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RESEARCH PAPER

The role of fintech and green finance in fostering environmental sustainability: Evidence from the ASEAN-5

Muhammad Rafi Bakri*, Tri Widodo Setiyo Prihadi, Ulfa Futri
Universitas Terbuka, Indonesia

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Abstract. Environment and economy are frequently seen as opposing forces. For every government initiative to boost the economy, there is an equal and opposite measure to protect the environment. The overarching goal of this research is to provide empirical evidence of how green finance and fintech sway policymakers to reduce the economic-environmental trade-off. Secondary data from 2000–2023, together with a sample of ASEAN-5 nations, are used in this analysis. To determine the impact of the study's independent variables on environmental damage, quantitative approaches, particularly CS-ARDL, are employed. The study's findings suggest that the five ASEAN nations may lessen their environmental impact by utilizing green finance and fintech. The government, with the exception of Singapore, needs to move swiftly, since the expected decline is too sluggish. Among the ASEAN-5 nations, Singapore has the potential to do more to protect the environment than its peers.

Keywords: fintech; green finance; environmental-economy; ASEAN-5

1. Introduction

Climate change has emerged as a global issue. Elevated carbon dioxide (CO_2) emissions significantly contribute to the increase in global surface temperatures. Countries that continue to depend on fossil fuels for their energy requirements contribute to the rising levels of CO_2 in the atmosphere (Yousaf & Fazal, 2022). The World Meteorological Organization (2023) indicated that CO_2 emissions from fossil fuels in 2022 and the first half of 2023 were elevated. Global CO_2 emissions from fossil fuels rose by 1% in 2022 relative to 2021, and the global average concentration continued its upward trajectory throughout 2022 and the first half of 2023. The Paris Climate Change Agreement, formulated on December 12, 2015, seeks to mitigate the climate change crisis by keeping the global temperature rise below 2°C relative to pre-industrial levels and restricting the increase to 1.5°C above pre-industrial levels (Udeagha & Ngepah, 2023). Consequently, researchers have concentrated on diverse factors, including green finance and fintech to identify methods for establishing a sustainable and eco-friendly world (Yousaf & Fazal, 2022).

In 2021, the United Nations Framework Convention on Climate Change (UNFCCC) estimated that the finance and technology sectors are projected to reduce carbon emissions by 40% by the

*Corresponding author. E-mail: 051027985@ecampus.ut.ac.id
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conclusion of 2030 (United Nation, 2024). The correlation between carbon emissions and green finance, through an environmentally oriented investment strategy, has garnered significant interest among numerous specialists (Rasoulinezhad & Taghizadeh-Hesary, 2022; Meo & Karim, 2022; Sun, 2022). Green finance enables private enterprises to fund ecologically sustainable activities that are crucial for promoting sustainable growth (Sachs et al., 2019). Green finance requires financial organizations to take pollution management and ecological preservation into account when issuing loans. Financial institutions may cease extending credit or withdraw funds from projects deemed too polluting and energy-intensive. This approach aims to inhibit the proliferation of environmentally detrimental firms (York et al., 2003).

Alongside green finance, fintech plays a significant role in mitigating carbon emissions (Tamasiga et al., 2022; Udeagha & Ngepah, 2023; Zhou et al., 2022). Fintech denotes innovative technologies within the financial services sector that can effectuate substantial changes in the execution of financial transactions. It encompasses a broad spectrum of financial activities, including payments, financial advisory, project finance, savings and loans, insurance, and regulatory compliance. Examples of fintech encompass peer-to-peer lending, crowdfunding, robo-advisors, blockchain, and cryptocurrencies. Fintech is regarded as more economical, convenient, comprehensive, and transparent for individual investors to evaluate and address their financial requirements more effectively. Consequently, fintech serves as a solution for sustainable funding (Kabir et al., 2023).

The ASEAN region is experiencing rapid economic growth, leading to a substantial rise in energy consumption (Mahi et al., 2020; Maneejuk & Yamaka, 2021). Energy consumption in the ASEAN region is expected to increase at an annual rate of 4.4% by 2030 (Mahi et al., 2020). According to Malarvizhi et al. (2019), the rise in energy consumption resulting from urbanization and industrialization in ASEAN-5 member countries has led to an increase in carbon dioxide (CO_2) emissions, as illustrated in Figure 1.

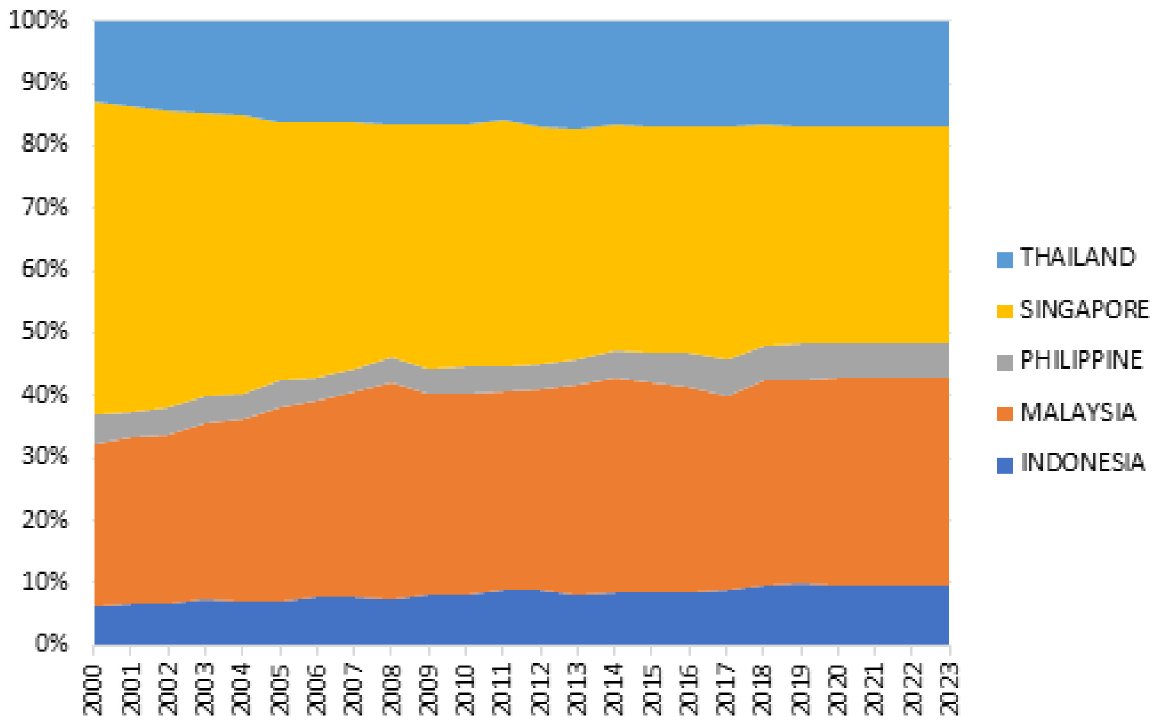

Figure 1. CO_2 emissions (metric tons per capita) in ASEAN-5 countries since 2000-2023

An active strategy is essential for utilizing fintech and green finance to tackle environmental issues. Green finance is regarded as an effective financial strategy for mitigating CO_2 emissions (Chen et al., 2021; Meo & Karim, 2022). Nonetheless, none of the research specifically delineates the conditions in the ASEAN-5 countries. Therefore, we will conduct an empirical analysis of the impact of green finance and fintech utilization on carbon emissions in the ASEAN-5 nations.

2. Theoretical foundation

According to Udeagha and Ngepah (2023), green finance and fintech play an important role in promoting environmental sustainability. They found that green finance and fintech, as along with energy innovation, contribute positively to environmental sustainability in BRICS countries. This study shows that the development of green financial products and the increased capacity of financial institutions to provide green credit services are essential to achieving carbon neutrality goals. Another study by Zhou et al. (2022) found that green finance serves as a mediator between green growth and fintech innovation. The presence of fintech enhances the effectiveness of green finance in encouraging sustainable business practices, ensuring that investments are channeled to sectors that support environmental sustainability.

The fintech sector plays a vital role in supporting green finance initiatives and helping to reduce carbon emissions through various innovative financial mechanisms. This study aims to examine and analyze the variables through which fintech can influence green finance and carbon emissions in ASEAN-5 member countries, namely Indonesia, Singapore, Malaysia, Thailand, and the Philippines.

2.1. Gross Domestic Product

Gross Domestic Product (GDP) is a monetary measure that represents the market value of all final goods and services produced within a country during a specific time period. GDP is often used as an indicator of a country's economic health and the well-being of its citizens. In the context of CO_2 emissions and environmental analysis, GDP plays an important role because it reflects economic activity related to energy consumption and carbon emissions. Le and Nguyen (2019) state that as an economy expands, pollution levels increase with economic growth; however, beyond a certain point, further economic growth may lead to a decline in pollution levels. This theory is based on research suggesting that when a country's income is low, its primary focus on increasing income, which may initially result in higher pollution, but as income levels rise, more attention is given to environmental protection, leading to a decrease in pollution levels.

According to Grossman and Krueger (1994) economic growth can cause environmental degradation in the early stages. However, as income levels increase, people tend to demand a cleaner environment and more efficient technologies, which ultimately lead to a reduction in CO_2 emissions. In other words, the statement suggests that public awareness and demand for a cleaner environment increase alongside rising income levels. Ultimately, this contributes to a decrease in CO_2 emissions and overall environmental improvement. Although rapid economic growth may cause environmental damage, sustained economic growth can encourage the adoption of more environmentally friendly policies and technologies in the long run.

According to Ang (2008), Malaysia's economic growth is significantly correlated with an increase in carbon emissions. This indicates that as Malaysia's economy grows and GDP increases, carbon emissions also increase. This finding suggests that larger economic activities, such as industrial production, are more likely to contribute to higher carbon emissions. This study emphasizes the importance of implementing effective energy policies. In other words, while economic growth may lead to increased CO_2 emissions, well-designed energy policies can help manage and mitigate these negative effects without hindering economic growth. Therefore, the implication of this finding in the context of GDP is that increasing GDP may contribute to increased CO_2 emissions, strategic efforts are needed to balance economic growth with carbon reduction initiatives.

2.2. Energy intensity and carbon emissions

The intensity and carbon emissions theory (INT) emphasizes the importance of energy efficiency and the use of renewable energy sources in reducing carbon emissions. According to Jamel and Derbali (2016), energy intensity and carbon emissions are studied in the context of how energy consumption and economic impact environmental degradation in Asian countries. They found that increased energy use and economic development often lead to higher carbon emissions, contributing to environmental degeneration. Similarly, Ang (2008) stated that Malaysia's economic growth, pollutant emissions, and energy consumption are closely interrelated. These findings suggest that improving energy efficiency can play significant role in reducing carbon emissions.

2.3. Industrial Value Added (IVA)

Industrial Value Added (IVA) is often associated with increased CO_2 emissions due to energy-intensive production processes. However, the application of clean technology and environmentally friendly industrial practices can mitigate the negative environmental impact of industrialization. Lean and Smyth (2010) emphasized that implementing cleaner technologies and sustainable practices can increase the economic value added by the industrial sector. While industrial production is typically energy-intensive and a major contributor to carbon emissions, improvements in energy efficiency, innovation in clean technology, and the adopting of sustainable methods can help reduce carbon footprints while boosting economic output. Additionally, Zhang (2010) found through empirical analysis that financial development can influence carbon emissions in China.

2.4. Green Finance Index

The Green Finance Index measures the effectiveness of sustainable financial investments in reducing carbon emissions. A country's carbon footprint can be significantly reduced by investing in green technologies and sustainable initiatives.

Research by Udeagha and Ngepah (2023) found that green finance and institutional quality have a significant influence on carbon emissions. Their findings indicate that countries with stronger institutions and good governance are more effective in utilizing green finance to reduce carbon emissions. Institutional quality includes factors such as transparency, accountability, and political stability, all of which contribute to the successful implementation of green projects.

Zhou et al. (2022) demonstrate that public spending and green economic growth in the Belt and Road Initiative (BRI) region are positively influenced by green finance. Their study shows finds that green finance flows in the BRI region enhance the effectiveness of public spending in supporting green projects and promoting more sustainable economic growth. In other words, green finance not only contributes to the reduction of carbon emissions but also plays an important role in facilitating the transition to a more inclusive and resilient green economy.

2.5. Trade balance level

Trade balance levels can influence a country's carbon dioxide emissions through its trade patterns. Some countries may import or export carbon-intensive goods, which can impact global carbon emissions. Chen et al. (2021) found a multivariate causal relationship between CO_2 emissions, energy consumption, Foreign Direct Investment (FDI), and GDP in BRIC countries (Brazil, Russia, India, and China). Their study shows that increased energy consumption and economic activity supported by FDI can lead to higher CO_2 emissions. They also observed that economic growth in these countries is often driven by energy-intensive sectors, which further contributes to rising emissions.

Wang et al. (2021) explored the relationship between trade, growth, and the environment. They argue that international trade can influence environmental outcomes through several channels. First, scale effects, where increased economic activity resulting from trade leads to higher emissions. Second, composition effects, where trade alters a country's economic structure, potentially increasing or decreasing emissions depending on the sectoral shifts. Third, technology effects, where trade facilitates the transfer of cleaner and more efficient technologies, thereby helping to reduce emissions.

2.6. Fintech

Total value of fintech usage can contribute reducing carbon emissions by enhancing operational efficiency, lowering transaction costs, and expanding access to green finance. Fintech can also support sustainability initiatives and helps minimize the environmental impact of financial activities. Lee and Shin (2018) discuss the fintech ecosystem, business models, investment decisions, and associated challenges. They illustrate how fintech creates a more dynamic and competitive financial ecosystem, offering innovative business models that adapt to an evolving market. Investment decisions in fintech are becoming increasingly complex and strategic, driven fintech's potential to disrupt traditional financial systems and unlock new opportunities for growth and sustainability.

Malarvizhi et al. (2019) explore the transformative power of innovation and disruption in financial services brought by fintech. They highlight how fintech is not only reshaping how financial services are delivered, but also altering the structure and dynamics of the financial industry itself. Key innovations include technologies such as artificial intelligence, big data, and blockchain, all of which increase efficiency, security, and transparency in financial transactions, while also helping to reduce the carbon footprint of the financial industry.

3. Material and method

3.1. Data in research

This study uses panel data from 2000 to 2023, with samples drawn from the ASEAN-5 countries: Indonesia, Singapore, Malaysia, Thailand, and the Philippines. The dependent variable in is CO_2 emissions, measured in kilotons (kt), which serve as a proxy for environmental quality and are denoted as COE. The independent variables in this study gross domestic product (GDP), energy and carbon intensity (INT), industrial value added (IVA), urban population (POP), green finance index (GFI), trade openness (TRO), and financial technology (FIN).

Green finance proxy (GFI) is a composite indicator derived from green credit, green insurance, green securities, and green investment, following the method used by Udeagha and Ngepah (2023). The intensity proxy (INT) combines both energy intensity and carbon energy intensity to reflect the overall use of fossil energy in supporting economic activities. These composite indices were constructed using Principal Component Analysis (PCA) method. Details of each variable are presented in Table 1.

Table 1. Variable details

Variables	Definition	Unit	Source
COE	Carbon dioxide emissions due to the use of fossil fuels	Kiloton (noun)	The Global Economy
GDP	Gross domestic product; the final value of a country's economic activity in a year.	Constant US$ 2010	World Bank Database
INT	PCA between energy intensity and carbon emission intensity	Energy or carbon emissions per GDP	World Bank Database
IVA	The added value of the economy will be industrialization	% of GDP	World Bank Database
POP	Population of residents living in urban areas	Soul	World Bank Database
GFI	PCA between green credit, green insurance, green securities and green investment	Green Finance Index	The Untouchables (2023)
TRO	Trade balance level	Local currency	World Bank Database
FIN	Total Value generated from the use of fintech	Local currency	The Crunchbase

3.2. Model specifications

This study uses the GFI and FIN variables as the two main explanatory variables. Additionally, the GDP variable is included to test the Environmental Kuznets Curve (EKC) hypothesis, which suggests that carbon emissions initially increase with economic growth (GDP) up to a certain threshold, after which emissions begin to decline as income continues to rise.

The research also incorporates other instrumental variables, namely energy and carbon intensity (INT), industrial value added (IVA), urban population (POP), and trade openness (TRO), as these factors are believed to significantly influence a country carbon emission level. The general equation used in this study is presented in Equation 1.

$$COE_{it} = f(GDP_{it}, INT_{it}, IVA_{it}, GFI_{it}, TRO_{it}, FIN_{it}) \quad (1)$$

From the general equation above, we developed four derivative models to support the analysis. The data used in this study were transformed using the natural logarithm (ln) to address the issue of large disparities in scale among the variables. The equations for each model are presented in Equation 2 to 5.

Model-1

$$\ln COE_{it} = \alpha_{it} + \beta_1 \ln GDP_{it} + \beta_2 \ln GFI_{it} + \beta_3 \ln FIN_{it} + \mu_{it} \quad (2)$$

Model-2

$$\ln COE_{it} = \alpha_{it} + \beta_1 \ln GDP_{it} + \beta_2 \ln GFI_{it} + \beta_3 \ln FIN_{it} + \beta_4 \ln INT_{it} + \mu_{it} \quad (3)$$

Model-3

$$\ln COE_{it} = \alpha_{it} + \beta_1 \ln GDP_{it} + \beta_2 \ln GFI_{it} + \beta_3 \ln FIN_{it} + \beta_4 \ln INT_{it} + \beta_5 \ln IVA_{it} + \mu_{it} \quad (4)$$

Model-4

$$\ln COE_{it} = \alpha_{it} + \beta_1 \ln GDP_{it} + \beta_2 \ln GFI_{it} + \beta_3 \ln FIN_{it} + \beta_4 \ln INT_{it} + \beta_5 \ln IVA_{it} + \beta_7 \ln TRO_{it} + \mu_{it} \quad (5)$$

3.3. Econometric techniques

Economic data is suscepttible to heteroscedasticity symptoms. To address this issue, this study applies the Slope Coefficient Homogeneity (SCH) test, as proposed by Pesaran and Yamagata (2008). The SCH test is effective in detecting and resolving heteroscedasticity, thereby enhancing the validity of the panel data used. The SCH test is formulated based in Equation 6.

$$\tilde{\Delta}_{SCH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{S}\tilde{S} - k\right) \quad (6)$$

This study also conducted a Cross-Section Dependence (CSD) test to examine the interdependence among cross-sectional units, in this case, the ASEAN-5 countries. The CSD test serves as a guideline for subsequent analyses. The formulation of the CSD is presented in Equation 7.

$$\text{CSD}_{\text{test}} = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{k-1+1}^{N} T_{ik} \quad (7)$$

Following this, the study proceeds with a unit root test and a panel cointegration test. The unit root test is used to determine whether the panel data is stationary. Stationary is a desirable property, as it indicates the data is suitable for further analysis. The panel cointegration test, on the other hand, assess whether a long-term relationship exists among the variables. Even if individual variables are non-stationary, they may still form a stable long-term relationship, justifying further analysis.

Finally, this study employs the Cross-sectionally Augmented Autoregressive Distributed Lags (CS-ARDL) model to analyze the influence of the independent variables on carbon emissions, the dependent variable. The method captures both short-term and long-term dynamics and is particularly effective in handling datasets that include a mix of stationary and non-stationary variables. The CS-ARDL equation is presented in Equation 8.

$$Y_{it} = \sum_{i=0}^{Pw} \alpha\, I, \mathrm{t},\ Y_{\mathrm{i,\,t-I}} + \sum_{1=0}^{Pz} \beta I\, , \mathrm{t},\ Z_{i,\,t-I} + \sum_{1=0}^{Px} \gamma I\, , \mathrm{t}, \overline{IX}_{i,\,t-I} + \varepsilon_{i,\,t} \quad (8)$$

4. Result and discussion

Before proceeding to the main analysis, we conducted a descriptive statistical analysis of the variables used in the study. Table 2 shows that energy intensity has the lowest average value (-0.503), while GDP has the highest average (26.388). COE has the second-highest average, with a value of 19.558. In addition, Table 2 presents the distribution characteristics of each variable. Based on the Jarque-Bera test, all variables have probability values greater than 0.05 ($p < 0.05$), indicating that they are normally distributed. The normality of the data suggests that it is suitable for further analysis.

Table 2 also provides insights into the skewness of the data distribution. Variables such as COE, INT, IVA, GFI, and FIN show negative skewness, indicating that their distributions are skewed to the left. In contrast, the GDP variable show positive skewness, meaning its distribution is skewed to the right. The standard deviation values of the variables fall within a relatively narrow range (0.1994 to 1.1796), suggesting a fair level of data stability. However, GFI has the highest standard deviation, which indicates significant variation in green finance among ASEAN-5 countries. This disparity may reflect differing levels of environmental awareness and commitment to sustainability, influenced by each country's effort to balance economic growth with environmental protection.

The pairwise correlation matrix in Table 3 is used to examine the strength of the relationship among independent variables in the model. A strong correlation may indicate multicollinearity, which can compromise the realiability of the analysis. Based on the results, none of the independent variables (FIN, GDP, GFI, INT, IVA, and TRO) exhibit strong correlations with one another. This conclusion is supported by the fact that no variables pair has a correlation coefficient above 0.8 ($r^2 > 0.8$). In addition, the Variance Inflation Factor (VIF) values range from 0.2 to 1.52,

Table 2. Descriptive statistics

	lnCOE	lnGDP	lnINT	lnIVA	lnGFI	lnTRO	lnFIN
Mean	19.55889	26.38861	0.503373	3.562901	0.329478	4.780322	1.590137
Median	19.66652	26.45268	0.184026	3.603185	0.089659	4.805348	1.564959
Maximum	20.71198	27.94669	0.652461	3.882182	1.184087	6.080688	0.865208
Minimum	18.18298	25.09172	4.133293	3.109061	6.859257	3.495598	2.589922
Std. Dev.	0.821696	0.685588	1.091728	0.199430	1.179658	0.709609	0.433294
Skewness	-0.196138	0.104606	-1.697137	-0.465093	-1.875422	0.234489	-0.478666
Kurtosis	1.584385	2.596189	5.294939	2.471621	9.881823	2.013027	2.644402
Jarque-Bera	10.78922	1.034164	83.93919	5.722149	307.1416	5.970285	5.214679
Probability	0.64541	0.596258	0.12333	0.057207	0.09222	0.050532	0.073730
Sum	2347.066	3166.634	-60.40481	427.5481	-39.53733	573.6386	-190.8164
Sum Sq. Dev.	80.34687	55.93367	141.8325	4.732910	165.5997	59.92183	22.34155
Observations	120	120	120	120	120	120	120

all of which are well below the commonly accepted threshold of 5 (VIF > 5). This further conforms that there are no signs of multicollinearity among the independent variables in the model.

Furthermore, the authors conducted heterogeneity and cross-section dependency (CSD) tests, following the methodology of Pesaran and Yamagata (2008). Based on the results, the study rejects the null hypothesis that the slope coefficients of each variable in model are the same across countries. Instead, it accepts the alternative hypothesis that the slope coefficients differ among countries. As shown in Table 4, the variables FIN, GDP, GFI, INT, IVA, and TRO exhibits significantly different slope coefficients at the 5% confidence level.

Table 4 also shows the results of the CSD test, which indicate interconnections among ASEAN-5 countries in addressing carbon emission issues. This finding suggests that regional cooperation is essential, as carbon emission challenges cannot be effectively resolved if each country acts in isolation. Additionally, the GFI and FIN variables are significant at the 5% level, indicating cross-country interdependence in green finance and fintech issues. Collaborative efforts among ASEAN-5 countries in these two areas could accelerate the reduction of carbon emissions. These findings are consistent with research by Udeagha and Ngepah (2023), who also identified interconnections among BRICS countries in their efforts to reduce carbon emissions.

After passing the classical assumption test, the analysis proceeds to the panel unit root test. This test aims to determine whether the panel data series (which includes both cross-sectional and time series dimensions) contains a unit root, indicating non-stationarity. Based on Table 5, four variables, COE, FIN, GDP, and GFI, are significant at different levels of significance. Other variables, such as INT, IVA, and TRO are significant only at the first differences or I(1). These results indicate that all variables reject the null hypothesis of the unit root test, meaning the data are stationary either at the level or first-difference form.

Table 3. Collinearity matrix and VIF

	lnCOE	**lnFIN**	**lnGDP**	**lnGFI**	**lnINT**	**lnIVA**	**lnTRO**	**VIF**
lnCOE	1							0.27
lnFIN	-0.029	1						0.20
lnGDP	0.010	-0.301	1					1.52
lnGFI	-0.141	-0.578	0.325	1				1.26
lnINT	0.242	-0.063	-0.085	-0.289	1			0.52
lnIVA	-0.177	0.639	0.039	-0.294	-0.158	1		0.47
lnTRO	0.760	-0.203	-0.452	-0.051	0.208	-0.485	1	1.01

Table 4. CSD and heterogeneity of slope coefficients

Model	**Delta**	
Model 1	15,631**	
Model 2	16,222**	
Model 3	19,152**	
Model 4	17,844**	
Cross-section dependence		
lnCOE	lnGDP	lnINT
8,432**	21,122**	15,211**
lnGFI	lnIVA	lnFIN
14,751**	13,898**	12,655**
lnTRO		
15,865**		

Note: **significant at 5% confidence level

Table 6 shows the results of the Kao-Residual and ADF Cointegration Tests, which are used to determine whether the error correction term (ECT) is equal to zero. If the ECT value is zero, it implies a long-term relationship between the independent and dependent variables in the model. The Kao Residual results show that all models have probability values below 0.05 ($p < 0.05$), indicating the presence of cointegration between the independent variables and carbon emissions. Similarly, the ADF test results support this conclusion, with p-values below 0.05. Based on these findings, the study proceeds to the CS-ARDL test to estimate both short-term and long-term effects between the variables.

The results of the CS-ARDL test, the main test in this study, are presented in Table 7. In the short term, almost all variables in each model significantly effect on carbon emissions. The only

Table 5. Unit root panel test

Variables	Trend and intercept level	First difference
lnCOE	-16.8489**	-
lnFIN	-4.2037**	-
lnGDP	-4.6871**	-
lnGFI	-5.2011**	-
lnINT	-0.5804	-1.9634**
lnIVA	-0.3071	-7.1746**
lnTRO	-1.3973	-7.9372**

Note: **significant at 5% confidence level

Table 6. Kao-Residual & ADF Cointegration Test

Variables	Kao residual		Augmented Dicky-Fuller	
	t-stat	prob.	*t*-stat	prob.
Model 1	-11.3105	0.0000	-12.8083	0.0000
Model 2	-11.2294	0.0000	-12.7062	0.0000
Model 3	-11.2838	0.0000	-12.7493	0.0000
Model 4	-2.20926	0.0000	-4.47750	0.0000

Table 7. CS-ARDL test results

Variables	Model 1	Model 2	Model 3	Model 4
Short Run				
ΔlnGDP	-0.4636**	-0.3433**	-0.3582**	-0.3574**
ΔlnGFI	-0.4367**	-0.3548**	-0.3694**	-0.4704**
ΔlnFIN	-0.2176**	-0.0912**	-0.0943**	-0.0298**
ΔlnINT		0.0308**	0.0331**	0.0307**
ΔlnIVA			0.0473**	0.2284**
ΔlnTRO				0.1753
Long Run				
lnGDP	0.3129**	0.3145***	0.3400***	0.3220***
lnGFI	-0.0192**	-0.0205**	-0.0186**	-0.0104**
lnFIN	-0.7212**	-0.8016***	-0.8523***	-0.7606***
lnINT		0.0136**	0.0159**	0.0220**
lnIVA			0.1049**	0.3054**
lnTRO				0.2893***

Note: ** significant 5%, *** significant 1%

exception is the trade level (TRO), which does not show a significant short-term effect. In the long term, however, all independent variables in all models have a significant influence on carbon emissions. These findings are particularly important for ASEAN-5 countries, as they highlight key factors affecting the achievement of long-term emission reduction targets.

The GFI variable, which represents the green finance proxy, has a significant influence on carbon emissions in ASEAN-5 countries. GFI refers to financial products, services, and investments that aim to support carbon emission reductions and promote the development of environmentally friendly products. In the context of ASEAN-5 countries, GFI has been shown to negatively affect carbon emissions, meaning that an increase in GFI is associated with a decrease in carbon emissions. Table 7 shows that the coefficients of GFI in both short and long term are significant at the 5% confidence level.

By facilitating access to capital, GFI can accelerate the adoption of green energy infrastructure in ASEAN-5 countries. This reduces dependence on fossil fuels and lower greenhouse gas emissions, ultimately improving air quality. GFI supports energy efficiency policies by providing financing for energy-efficient projects and technologies. These include investments in energy-efficient buildings, industrial processes, and transportation systems. Energy efficiency measures help reduce both energy consumption and greenhouse gas emissions, playing key role in enhancing environmental quality and reducing pressure on natural resources (Mahi et al., 2020).

GFI also contributes to biodiversity conservation and environmental protection in ASEAN-5 countries. Investments in initiatives aimed at conserving natural habitats, supporting wildlife conservation, and promoting sustainable agriculture help protect ecosystems, maintain biodiversity, and sustain ecological balance (Sun, 2022). By supporting activities such as organic farming, agroforestry, and sustainable land management, GFI helps mitigate deforestation, land degradation, and water pollution associated with conventional agricultural practices. Additionally, GFI supports programs and projects that strengthen climate resilience and adaptive capacity in ASEAN-5 countries (Meo & Karim, 2022).

Furthermore, fintech also has a significant influence on carbon emissions, both in the short and log term. Table 7 shows that the FIN variable has a significant effect at the 5% confidence level and carries a negative coefficient. This indicates that fintech can be leveraged to reduce carbon emissions. By promoting online banking, digital payments, and electronic documentation, fintech innovation help reduce paper consumption and deforestation. These changes contribute to forest conservation, lower carbon emissions from paper production, and reduce the overall waste generation. Additionally, fintech often employs modern cloud-based computing techniques, which are generally more energy-efficient.

Fintech can also reduce environmental impact and optimize resource use (Puschmann et al., 2020). Through digital banking, mobile payment solutions, and microfinance platforms, fintech empowers individuals and small businesses, particularly in underserved areas of ASEAN-5 countries, to participate in the formal economy. As financial inclusion expands, economic growth and sustainable development are both enhanced. Fintech also encourages green investments and the integration of environmental, social, and governance (ESG) factors into investment decisions through digital platforms and advisory robo-techs. Moreover, fintech facilitates investors access to sustainable investment opportunities such as renewable energy projects, green bonds, and socially responsible funds. This helps channel more capital into initiatives that support the transition toward a low-carbon economy.

The GDP variable exhibits a unique influence on carbon emissions. Based on Table 7, GDP has a significant influence on carbon emissions in both the short and long term. However, the direction of the influence varies over time. In the short term, GDP has a negative effect on carbon emissions, whereas in the long term, it exerts a positive effect. Among all variable analyzed, GDP also has the largest, indicating the strongest influence on carbon emissions.

This seemingly contradictory result is actually consistent with the conditions in ASEAN-5 countries. In many cases, economic growth leads to increased consumption of resources, including energy, water, minerals, and raw materials, which places significant pressure on the environment and result in resource depletion and ecological damage. For example, the expansion of mineral and fossil fuel extraction often causes soil erosion, habitat destruction, and water pollution. Similarly, rapid industrialization and economic growth contribute to higher levels of air and water pollution, especially where industrial waste discharge and wastewater treatment are poorly managed.

Economic expansion typically requires more land for infrastructure, agriculture, and urban development (Andrée et al., 2019; Q. Wang & Su, 2019). This often results in deforestation and habitat loss, which can destroy ecosystems, reduce biodiversity, and disrupt natural processes. Because forests act as carbon sinks, deforestation also leads to increased greenhouse gas emissions. Moreover, economic growth driven by carbon-intensive industries, such as coal-fired power plants and heavy machinery manufacturing, further exacerbates climate change.

At a certain stage of economic development, governments inevitably feel the need to control carbon emissions while continuing to accelerate economic growth, particularly in the medium to long term. this balance can be achieved through the implementation of several key policies, such as incorporating environmental considerations into national development plans to ensure that growth is sustainable, enforcing strict environmental regulations to control pollution, strengthening regulatory frameworks and monitoring systems to ensure compliance and accountability, promoting research and development in environmentally friendly technologies and innovations, and transitioning to sustainable development practices. By doing so, ASEAN-5 countries can better align economic growth with environmental protection, ensuring long-term sustainability and resilience. This finding aligns with the conclusion of Mikhaylov et al. (2020), who observed that the relationship between GDP and carbon emission follows an inverted U shape. In the short term, economic growth leads to increased carbon emissions, but as GDP continues to rise, emission gradually decline due to improved efficiency and cleaner technology.

The INT variable, which represents a combination of energy intensity and carbon emission intensity, also has a significant effect on carbon emissions. Energy intensity refers to the amount of energy required to achieve a specific economic output. According to Table 8, the INT is positive, indicating that an increase in energy intensity corresponds to an increase in carbon emissions. This result is consistent with the findings for the GDP variable, achieving a certain level of economy output often comes at the expense of environment health. However, in the long term, the INT coefficient is smaller than in the short term. This suggests that ASEAN-5 countries have gradually improved energy efficiency, particularly in reducing fossil fuel dependence while maintaining economic momentum. This reflects a transitional phase where, in the short term, there is a trade-off between economic growth and environmental degradation, but over time, these countries begin to decouple economic progress from carbon emissions.

This result is consistent with the findings of Adebayo et al. (2020), who identified a positive relationship between energy intensity and carbon emission levels. Based on this, several policy recommendations are proposed. First, international agreements, such as the Copenhagen Accord and the Paris Agreement on Climate Change, are crucial, binding, and effective because they provide a global forum for addressing carbon emissions. Second, a low-carbon development model can be realized through increasing the efficiency and optimizing energy consumption structures. This has important implications for future policies that should encourage the adoption of energy-efficient technologies and reduce the reliance on fossil fuels. Finally, initial cointegration results show that the energy intensity trends in ASEAN-5 countries are interconnected. This suggests that a uniform regional policy has yet to be implemented. Therefore, while each country must tailor policies to its own circumstances, regional cooperation and coordination are also necessary to achieve sustainable development with low carbon emissions (Nsubuga & Rautenbach, 2018; Ridwansyah et al., 2023).

The next variable is IVA, which refers to the additional value generated by a country's industrial sector. IVA has a significant positive effect on carbon emissions. This result is surprising, given that industrialization typically produces substantial pollution, including carbon emissions. Since industrialization is closely tied to GDP, countries striving for high-income status often pursue aggressive industrial policies, which in turn lead to increased carbon emissions (Amoah et al., 2024).

To encourage sustainable economic growth in the ASEAN-5, international alliances and partnerships are crucial. these alliances can support capacity-building, offer training programs, and foster research collaboration to develop and disseminate low-carbon solutions. Through partnership with international organizations, governments, and private sectors actors, ASEAN-5 countries can gain access to funding, knowledge, and technology transfers that support the transition to cleaner industrial practices.

However, ASEAN-5 countries face multiple challenges in reducing emissions and managing industrial growth. Investing in sustainable industrial development is particularly difficult due to the limited financial resources. Securing the capital required to adopt eco-friendly technologies is persistent barrier. To address these obstacles and bridge the financing gap, international cooperation and innovative financing mechanisms are essential (Allard et al., 2018).

The final variable analyzed is TRO, which represents the level of trade in the ASEAN-5 countries. Trade level refers to the difference between the value of exports and imports within a given year. Table 8 shows that trade level does not have a significant effect on carbon emissions in the short term. However, the long term, trade level has a significant and positive effect on carbon emissions.

Trade openness is a policy that enhances domestic production by enabling access to higher-quality inputs, more affordable and advanced technologies, and improved management practices. As a result, ASEAN-5 countries have increasingly liberalized trade, leading to higher volumes of both imports and exports. Several trade agreements have also been established, facilitating smoother exchange of goods and services. over recent years, ASEAN-5 international trade has grown rapidly. By encouraging industrialization and trade openness, economic growth can be achieved more sustainably. However, since the process unfolds gradually, the associated environmental impacts, such as increased carbon emissions, are more apparent in the long term.

Table 8. Causality test

Null Hypothesis	Obs	F-Statistic	Prob.
lnFIN-lnCOE	115	0.24092	0.0245
lnCOE-lnFIN		0.85452	0.3525
lnGDP-lnCOE	115	2.05800	0.0154
lnCOE-lnGDP		0.39446	0.0045
lnGFI-lnCOE	115	0.01750	0.0022
lnCOE-lnGFI		0.22396	0.0044
lnINT-lnCOE	115	3.79166	0.0444
lnCOE-lnINT		1.51273	0.0221
lnIVA-lnCOE	115	0.54658	0.0461
lnCOE-lnIVA		0.67456	0.4132
lnTRO-lnCOE	115	13.4628	0.0004
lnCOE-lnTRO		0.73788	0.3922

The next analysis presented is the Causality Test, the results of which are summarized in Table 8. The test reveals that there are causal relationships between the independent and dependent variables, either in a one-way or two-way direction. One-way causal relationships are observed in the in the following cases: fintech and carbon emissions, industrialization and carbon emissions, and trade levels and carbon emissions. This means fintech influences carbon emissions, but carbon emission does not affect fintech. Similarly, industrialization and trade levels influence carbon emissions, without reciprocal effects.

On the other hand, three variables demonstrate how two-way causal relationships: GDP and carbon emissions, green finance and carbon emissions, energy intensity and carbon emissions. In these cases, changes in GDP can lead to changes in carbon emissions, and vice versa. This support the earlier CS-ARDL findings, which showed that GDP's effect on carbon emissions changes direction between the short and long term. At certain points, high levels of carbon emissions may prompt stakeholders to curb economic activities, thereby impacting GDP. Similarly, mutual causality exists between carbon emissions and both green finance and energy intensity, indicating that each can influence the other over time.

To conclude the analysis, the author conducted a forecast of future carbon emissions from each ASEAN-5 country, as illustrated in Figure 2. The forecasting results appear relative consistent across countries: the blue line, which represents the central prediction, shows only a moderate increase in carbon emissions. However, Singapore's blue line is steeper than those of the other countries, indicating that Singapore is projected to be the most effective country in curbing carbon emissions in the future compared to the rest of the ASEAN-5 region.

If we consider the downward standard error, represented by the green line, it suggests that all ASEAN-5 countries have the potential to reduce carbon emissions in the future. even so, Singapore's green line remains the steepest among the ASEAN-5, Further reinforcing the notion that is better positioned to control emissions. With a status as a developed country and its adoption of advanced technologies, Singapore is more capable in expanding renewable energy use and increasing fossil fuel efficiency without disrupting economy growth. In contrast, the other ASEAN-5 countries, which are still developing, remain highly dependent on fossil fuels. These nations are at a stage where the complete elimination of fossil fuel use is not yet feasible, and they must gradually reduce their dependence over time. Finally, Figure 2 also include the red line,

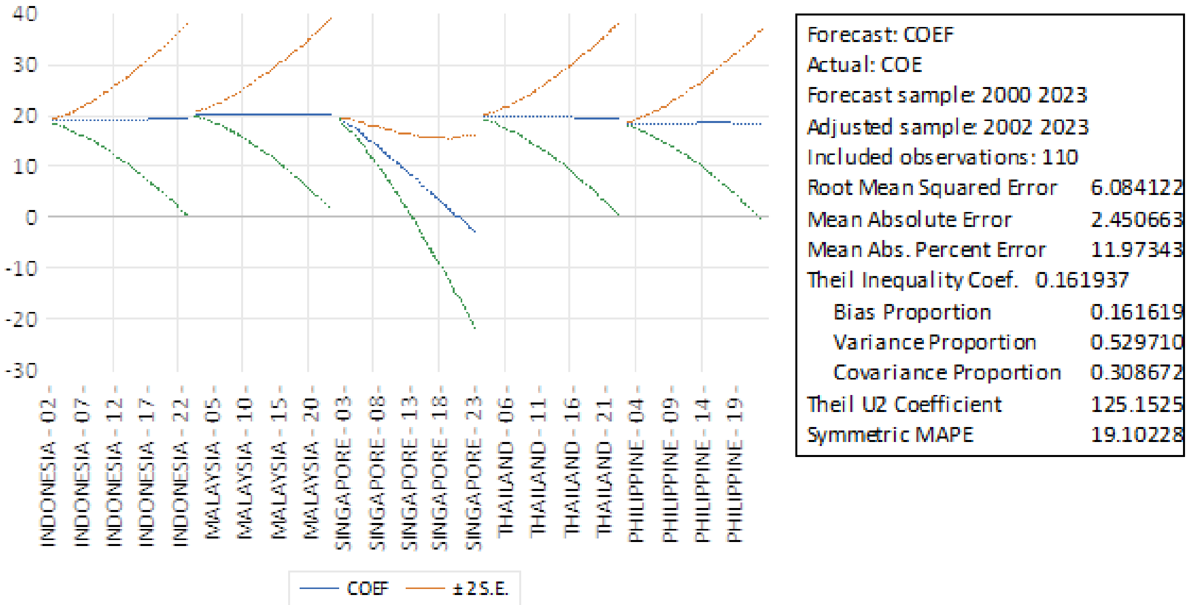

Figure 2. Forecasting COE of ASEAN-5 countries

representing the upper bound of prediction error, which suggests that all countries, without exception, may experience some increase in carbon emissions in the future. Once again, Singapore is projected to have the smallest or the most gradual increase, emphasizing its comparative advantage in managing environmental impact.

5. Conclusion and recommendation

This study underscores the significance of green finance and financial technology (fintech) in mitigating carbon emissions in the ASEAN-5 nations: Indonesia, Malaysia, Singapore, Thailand, and the Philippines. Green finance supports the funding of environmentally sustainable projects, including renewable energy and energy efficiency initiatives, which demonstrably reduce carbon emissions. Conversely, fintech contributes to mitigating environmental externalities through innovations such as digital banking and electronic payments, which enhance financial inclusion while diminishing paper usage.

Economic growth (GDP) exerts a dual influence on carbon emissions. While it may contribute to emissions reductions in the short term, especially with the implementation of sustainability policies, in the long term, unchecked economic growth can lead to increased emissions. Additional factors such as energy energy intensity, industrialization, and trade volumes also significantly impact emission levels in the region.

To effectively reduce carbon emissions, ASEAN-5 governments must strengthen the role of green finance by offering incentives for financial institutions to fund green projects, and by promoting fintech innovations that foster sustainable investment. The transition from fossil fuels to renewable energy must be accelerated through targeted subsidies and regulatory streamlining. Regional cooperation on cross-border technology transfer and joint policy formulation is also crucial. Moreover, policies that promoting the integration of clean technologies in the industrial sector and the advancement of sustainable urban planning should be reinforced to mitigate the adverse effects of industrialization and urban expansion.

Government should incorporate green finance and fintech into national development strategies to accelerate carbon emission reduction. Regulations frameworks that promote fintech and green finance will facilitate the adoption of green technologies within the financial industry. Through implementation these measures, the ASEAN-5 nations can fast-track the transition to a low-carbon, sustainable economy, and achieve their internationally recognized emissions reduction targets.

This study also identifies areas for improvement in future research. Specifically, some variables, such as GFI and INT, were constructed using PCA due to the lack of standardized numerical indicators. PCA was used to aggregate multiple related data points into a single representative metric. Although statistically valid, these constructed variables may not fully reflect the actual conditions of green finance and energy intensity in each country, as they essentially derived constructs.

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