Determinants of Electricity Consumption on The Green Economy Across Five ASEAN Countries: Singapore, Thailand, Malaysia, Vietnam, and Indonesia

Maulida Dewi Pangestika[1*], Fatata A'izza Rosyada[2] , Fafurida[3], Fredericho Mego Sundoro[4]

[1,3,4] Faculty of Economics and Business, Semarang State University, Semarang, Indonesia
[2] Agro-Maritime Logistics, IPB University, Bogor, Indonesia

*E-mail: maulidadewi@mail.unnes.ac.id

Abstract. Electricity is a fundamental necessity that underpins all activities. This is evidenced by the rising trend in electricity consumption across various ASEAN countries, including Singapore, Thailand, Malaysia, Vietnam, and Indonesia. Renewable electricity is sourced from renewable natural resources and presents a viable alternative for sustaining electricity supply. This research analyzes the impact of renewable electricity consumption, gross domestic bruto, and foreign direct investment on carbon emissions. The analysis used in this research involves panel data regression analysis on the five ASEAN countries from 1990 to 2022. The research applies an Autoregressive Distributed Lag Model (ARDL) approach. The findings of this research offer crucial insights for policymakers and stakeholders, enabling them to utilize technological progress to achieve sustainable energy development. The research results show that GDP and electricity consumption have a significant influence in the long term, while electricity consumption also has a considerable impact in the short term.

Keywords: Renewable Electricity Consumption, Green Gross Domestic Bruto, Autoregressive Distributed Lag Model.

1 Introduction

The interconnections between Foreign Direct Investment (FDI), Gross Domestic Product (GDP), and renewable energy consumption in the contemporary global economy have become increasingly significant. This condition particularly shapes environmental outcomes such as CO2 emissions patterns. Considering the broader context, the ASEAN area compares five diverse countries: Thailand, Vietnam, Malaysia, Indonesia,

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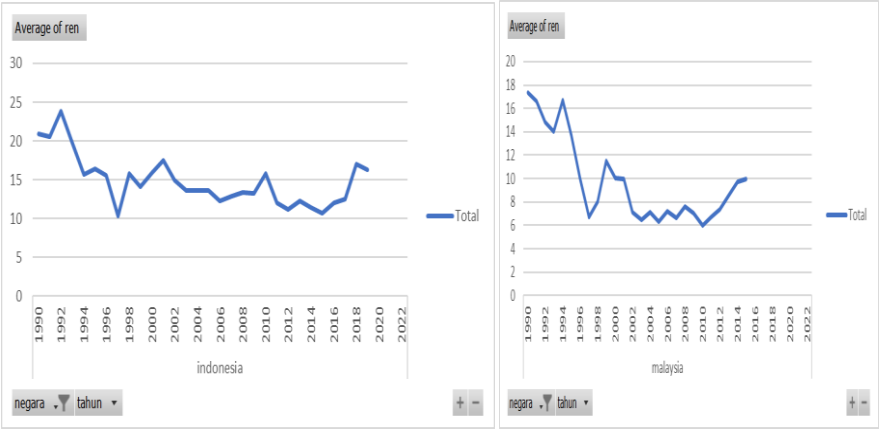
and Singapore. These nations represent a dynamic blend of emerging economies undergoing rapid industrialization and urbanization, making them ideal case studies for exploring the multifaceted effects of economic growth strategies on environmental sustainability [1], [2], [3].

Foreign Direct Investment (FDI) is an investment made by a company or individual in one country into business interests in another country. The key features of FDI are related to direct control by the investors, long-term commitment, and active management, including technology usage, expertise, and skill management. The consideration of FDI related to how international capital flows influence the production processes and energy consumption patterns within recipient economies, potentially leading to changes in CO2 emissions levels [4].

Gross Domestic Product (GDP)- understanding the correlation between GDP and CO2 emissions is essential for developing sustainable economic policies throughout the countries. GDP growth is often seen as a positive sign of a thriving economy, while it does not inherently account for the environmental costs associated with such growth. The essential features of GDP are related to the total market value of goods and services produced, final goods and services, period, and components: production, income, and expenditure [5], [6].

Renewable electricity is defined as electricity produced from sources of energy that can be naturally renewable in a relatively short period, such as sunlight, wind, water, biomass, and earth heat. This energy differs from fossil energy sources in that it does not drain limited natural resources and produces minimal or even zero greenhouse gas emissions during its production. (Kulagin et al., 2020). In addition, renewable electricity has the potential to improve energy sustainability and provide economic benefits through job creation and technological development. In many countries, the consumption of electricity has significantly increased shown by Figure 1.



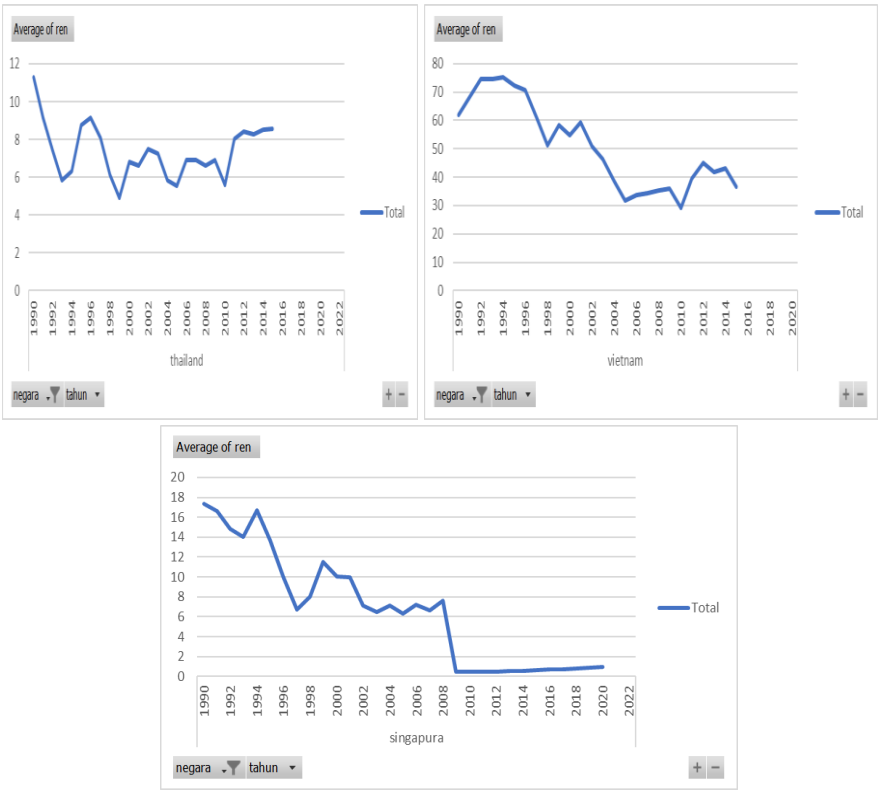


Figure 1. Consumption of electricity in countries ASEAN

As the world seeks to transition away from fossil fuels towards more sustainable energy sources, adopting renewable energy technologies offers a promising avenue for reducing CO2 emissions—countries prioritizing renewable energy consumption benefit from reduced environmental impact and foster a cleaner, more resilient economy. Integrating renewable energy into national energy mixes requires strategic planning and investment, highlighting the importance of aligning economic development goals with environmental sustainability objectives. [7], [8].

The research measured the impact over short- and long-term periods using the Autoregressive Distributed Lag (ARDL) model. This model estimates short-run and long-run relationships regardless of whether the variables are I(0) or I(1). This flexibility makes it particularly suitable for studying the impact of FDI, GDP, and REN consumption on CO2 emissions across different time horizons [9].

This manuscript evaluates the influence of Foreign Direct Investment (FDI), Gross Domestic Product (GDP), and renewable energy usage on CO2 emissions across brief and extended durations. This research considers the general theoretical foundation and empirical data. The analysis seeks to explain the complex associations among these variables and their consequential impacts on environmental degradation, mainly the evidence through CO2 emissions. [5], [10].

2 Method

This study uses a panel data approach to determine dynamic phenomena in a certain period. This study use five countries in ASEAN, including Singapore, Malaysia, Thailand, Vietnam, and Indonesia. Some countries have different economic values, ranging from the economy to natural resources, so researchers want to know the dynamic relationship between these variables. The study's independent variables were foreign direct investment, renewable energy consumption, and gross domestic gross. Carbon emissions are a dependent variable in this study, and data was used from 1990 to 2022. The research data model is explained as follows:

$$CO_2 = \beta_0 + \beta_1 REN_{it} + \beta_2 FDI_{it} + \beta_3 GDP_{it} + \varepsilon_{it} \quad (1)$$

This equation describes the cross section or the number of observations, while t is the year in this study. The advantage of the ARDL model is that in addition to looking at the dynamic side, ARDL has a flexible model in stationarity testing and does not require a large sample in the study. Here are the short-term ARDL models as follows:

$$CO_{2_{it}} = \beta_0 + \sum_{i=1}^{p} \gamma_i CO2_{t-i} + \sum_{j=1}^{q1} \delta_j REN_{t-j} + \sum_{m=1}^{q2} \varphi_m FDI_{t-m} + \sum_{r=1}^{q3} \mu_r GDP_{i-r} + \varepsilon_{it} \quad (2)$$

Meanwhile, the long-term ARDL model is as follows:

$$\Delta\, CO2 = \beta_0 + \sum_{i=1}^{p} \gamma_1 \Delta\, CO2_{t-i} + \sum_{j=1}^{q1} \delta_j \Delta REN_{t-j} + \sum_{m=1}^{q2} \varphi_m \Delta FDI_{t-m} + \sum_{r=1}^{q3} \mu_r \Delta GDP_{i-r} + \vartheta Z_{t-1} + \varepsilon_t \quad (3)$$

The difference between the two models lies in the Δ which symbolizes variable changes, as well as ε_tThe term error is for the short and long term. The long-term is more about the final impact of a variable relationship that has had adjustments in a specific time. The variables in this study are explained in Table 1. The table provides a detailed overview of the variables used in the study. So that measurement, data collection, and procedures are precise.

Table 1. Operational Definition of Research Variables

Symbol	Variable	Definition	Source
CO2	CO2 emissions	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide from solid, liquid, and gas fuels and gas consumption.	World bank
FDI	Foreign direct investment, net inflows	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an	Word bank

		enterprise operating in an economy other than the investor's. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital, as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors and is divided by GDP.	
GDP	Gross domestic gross	Annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for the depreciation of fabricated assets or for the depletion and degradation of natural resources.	Word bank
Ren	Renewable electricity output	Renewable electricity is the share of electricity generated by renewable power plants in total electricity generated by all types of plants.	World bank

Some stages that need to be considered in the ARDL model include stationary, cointegration, and bound tests to ensure that the ARDL model is feasible and best used in this study. The software in this study is e-views to help the data running process. Unit root tests are divided into groups: augmented Dickey-Fuller, Fisher Chi-Square, Philips Perron, etc. The hypothesis in this test has a probability value of less than 5% [11]. This model combines autoregressive (AR) and Distributed Lag (DL). The AR model is a model whose variables are influenced by past variables. [12].

3 Results and Analysis

The root unit test is used as an initial stage in the study to ensure stationary data. The root test of the unit is shown in Table 2. The researcher used the ADF (Augmented Dickey-Fuller test) and PP (Philips-Perron Test) unit root tests. The unit root test results showed that the CO2 variable was stationary at the level while the foreign direct investment, gross domestic gross, and stationary renewable electricity variables were at the first difference level. These findings imply using ARDL because the research data has flexibility over stationary.

Table 2 explains the estimation of the cointegration test results used to analyze whether a variable has a long-term influence. The test used in the ARDL model is the Johansen test, which is used so that each cross-section is separate. The results of the

cointegration test can be seen from the probability value. If the value is above the significance, then it has an influence on the long term, and the model is suitable for ARDL, but if it does not have cointegration, the model used is ECM.

Table 2. Unit root test.

Variables	ADF		PP	
	Level T-stats	1st Diff T-stat	Level T-stat	1st Diff T-stat
CO2	8,38103	56,1886	14,1974	91,5104
	(0,5917)	(0,0000)**	(0,1642)	(0,0000)**
FDI	21,9262	93,1380	31,7571	126,853
	(0,0155)**	(0,0000)**	(0,0004)**	(0,0000)**
GDP	51,3295	117,639	60,4875	99,7522
	(0,0000)**	(0,000)**	(0,0000)**	(0,0000)**
Ren	19,6803	54,6278	20,3389	89,8599
	(0,0324)**	(0,0000)**	(0,0262)**	(0,0000)**

Notes: statistical significance is indicated by ** at the 1% and 5%, respectively, intercept and trend to test all parameters.

Table 3. Summary of Johansen co-integrated test from max eigen test

Dep. Var	f-statistic	probability	result
None	66,16	0,0000	
At most 1	17,74	0,0595	No cointegration
At most 2	14,17	0,1656	No cointegration
At most 3	10,61	0,3891	No cointegration

Notes: significance is indicated ** at the 5%, respectively, intercept and trend to test all parameters.

Table 4. PMG ARDL estimation long-run

Variables	coefficient	t-statistic	Prob
	Long run estimation		
FDI	-0,025070	-1,234620	0,226
GDP	0,070389	3,847479	0,0003**
REN	-0,033117	-14,72890	0,0000**

Notes: statistical significance is indicated by ** at the 1% and 5%, respectively, intercept and trend to test all parameters.

Based on the results of the long-term ARDL estimate, it can be seen that foreign direct investment influences carbon emissions by 2.5%, where if there is an increase in investment by one unit, foreign direct investment will decrease. This means that foreign direct investment has a negative relationship and no significant effect. This is supported by research. [13]Other variables, such as renewable electricity consumption, have a negative coefficient, meaning that increasing sustainable electricity consumption will reduce carbon emissions by 3.31% and have a significant effect. This means that if there

is an increase in renewable electricity, carbon emissions will decrease significantly. This is due to the phenomenon that the addition of electricity consumption will reduce carbon emissions. This is by research, [14] It was explained that the economy could experience degradation and increase without energy innovation. For this reason, it is necessary to have the effect of technology to avoid pollution. This step helps reduce carbon emissions, and income levels will increase as the economy recovers. This is evidenced by the results of the long-term ARDL model estimation; economic variables have a positive coefficient, meaning that the more a country's economy increases, the more carbon emissions also increase by 7% and have a significant influence. This is in line with research [15].

This increase in electricity consumption will affect carbon emissions, especially electricity emissions produced from fossil energy that is more coal-fueled. To improve the efficiency of electricity use and reduce carbon emissions, the government requires low-power equipment, rotation of fuel quantities, etc. As a result, to support clean energy and reduce emissions, clean energy optimization needs to be implemented. [16]. This also aligns with the research results from long-term ARDL estimates that increasing renewable electricity influences carbon emissions. However, in its development, it may be more important to reconsider the strategy that will be implemented if it uses a sustainable economic transition with renewable electricity.

Table 5. PMG/ARDL short-run estimation

Variable	Coefficient	T-statistic	Prob
Short run estimation			
CO2	-0,085438	-1,954800	0,0561
ΔCO2(-1)	-0,022184	-0,220309	0,8265
ΔCO2(-2)	0,101143	0,552416	0,5831
ΔCO2 (-3)	0,122741	0,840025	0,4048
FDI	0,008776	1.567263	0.1232
ΔFDI (-1)	0.008776	1.567263	0.1232
ΔFDI (-2)	0.006367	1.184025	0.2419
ΔFDI (-3)	0.000491	0.141681	0.8879
GDP	-0.004242	-0.898333	0.3732
Δ GDP (-1)	-0.002203	-0.384960	0.7019
Δ GDP (-2)	-0.001710	-0.357982	0.7218
Δ GDP (-3)	-0.005007	-1.104469	0.2746
REN	-0.007861	-1.711685	0.0930
ΔREN (-1)	0.000139	0.099550	0.9211
ΔREN (-2)	0.002427	0.612430	0.5430
ΔREN (-3)	0.008108	3.113736	0.0030**

Notes: statistical significance is indicated by ** at the 1% and 5%, respectively, intercept and trend to test all parameters.

The regression results from the short-term estimates are comprehensively obtained based on the lag used in this study. The ARDL model is a model that looks at the dynamic pattern of the dependence of a variable. So, CO2T-1 emissions have a

negative coefficient value, meaning that the higher the emission value in 2021, the lower the carbon emission value in 2022, but this does not have a significant influence, as well as for carbon emissions in the previous year. Meanwhile, the foreign direct investment variable is pretty interesting because there has been an increase in foreign direct investment in the last 1-3 years, which will increase carbon dioxide emissions. Still, it has a small relationship. As for GDP, it has had a negative coefficient for the last three years, so the increase in the economy of a country will reduce carbon emissions, but this does not have a significant influence on the variable of renewable electricity consumption influences in the previous 3-year period that the more renewable electricity consumption increases, the more carbon emissions also increase, this has a significant effect.

The determination of lag in this study uses the Akaike Information Criterion (AIC), a statistical measure used on various regression models to determine lag to get the best model in balancing goodness of fit and simplicity. The following are the results of the AIC.

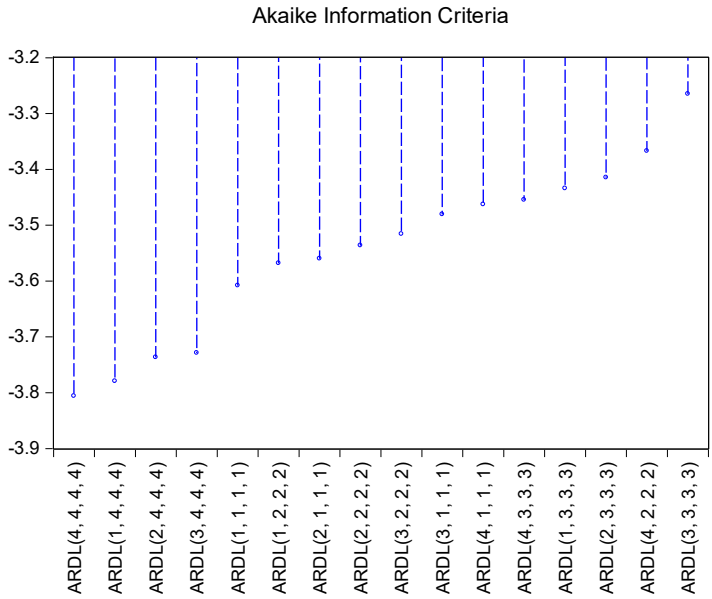


Figure 2. Akaike Information Criterion

The image shows a dot pattern with several lines and some lag values. The dots in the image show changes in the AIC value with varying amounts of lag. As for this study, it is necessary to pay attention to the lowest line at lag 4 to show the optimal model. So, the researcher uses lag 4.

The diagnostic model is a series of statistical tests used to evaluate the economic model that has been built. The purpose of the diagnostic test is to ensure that the model used does not violate the basic assumptions. Several tests need to be considered from the following table:

Table 6. Model diagnostic test

lags (p)	F	Df	Prob> F
Durbin – Watson stat			
			0,32838
Cameron Trivedi's decomposition of the LM test			
Heteroskedasticity	7,437607		0,0000
Skewness/kurtosis test for normality			
	Obs	Jaque-bera	Prob> chi2
	119	1,00637	0,6046

The results of the classical assumptions in this model use several tests, including normality, heteroskedasticity, and autocorrelation. The classical assumption test has a hypothesis that when the probability value is greater than the significant value, it is free from the classical assumption problem. In this model, heteroskedasticity and autocorrelation diseases are present.

4 Conclusion

This research examines the effects of foreign direct investment, gross domestic product, and electricity consumption on carbon emissions. The findings from the ARDL estimation, which integrates autoregressive (AR) components with distributed lags (DL), indicate that the application of this regression technique requires passing a unit root test to ensure different levels of stationarity and addressing issues related to cointegration. According to the results obtained from the ARDL model, in the long term, both the gross domestic product and electricity consumption variables significantly impact carbon emissions. However, in the short term, renewable electricity consumption emerges as the variable with a notable influence, as evidenced by estimates made in 2019..

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