Does financial efficiency modify CO2 emission? Using panel ARDL-PMG in the case of five selected ASEAN countries

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Abstract. Financial efficiency reduces carbon emissions by optimising resource usage, encouraging innovation and investment in low-carbon technology and solutions, and increasing transparency and accountability. This study examined the short- and long-term equilibrium relationships between CO2 emissions, financial efficiency, GDP, and energy consumption in five ASEAN nations from 1980 to 2020. Data stationarity was tested using the panel unit root test. The Autoregression Distribution Lag Pooled Mean Group (ARDL-PMG) model is best for empirical research because the data are long time series. The ARDL-PMG model shows that all variables affect CO2 emissions in the short term. Gross domestic product per capita and energy use affect CO2 emissions but not financial efficiency over time.

1 Introduction

Carbon dioxide emissions cause climate change, a global issue. Climate change increases sea levels, natural disasters, biodiversity loss, and food and water scarcity, endangering human health, the environment, and the economy. Energy efficiency, renewable energy, and carbon capture and storage reduce CO2 emissions. Energy efficiency, public transportation, and sustainable lifestyles can reduce carbon emissions. However, unlike wealthy nations, emerging countries' energy consumption has risen with economic expansion. Thus, legislators must balance energy, economic expansion, and environmental challenges [1]. Financial efficiency strategy is predicted to reduce CO2 emissions more. Financial efficiency is a company's capacity to cut expenses and boost earnings. Financial efficiency techniques can minimize the company's carbon footprint and greenhouse gas emissions. Investing in green energy sources like solar or wind power can lower energy prices and emissions. Putting a price on carbon and providing financial incentives for firms to cut emissions can also encourage emission reduction. As corporations reduce carbon expenses and maximize earnings, this can boost financial efficiency.

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Climate change, ecological degradation, and greenhouse gases (GHGs) have been major issues in economic and political policy in most developed and developing nations [2]. The goal is to understand and address how financial changes and other control variables affect CO_2 emissions. This goal connects with UN Sustainable Development Goal 13 (Climate Action) from 2015. This project aims to improve resilience and adaptability to natural disasters, integrate sustainable energy solutions into national policies, and raise awareness to combat climate change by 2030 (United Nations, 2015). Ironically, the primary GHGs continued to rise in 2021 and in the first half of 2022, according to a report by the World Meteorological Organisation (WMO). According to preliminary figures from the Global Carbon Project (GCP), worldwide CO_2 emissions for the first five months of 2022 (January to May) have been 1.2% higher than those for the same period in 2019, which was before the pandemic (United in Science 2022). The Association of Southeast Asian Nations (ASEAN) is concerned about climate change, given that Southeast Asia is recognised as one of the most susceptible regions to the impacts of global climate change.

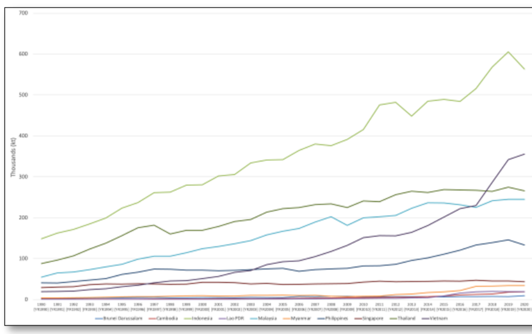

Fig. 1. Territorial carbon dioxide (CO_2) emissions in Southeast Asia from 1990 to 2020, by country (in thousands of kilo tons)

Figure 1 shows that all ASEAN countries' CO_2 emissions rose from 1990 to 2020. Indonesia emits the most CO_2 in ASEAN, over 600 million metric tons. Thailand had the second-highest CO_2 emissions till 2019, but in 2020, they dropped from 286 million to 256 million. Malaysia's CO_2 emissions grew to third behind Indonesia and Thailand from 1990 to 2019. Malaysia has the second-highest CO_2 emissions behind Thailand, jumping from 232 million to 273 million metric tons in 2019. Other ASEAN countries have similar challenges, but Laos, Myanmar, Cambodia, and Brunei have stagnated.

This study examines how financial efficiency, energy consumption, GDP, and CO_2 emissions affect Indonesia, Malaysia, Thailand, the Philippines, and Singapore. This work will benefit policymakers and boost scholarly knowledge. Financial efficiency impacts ASEAN CO_2 emissions in many ways. If financial resources are allocated to sustainable development, cleaner energy sources and technologies can minimize CO_2 emissions. However, improper financial allocation can encourage fossil fuel businesses to underinvest in renewable energy and energy efficiency. Additionally, financial efficiency can affect renewable energy project funding and clean energy technology investment, which can affect CO_2 emissions. Thus, the ways the ASEAN countries allocate and use financial resources may affect CO_2 emissions. However, government laws, technology improvements, and each country's economic progress may complicate the association of financial efficiency and CO_2 emissions. Hence, there is a pressing need for a comprehensive empirical study to ascertain the precise nature and magnitude of financial efficiency and CO_2 emissions on ASEAN countries. The following study sections are organized as follows. Section 2 reviews the scholarly research on the themes. Section 3 details the model, technique, and data used in this study. Finally, Section 4 discusses the results and estimated models. The study ends with a complete conclusion and various recommendations for further research.

2 Literature Review

2.1 CO_2 Emission

Many previous studies have been conducted to examine the factors contributing to reducing carbon emissions [1–11]. Among the most significant variables are energy consumption [10,12–14], foreign direct investment [4,9,15], economic growth [3,4,6,9,16], trade openness [6,17], financial efficiency and development [2,18–26] and many other variables. The Environmental Kuznets Curve (EKC) model is commonly utilised in conjunction with the examination of renewable-energy usage towards CO2 emissions and GDP [27]. Modern-growth theories have also emphasised the potential of technical advancements in guiding the economy towards an objective of sustainability [28]. For this study, the variables that have been chosen are energy consumption, financial efficiency, and economic growth to be further investigated.

2.2 Financial Efficiency

Most of the research done about the nexus between financial efficiency and CO2 emission has contributed various results. The development of a nation's financial industry has the potential to reduce investment costs associated with renewable-energy sources and promote their utilisation [5]. The study conducted by Hafeez et al. [5] on the examination of the connection of financial efficiency, eco-innovation, and CO2 emissions in highly polluted Asian economies, in which are the ARDL pooled mean group (ARDL-PMG) model was employed for this purpose, indicates that both financial-institution efficiency and the financial market have a positive and significant impact on CO2 emissions. However, financial development is insignificant in the CO2 emissions model for the same countries.

Numerous academics have proposed the presence of an inverse association on financial efficiency and CO2 emissions, which has been revealed by Rahman et al. [26] who have studied seventeen Asia-Pacific countries by using the Driscoll and Kraay's standard error and panel-corrected standard error (PCSE) models. The disparate influence of financial development and energy utilisation on carbon dioxide (CO2) emissions has been extensively explained over an extended period. In general, the results obtained by employing an irregular approach in China have underscored the importance of considering asymmetry when examining the association between CO2 emissions and macroeconomic indices. Additionally, the present study provides clarification on the inconclusive findings of preceding research about the positive effect of financial development on CO2 emissions. More crucially, the research has also suggested that in the context of China, the advancement of financial development plays a significant role in expanding environmental conditions by reducing CO2 emissions [24].

2.3 Gross Domestic Product

Other important areas of CO2 emission factors are economic development and rising energy consumption. The efficiency of the environment will suffer as a direct result of an increase in economic activities. Another finding in India, using the dynamic ordinary least square (DOLS) method, which has analysed environmental degradation, has added that economic development is accompanied by a decrease in the durability and usefulness of the environment [29]. Growth production is an often-overlooked facet of environmental management. Variations in the gross domestic product (GDP) have been assumed to be the primary driver of changes in CO2 emissions [27]. Consequently, maintaining a high level of economic growth may be an option for achieving the long-term goal of reducing CO2 emissions. Also, it has been discovered that GDP is the most significant SDG indicator having a unidirectional association with consumption-based CO2 emissions. This finding illustrates a direct association between economic growth and the need for energy, causing in a subsequent rise in CO2 emissions [26].

2.4 Energy Consumption

Energy consumption in power plants, cement factories, oil refineries, and gas-based industries contributes to environmental emissions. The autoregressive distributed lag (ARDL) approach confirmed co-integration among all time series variables. This co-integration lets us study how economic development and energy use affect the environment. [30]. Additionally, a large body of research has shown a positive link between energy use and CO2 emissions, meaning that higher energy use increases CO2 emissions [31,32]. However, a decrease in energy-intensive products and a reduction in CO2 emissions should result from an increase in energy imports. For the causal relationship result, Salahuddin and Gow [33] have found that bidirectional Granger causality runs from energy consumption to CO2 emissions. To clarify, increasing energy consumption increases carbon emissions.

The International Energy Agency has identified a significant increase in carbon dioxide CO2 emissions resulting from disorganised and inefficient energy consumption. This rise in emissions has led to ecological challenges that cannot be effectively addressed without collaboration between private and public entities [5]. A study done by Khalid et al. [34] has found that renewable energy consumption has substantial effects on CO2 emissions by using asymmetric nonlinear ARDL. The effect of economic development and energy consumption on long-term carbon dioxide emissions exhibits an uneven pattern. These findings have demonstrated the significance of taking asymmetry into account when examining the correlation between CO2 emissions and the macroeconomic variables. Meanwhile, Lahiani [24] has suggested that long-term CO2 emissions are affected asymmetrically by economic development and energy use. These findings have demonstrated the significance of taking asymmetry into account when examining the correlation between CO2 emissions and the macroeconomic variables.

3 Data and Methodology

This study incorporates several variables, namely CO2 emissions (measured in metric tonnes per capita), financial development index, financial institution efficiency, financial market efficiency, GDP per capita (constant 2015 US$), and energy use (measured in kilogrammes of oil equivalent per capita) in the countries of Indonesia, Malaysia, Singapore, the Philippines, and Thailand. The data spans the period from 1980 to 2020.

Table 1. Variables and Data Definition

Variable	Description
Carbon emissions (CO2)	Cement and fossil fuels emit CO2. Gas flaring and CO2 f solid, liquid, and gas fuels create them.
Financial efficiency	It is a compilation of data pertinent to the turnover ratio of the stock ma which is defined as the ratio of shares traded to market capitalization. The efficiency with which financial resources are distributed and employed w an economy.
Gross domestic product	It is an aggregate value contributed by resident producers in the econ encompassing product taxes and excluding subsidies that are not accour in the product value.

Energy use	It encompasses various factors, including domestic production, imports, alterations in stock levels, and exports, while excluding the provision of to ships and planes engaged in international transit.

To test data stationarity, unit root tests were performed. Hadri Lagrange Multiplier and Im-Pesaran-Shin (IPS) W are used. The HLM test is superior to conventional unit root tests since it includes panel data cross-sectional dependence. For each unit root process, the Im-Pesaran-Shin (IPS) W unit root test is included. Both tests assume stationarity with a unit root for the null hypothesis and stationarity without one for the alternative.

The cointegration of the variables has been tested for the empirical analysis using the ARDL pooled mean group (ARDL-PMG) combined test, which has superior qualities to the conventional cointegration methodologies. This is because the conventional cointegration test method is only appropriate for data sets with large sample sizes. Apart from that, their conclusions are very unstable when using data from a tiny sample size. In contrast, the ARDL bound test provides favourable characteristics for data from small samples.

$$CO2_{it} = \varphi_0 + \varphi_1 FE_{it} + \varphi_2 GDPpc_{it} + \varphi_3 EC_{it} + \varepsilon_{it} \quad (1)$$

In the following stage, the above specification has been rearranged in the form of the proposed error-correction modelling, which has changed Equation 1 into the ARDL-PMG model proposed by Pesaran et al. (1999) as explained below:

$$\Delta\, CO2_{it} = \varphi_0 + \sum_{i=1}^{p} \pi_{1k} + \Delta\, CO2_{it-i} + \sum_{i=2}^{p} \pi_{2k}\, \Delta FE_{it-i} + \sum_{i=3}^{p} \pi_{3k}\, \Delta GDPpc_{it-i} + \sum_{i=4}^{p} \pi_{4k}\, \Delta EC_{it-i} + \varphi_1 CO2_{it-1} + \varphi_2 FE_{it-1} + \varphi_3 GDPpc_{it-1} + \varphi_4 EC_{it-1} + \lambda . ECM_{it-1} + \varepsilon\_it \quad (2)$$

Panel data management procedures vary by cross-sectional count. ARDL-PMG is optimal for long-term data analysis in this investigation. This method captures short- and long-term effects, unlike others that solely catch long-term effects. Equation 2, shown above, clearly divides short- and long-run estimates into first-difference variables and -j2-4 estimates. However, if the ECM estimate (l) is sufficiently negative, cointegration among the expected long-run estimates must be proven. Another benefit of this approach is its ability to handle series integration characteristics and estimate model variables with I(0) and I(1) components. In addition, the Autoregressive Distributed-Lag Panel Mean Group (ARDL-PMG) method is useful when time series data is scarce. A short-term adjustment mechanism has helped integrate this dynamic model with serial correlation, endogeneity, and heteroskedasticity problems.

4 Findings

4.1 Panel Unit Root Test

The stationarity test of all variables should be done before estimating the dataset. If panel data variables are non-stationary, estimators are inefficient. The Im Pesaran Shin (IPS) test is a panel unit root test that is useful in determining the stationarity of a panel dataset. The main advantage of the IPS test is that it accounts for cross-sectional correlations, which are often present in the panel data and can lead to biased results if not properly addressed. The null hypothesis posits the presence of a unit root.

Table 2. Im-Pesaran Unit Root Test

AR parameter: Panel-specific	Asymptotics: T, N -> Infinity sequentially
Panel means: Included	

Time trend: Not included

ADF regressions: No lags included

Statistics			Fixed-N exact critical values p-value
Co2	Zt-tilde-bar	-1.3451	0.0893
FE	Zt-tilde-bar	-3.9174	0.0000
GDPPC	Zt-tilde-bar	-2.5727	0.0050
Energy	Zt-tilde-bar	-0.7431	0.0287

4.2 Hadri Lagrange Multiplier

The Hadri Lagrange multiplier, a first-generation panel unit root test model, has been modified to serve as a unit root test for panel datasets, enabling the assessment of the entire model. Based on the outcomes of the panel unit root test for the model shown in Table 2 above and Table 3 below, the p-values are all significant at the 1% level in both parts of the panel unit root methods: the common (the Hadri LM test) and the individual unit root (the IPS test). All variables in the study provide evidence to reject the null hypothesis of a unit root and support the alternative hypothesis of no unit root.

Table 3. Hadri Lagrange Multiplier Test

Time trend: Not included		Asymptotics: T, N	-> Infinity
Heteroskedasticity: Not robust			sequentially
LR variance: Not used			
	Statistics	p-value	
CO2	20.7549	0.0000	
FE	14.1919	0.0000	
GDPPC	34.5416	0.0000	
Energy	21.8995	0.0000	

This study has employed the panel ARDL technique to assess the impacts of financial efficiency, gross domestic product, and energy consumption economic towards CO2 emissions in the five selected ASEAN countries.

Table 4. Mean Group – Autoregressive Distributed Lag Approach (PMG-ARDL)

D.co2	Coefficient	Std. err.	z	P>z	[95% conf.	interval]
__ec						
FinEff	70.33603	46.41626	1.52	0.103	-20.63818	161.3102
Gdppc	.3555895	.1127859	3.15	0.002	.1345331	. 5766459
Energy	.3323958	.1036939	3.21	0.001	.1291595	.535632
SR						
__ec	-.3089479	.0989485	-3.12	0.002	-.5028834	-.1150123
DFinEff.	-33.01745	22.80987	-1.45	0.048	-77.72397	11.68907
DGdppc	.5233533	.4048554	1.29	0.196	-.2701487	1.316855
DEnergy	.0770879	.0250144	3.08	0.002	-.1261152	.0280606
_cons	1.094851	4.894267	0.22	0.823	-8.497736	10.68744

Based on our PMG-ARDL results, in the short run, our models have shown that all the variables significantly affect CO2 emissions. The development of efficiency in finance can lead to lowering down CO2 emissions. This finding is aligned with [33] whose findings support that financial development negatively affects carbon-emission intensity. The growth of GDPPC and energy consumption would lead to higher CO2 emissions [34]. In the context of long-term analysis, it is seen that there occurs a notable association among gross domestic product per capita and energy consumption with respect to CO2 emissions. However, it is worth noting that financial efficiency does not exhibit a similar level of significance in this regard, which aligns with the conclusions drawn by Hafeez et al. [7].

5 Discussion and Conclusion

This study aims to analyze and mitigate the effects of financial developments and other control variables on CO2 emissions. Besides the Environmental Kuznets Curve (EKC) model, which links CO2 emissions to GDP, modern-growth theories have stressed the potential of technological advances to direct the economy toward sustainability. Our findings clearly support these views. In addition to other variables, financial development affects short-term CO2 emissions. The causality effect of the variables utilized in the models may explain the study's principal weakness, which is the findings' inconsistency, especially over time. This topic should be examined more in the future. This work will contribute to the topic regarding green economics and green resources, which should adapt an economy to maintain the environment for sustainability directly and indirectly. Studying this field helps stabilize climate change, conserve ecosystems, promote sustainable development, international collaboration, human health, and reduce sea-level rise. In recent years, CO2 emissions have been emphasized. In recent years, net-zero emissions have also become a buzzword. This has happened because industrialized nations must reduce energy use to reduce CO2 emissions. In the future, researchers who want to continue the study should consider variable causality. Additionally, the general people should reduce their carbon footprint by using less energy, taking public transportation, and adopting sustainable habits.

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