LGE - 2.671150 \times LEE + 0.436636 \times LEG - 1.074698 \times LFD + \varepsilon$$

Table 8. Short-run coefficients of the Vector Error Correction Model (VECM)

$D(LCO_2(-1))$	D(LGE(-1))***	D(LEE(-1))***	D(LEG(-1))*	D(LFD(-1))***	C
1.000000	2.232531	-2.671150	0.436636	-1.074698	0.006524
	(0.18895)	(0.64560)	(0.23350)	(0.20788)	
	[11.8155]	[-4.13750]	[1.86994]	[-5.16983]	

Note: ***denotes significance at the 1% level. *denotes significance at the 10% level. Standard errors were reported in ( ), and *t*-statistics were reported in [ ].

In the short-run estimation (lag 3), all variables, namely energy transition (LGE), energy intensity (LEE), economic growth (LEG), and financial development (LFD), were found to be statistically significant.

Firstly, the empirical findings indicated that both energy transition (LGE) and economic growth (LEG) were positively associated with CO_2 emissions in the short run. These results are consistent with prior studies, including Bui et al. (2023), Hung et al. (2022), Jebli & Youssef (2017), and Luo & Zhao (2025).

Secondly, the results demonstrated that energy intensity (LEE) and financial development (LFD) were negatively and statistically significantly associated with CO_2 emissions in the short run, to be in line with the findings of Du et al. (2019), Mardani et al. (2019), and Ortega-Ruiz et al. (2020), Xiong & Qi (2018).

Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, these findings suggested heterogeneous and short-run dynamics across economic and financial factors. The importance of carefully designed and targeted policy measures is highlighted, in order to balance economic development with climate-related objectives.

4.6. Model Evaluation

(a) Granger Causality Test

The short-run Granger causality results in Table 9 did not provide evidence of direct causal linkages with CO_2 emissions. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, this suggests that short-run adjustments in the explanatory variables may not translate into immediate changes in the decarbonization trajectory. Energy intensity and financial development were found to Granger-cause economic growth, indicating that improvements in energy efficiency and financial deepening are associated with short-run economic expansion. In addition, financial development shows weak evidence of influencing the renewable energy transition.

These findings imply that the explanatory variables may affect CO_2 emissions indirectly through intermediate macroeconomic mechanisms rather than through immediate direct effects. In particular, changes in energy intensity and financial development can first stimulate economic growth, which in turn may alter energy demand, industrial activity, and consumption patterns, thereby influencing emission dynamics over time. Similarly, the role of financial development in supporting renewable energy transition suggests an additional transmission channel, whereby improved access to finance facilitates investment in cleaner technologies, which may gradually contribute to emission reduction.

Overall, these findings suggest that indirect channels—particularly through economic growth and renewable energy transition—may be more relevant than direct short-run effects in shaping emission dynamics, thereby highlighting the complexity of the decarbonization process.

Table 9. Results of the Granger Causality test

Dependent Variable: D(LCO₂,2)			
Excluded	**Chi-sq**	***df***	**Prob.**
D(LGE,2)	0.755513	2	0.6854
D(LEE,2)	0.413854	2	0.8131
D(LEG,2)	1.171202	2	0.5568
D(LFD,2)	2.116699	2	0.3470
All	5.897106	8	0.6588
Dependent Variable: D(LGE,2)			
Excluded	**Chi-sq**	***df***	**Prob.**
D(LCO₂,2)	0.136448	2	0.9341
D(LEE,2)	0.495894	2	0.7804
D(LEG,2)	0.972278	2	0.6150
D(LFD,2)	5.082801	2	0.0788
All	13.74647	8	0.0886
Dependent Variable: D(LEE,2)			
Excluded	**Chi-sq**	***df***	**Prob.**
D(LCO₂,2)	2.212134	2	0.3309
D(LGE,2)	3.904286	2	0.1420
D(LEG,2)	2.997718	2	0.2234
D(LFD,2)	0.392422	2	0.8218
All	5.981683	8	0.6493
Dependent Variable: D(LEG,2)			
Excluded	**Chi-sq**	***df***	**Prob.**
D(LCO₂,2)	2.419486	2	0.2983
D(LGE,2)	2.749969	2	0.2528
D(LEE,2)	8.633912	2	0.0133
D(LFD,2)	9.187116	2	0.0101
All	28.17129	8	0.0004
Dependent Variable: D(LFD,2)			
Excluded	**Chi-sq**	***df***	**Prob.**
D(LCO2,2)	1.565788	2	0.4571
D(LGE,2)	1.297136	2	0.5228
D(LEE,2)	0.494987	2	0.7808
D(LEG,2)	4.217235	2	0.1214
All	7.429560	8	0.4911

(b) Stability Test of the Model

The inverse roots of the AR characteristic polynomial all lie within the unit circle, as shown in Figure 1. This indicates that the VECM model is stable and the estimation results are reliable.

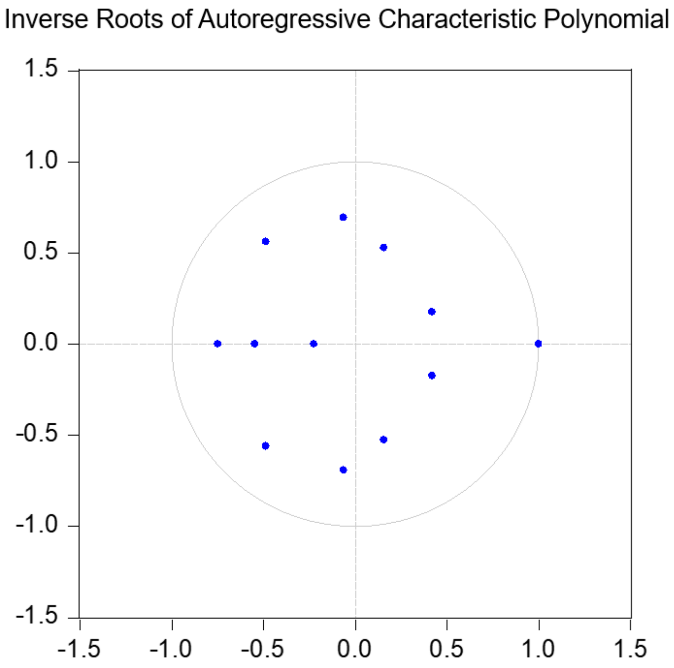

Figure 1. Stability test of the Vector Error Correction Model (VECM)

(c) Autocorrelation Test

The results of the Portmanteau tests for residual autocorrelation, reported in Table 10, show that all Prob* values are greater than 0.1, indicating the absence of residual autocorrelation at the 1% significance level. This diagnostic evidence further supports the adequacy of the VECM model, complementing the stability results, and confirms that the estimated model is robust for explaining the relationships among the variables.

Table 10. Residual Portmanteau tests for autocorrelations

Lags	Q-Stat	Prob.*	Adj Q-Stat	Prob.*	*df*
1	22.29138	–	23.26057	–	–
2	37.57933	–	39.93833	–	–
3	56.61118	0.1149	61.68902	0.0497	45
4	73.09593	0.3767	81.47072	0.1644	70
5	95.82916	0.4569	110.1864	0.1366	95

Note: *Test is valid only for lags larger than the vector autoregression lag order.

(d) Heteroskedasticity Test Using White's Test

The results of the White heteroskedasticity test in Table 11 showed that the probability values were greater than 0.1, indicating the absence of heteroskedasticity in the regression model at the 1% significance level.

Table 11. White heteroskedasticity test

Chi-sq	*df*	Prob.
337.5480	330	0.3754

(e) Shock Transmission Mechanism and Variance Decomposition

The variance decomposition results reported in Table 12 indicate that CO_2 emissions were largely explained by their own shocks, accounting for more than 70% of the forecast error variance even in the long run. This suggested a high degree of persistence in emission dynamics. Among the explanatory variables, renewable energy transition appeared to be the most influential external factor, contributing approximately 25% to the variation in CO_2 emissions after ten periods. In contrast, energy intensity, economic growth, and financial development accounted for only a relatively small share of the variation. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, these findings suggested that while energy transition became increasingly relevant over time, the strong persistence of emissions might reflect structural constraints in the decarbonization pathway. This, in turn, highlights the potential importance of sustained and long-term policy efforts, rather than short-term adjustments alone.

Table 12. Results of variance decomposition analysis

Period	S.E.	D(LCO$_2$)	D(LGE)	D(LEE)	D(LEG)	D(LFD)
1	0.035180	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.046691	86.65983	12.21067	0.022235	0.820067	0.287196
3	0.054239	78.08838	20.49763	0.526777	0.659834	0.227377
4	0.061180	76.84812	19.57121	1.402994	1.841828	0.335846
5	0.068346	76.12587	20.69758	1.295904	1.511795	0.368852
6	0.074897	75.07745	21.43042	1.086068	1.996462	0.409606
7	0.080390	73.64258	23.01067	0.949083	1.988267	0.409398
8	0.084666	72.69956	24.09972	0.925333	1.882998	0.392392
9	0.089442	72.08818	24.87209	0.873759	1.766564	0.399406
10	0.093914	71.59041	25.40975	0.818275	1.779171	0.402387

5. Discussion

This study empirically examined the effects of energy transition, energy intensity, economic growth, and financial development on Vietnam's carbon neutrality objective over the period 1995–2022, with reference to the country's carbon neutrality objective. The main findings are as follows:

First, the findings indicated that energy transition was positively associated with CO_2 emissions in both the short and long run in Vietnam. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, this result suggested that the current process of transition might not yet effectively support the decarbonization pathway. In the short run, this pattern could be interpreted through the "energy addition" effect, whereby renewable energy expansion supplements rather than substitutes fossil fuel consumption. Despite the rapid growth of solar and wind capacity, coal-fired power generation continues to play a dominant role in the electricity mix, while electricity demand has increased substantially. As a result, renewable energy deployment appears to add to total energy supply, thus contributing to higher overall energy use and associated emissions.

In addition, the transition toward renewable energy is inherently capital- and material-intensive. The expansion of renewable infrastructure, such as solar farms, wind projects, and transmission networks, relies heavily on carbon-intensive inputs, including cement, steel, and industrial equipment. Consequently, during the early stages of transition, these investment-driven activities may partially offset the intended emission reductions, thereby weakening the short-run environmental benefits.

In the long run, the persistence of a positive association between energy transition and CO_2 emissions may reflect deeper structural constraints within the Vietnamese economy. If carbon-intensive sectors, particularly heavy industry, continue to expand and fossil fuels remain embedded in the energy system, deployment of renewable energy alone may be insufficient to alter emission trajectories. This suggests that the advancement of Vietnam toward carbon neutrality has not yet been accompanied by a comprehensive structural transformation toward low-carbon production systems.

From a policy perspective, these findings implied that achieving the net-zero target requires more than expanding renewable energy capacity. Effective decarbonization depends on ensuring that renewable energy directly substitutes fossil fuels, accelerating the phase-out of coal, and promoting structural economic transformation toward less carbon-intensive sectors. Without such coordinated and systemic changes, the energy transition may yield limited development toward carbon neutrality, despite substantial investment and considerable capacity expansion.

Second, energy intensity was negatively associated with CO_2 emissions in the short run but positively associated with emissions in the long run. In the short term, improvements in energy efficiency enable firms to produce the same level of output with lower energy consumption. Technological upgrading, process optimization, and energy-saving policies could reduce waste and enhance production efficiency, thereby contributing to lower emissions. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, this suggested that reductions in energy intensity might support short-run progress along the decarbonization pathway by alleviating environmental pressure.

However, it is anticipated that this relationship could reverse in the long run in view of the possibility of rebound effect. Along with the improvement of energy efficiency, the cost of providing effective energy services would decline. Lower production costs may encourage firms to expand output, while households may increase consumption due to reduced energy-related expenses. Consequently, total energy demand may rise despite gains in efficiency. This phenomenon, commonly referred to as the Jevons Paradox, implies that improvement in energy efficiency may inadvertently increase aggregate energy consumption. In a rapidly growing economy such as Vietnam, where industrial expansion and rising incomes continue to drive energy demand, this rebound effect may be particularly pronounced. This suggests that while policies promoting energy efficiency could contribute to carbon neutrality in the short run, their long-run effectiveness may be limited if not accompanied by appropriate structural and regulatory measures. Therefore, achieving the net-zero target requires that energy efficiency policies be complemented by broader interventions, including management on the demand side, structural transformation toward less carbon-intensive sectors, and policy mechanisms that ensure efficiency gains do not translate into higher aggregate energy consumption.

Third, economic growth was demonstrated to be positively associated with CO_2 emissions in both the short and long run in Vietnam. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, this pattern suggested that current growth dynamics might pose challenges for the decarbonization pathway.

In the short run, this relationship could be interpreted through the scale effect of economic expansion, whereby increases in output, industrial activity, and investment were associated with higher energy demand and, consequently, higher emissions. As economic activity intensifies, demand for electricity, transportation, construction materials, and manufactured goods rises; most of which remain closely linked to fossil fuel consumption in Vietnam. As a result, short-term economic expansion appears to be accompanied by higher emission levels.

In the long run, the persistence of this positive association may reflect that Vietnam remains in a scale-driven growth phase, where structural transformation toward low-carbon production has not yet been fully realized. According to the EKC, economic development may initially lead to higher emissions before declining beyond a certain income threshold. However, empirical evidence suggested that Vietnam have not yet reached this turning point. Economic growth continues to rely heavily on manufacturing, construction, and other energy-intensive sectors, thus indicating that dependence on fossil fuel remains embedded in the production structure. From a policy perspective, these findings implied that achieving carbon neutrality requires not only sustaining economic growth but also fundamentally transforming the growth model. In particular, progress toward the net-zero target depends on accelerating the adoption of cleaner technologies, improving energy efficiency, and increasing the share of low-carbon sectors within the economy. Without such structural adjustments, continued economic expansion may limit the effectiveness of decarbonization efforts.

Fourth, financial development was found to be negatively associated with CO_2 emissions in the short run but positively associated with emissions in the long run. Given that CO_2 emissions were employed as a proxy indicator of progress toward carbon neutrality, this pattern suggested that financial development might support short-term improvements along the decarbonization pathway but could not ensure sustained emission reductions over time.

In the short run, a more developed financial system could ease access to capital, thus enabling firms to invest in energy-efficient technologies, upgrade production processes, and adopt cleaner production methods. Financial deepening may facilitate investment in renewable energy projects and technological innovation by reducing financing constraints. Through improved capital allocation, firms may enhance operational efficiency and reduce energy waste, leading to lower emission levels in the short term.

However, the long-run relationship points to a different dynamic. If financial expansion is not aligned with green investment priorities, increased availability of credit may stimulate overall economic activity without environmental targeting. Capital may be directed toward energy-intensive sectors such as heavy industry, construction, and infrastructure, which remain dependent on fossil fuels. In addition, expanded access to credit may increase household consumption and energy demand. This pattern may reflect a "financial deepening effect without green targeting", whereby broader financial expansion reinforces scale effects that are associated with higher aggregate emissions.

From a policy perspective, these findings implied that the long-term environmental impact of financial development critically depended on the direction of capital allocation. Achieving carbon neutrality therefore requires not only financial deepening but also the establishment of a robust green finance framework that channels financial resources toward low-carbon sectors. Without such mechanisms, financial development may inadvertently reinforce carbon-intensive growth patterns, thereby constraining progress along the decarbonization pathway.

Taken together, the above findings implied that Vietnam could devote more to achieving Net-Zero 2050 commitment, namely by expanding renewable energy and promoting economic growth. A successful decarbonization strategy must ensure that renewable energy genuinely substitutes fossil fuels, that improvements of energy efficiency are accompanied by structural transformation, and that financial development is strategically aligned with green investment frameworks. Without such coordinated reforms, short-term gains may be offset by long-term structural pressures, thereby complicating the pathway toward carbon neutrality.

Based on the empirical findings, the study concluded with the following policy implications:

The empirical findings suggested that Vietnam's pathway toward carbon neutrality requires a comprehensive and coordinated policy framework that addresses both short-run dynamics and long-run structural constraints.

First, energy expansion must shift from an "energy addition" model to an effective "energy substitution" strategy. While Vietnam has made significant progress in increasing solar and wind capacity, fossil fuels, in particular coal, continue to play a dominant role in electricity generation. Policymakers should therefore accelerate the gradual phase-out of coal-fired power plants, strengthen carbon pricing mechanisms, and enhance grid integration to ensure that renewable energy directly replaces high-emission sources rather than merely supplementing total supply.

Without such substitution, renewable expansion alone may not achieve meaningful emission reductions.

Second, improvements of energy efficiency should be complemented by demand-side management policies to mitigate potential rebound effects. While efficiency gains generate short-term emission reductions, long-term increases in production and consumption may offset these benefits. Vietnam should strengthen regulatory standards, enforce mandatory energy audits for energy-intensive industries, and promote technological upgrading alongside structural transformation toward less carbon-intensive sectors. Integrating efficiency measures with industrial restructuring is crucial to sustaining long-term emission reductions.

Third, given that economic growth remains closely linked to carbon emissions, Vietnam should be prepared to transition from a scale-driven growth model to a productivity- and innovation-driven model. Structural reforms should prioritize high-tech manufacturing, digital industries, and service sectors with lower carbon intensity. Meanwhile, environmental regulations must become progressively stricter as income levels rise, in order to help the economy move toward the turning point suggested by the EKC.

Fourth, financial development should be strategically aligned with green objectives. Although financial deepening can initially support clean technology investment, long-term credit expansion without environmental targeting may reinforce carbon-intensive growth. Therefore, Vietnam should strengthen its green finance framework through clear green taxonomies, mandatory ESG disclosure standards, green bond development, and preferential credit policies for low-carbon projects. Aligning financial incentives with climate objectives is essential to prevent the "financial deepening effect" from undermining decarbonization efforts.

Overall, achieving Vietnam's Net-Zero 2050 commitment requires an integrated policy approach in which renewable energy deployment, energy efficiency, structural transformation, and green finance are mutually reinforcing. Fragmented or isolated policy measures may generate short-term improvements but are unlikely to deliver sustained emission reductions. A coordinated transition strategy that combines fossil fuel phase-out, industrial upgrading, and climate-aligned financial reform will be critical to ensuring a credible and sustainable pathway toward carbon neutrality.

6. Conclusions

This study investigated the impact of energy transition, energy intensity, economic growth, and financial development on the carbon neutrality objective of Vietnam over the period of 1995–2022. The results revealed clear asymmetries between short-run and long-run effects caused by the interrelationship among the above variables. Renewable energy transition and economic growth increase CO_2 emissions in both perspectives, thus indicating that Vietnam's current development model remains carbon-intensive and that renewable expansion has not yet effectively substituted fossil fuels. Energy intensity and financial development were found to reduce CO_2 emissions in the short run but increase them in the long run, hence suggesting the possibility of rebound effects and scale-driven financial expansion. These findings implied that Vietnam has not yet reached structural decarbonization and remains in a scale-dominated growth phase. Achieving the Net-Zero 2050 target demands coordinated reforms to ensure fossil fuel substitution, sustained efficiency gains, low-carbon structural transformation, and climate-aligned financial development.

Limitations of the study and recommendations for future research: The study did not fully consider additional control variables in the model, such as trade openness, urbanization, industrial structure, technological innovation, and population growth. Due to data constraints, the analysis only examined the impact of energy transition, energy intensity, economic growth, and financial development on CO_2 emissions in Vietnam over the period 1995–2022. These limitations suggest potential avenues for further development in future research.

Author Contributions

Conceptualization, N.N.H.; methodology, N.N.H.; software, N.N.H. and L.N.Q.; formal analysis, N.N.H.; data curation, N.N.H. and H.P.T.; original draft preparation, N.N.H.; review and editing, N.N.H. and L.N.Q.; supervision, N.N.H. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Declaration on the Use of Generative AI and AI-assisted Technologies

The authors used generative AI only for language editing and improving readability. All conceptualization, analysis, and conclusions were conducted by the authors, who take full responsibility for the content of the manuscript.

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