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Efficiency Of Natural Resources And Carbon Dioxide In Asean-6

Cacak Rinunate[1*], Aliasuddin[2], Ernawati[3]

E-mail: cacak.rinunate@gmail.com, aliasuddin@feb.usk.ac.id, minaraqi@usk.ac.id
Universitas Syiah Kuala

ABSTRACT

This study analyzes the effect of natural resource efficiency, renewable energy, ICT, and economic growth on carbon dioxide (CO_2) emissions in ASEAN-6 countries, namely Indonesia, Malaysia, Thailand, the Philippines, Vietnam, and Singapore. This study uses panel data for the period 1990-2023 and is analyzed using the panel Autoregressive Distributed Lag (ARDL method to estimate the short-term and long-term relationships between variables. The results show that in the long term, natural resource efficiency and renewable energy tend to play a role in reducing CO_2 emissions, while ICT and economic growth show varying relationships depending on the economic structure and level of development of each country. In the short term, carbon emission dynamics are influenced by changes in economic activity, energy utilization, and the intensity of digital technology use. These findings provide an understanding that efforts to reduce carbon emissions in ASEAN-6 cannot rely on a single factor, but require synergy between increasing resource efficiency, accelerating the renewable energy transition, utilizing environmentally friendly ICT, and managing sustainable economic growth. Therefore, this study recommends strengthening integrated low-carbon development policies to support climate change mitigation commitments without hampering regional economic growth.

Keywords: CO2, Energy, Natural Resources, Technology, Economy

INTRODUCTION

Climate change has become an unavoidable global issue because it directly impacts human survival, ecosystems, and economic sustainability. The increase in Earth's temperature is largely triggered by the accumulation of greenhouse gasses released from human activities. There are various types of greenhouse gasses, such as carbon dioxide (CO_2), which have the most dominant influence on global warming. The Intergovernmental Panel on Climate Change (IPCC) report confirms that CO_2 contributes more than 70% of the total global greenhouse gas emissions. The selection of CO_2 as the focus of research is based on its most significant role in driving climate change compared to other greenhouse gasses such as methane (CH_4) or nitrous oxide (N_2O). Additionally, CO_2 has the closest relationship with economic activities and fossil fuel consumption, making it a key indicator in measuring the extent to which economic development contributes to environmental degradation (Daeli, 2024).

Economic progress in ASEAN continues to contribute to carbon emissions. This growth is driven by industrialization, increased international trade, and closer regional economic integration thru various regional agreements (Lim & Liu, 2024). However, this accelerated growth also brings about consequences such as increased energy consumption, dependence on fossil fuels, and a rising carbon emission rate. This situation makes the issues of energy efficiency and carbon emission reduction highly relevant to study in this region, especially since the ASEAN-6 faces a dual dilemma of maintaining high economic growth while fulfilling global

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commitments to sustainable development and climate change mitigation (Pangestu & Ayuningsasi, 2024).

Development in ASEAN-6 still heavily relies on the exploitation of natural resources, whether from fossil fuels or the mining and forestry sectors. The use of these resources often does not consider sustainability aspects, leading to environmental damage and an increased carbon footprint. The efficiency of natural resource utilization is still low, as reflected in the high energy intensity per unit of economic growth in most countries. This indicates the need for new strategies in resource management that are more wise and economical (He et al., 2025).

The concept of natural resource efficiency emerges as one of the important solutions in addressing this challenge. This concept emphasizes the importance of generating high economic output while minimizing the input of natural resources and energy used. Resource efficiency not only reduces production costs but also lowers the carbon emissions generated in the process. Thus, improving efficiency becomes the key to achieving low-carbon economic growth (González et al., 2025).

In addition to resource efficiency, energy transition is also a crucial factor in climate change mitigation efforts. The transition from fossil fuels to renewable energy has become an important agenda at both the global and regional levels. Renewable energy sources such as solar, wind, water, and biomass are seen as capable of providing sustainable energy while significantly reducing carbon emissions. In the ASEAN-6 region, the utilization of clean energy presents both an opportunity and a significant challenge amid the rising energy demand (Makhoukh et al., 2025).

Renewable energy has become one of the main topics in global development discussions due to its contribution to reducing carbon emissions. Energy sources such as solar, wind, water, and biomass are seen as capable of replacing the long-standing heavy reliance on fossil fuels. However, the transition to clean energy is not a simple process as it involves technological aspects, investment costs, and regulatory readiness. The potential of renewable energy is indeed abundant, but its utilization is often hindered by structural barriers (Hafdaoui et al., 2025).

In this context, information and communication technology or ICT plays an increasingly important role. ICT is no longer viewed merely as a communication tool, but rather as a key catalyst in driving energy efficiency and environmental management. Thru digital systems, energy data can be monitored in real-time, allowing potential waste to be identified and reduced immediately. In other words, ICT serves as a bridge between energy transition efforts and the effectiveness of its use (Lorente et al., 2025).

The presence of ICT in the energy sector opens up opportunities to enhance transparency and efficiency in resource management. For example, the implementation of smart grids allows energy distribution to become more adaptive according to existing needs and production capacity. This is very important in the context of renewable energy, which is fluctuating in nature, such as solar and wind power. Without ICT support, the integration of clean energy into the national system will face many technical challenges (Gholipour et al., 2023).

This ICT phenomenon highlights the need for an in-depth study on the dual role of digital technology toward the environment. ICT becomes an instrument to optimize energy efficiency and minimize emissions, but on the other hand, it also adds an energy burden from the digitalization sector. Thus, research on the relationship between ICT and carbon emissions is not only theoretically important but also crucial for public policy and development strategy (Wang et al., 2025).

Economic growth remains the primary indicator in assessing a country's economic performance. Economic growth is often used as a benchmark for development success, as it reflects the increase in the production of goods and services as well as the improvement in the welfare of the community. However, in the context of the environment, high economic growth does not always mean positive. The increase in economic growth is often accompanied by a rise in fossil fuel consumption and excessive exploitation of natural resources (X. Chen & Ding, 2023).

In the context of sustainable development, it is important to view economic growth not only as an indicator of economic growth but also how that growth impacts environmental quality. Development that focuses solely on economic growth without considering carbon emissions will incur significant social and ecological costs in the future. Thus, studies on the relationship between economic growth and CO_2 are becoming increasingly important to ensure a balance between growth and sustainability (Xu et al., 2024).

The interaction between economic growth, ICT, renewable energy, and natural resource efficiency has very important strategic implications in formulating low-carbon development policies. Economic growth that drives increased energy demand needs to be balanced with the utilization of renewable energy to avoid increasing carbon emissions. On the other hand, resource efficiency plays a role in reducing the wastage of production inputs, which often leads to increased emissions. ICT serves as a connector that enables production and energy systems to become more efficient and integrated. However, the relationships between these variables do not always show a unidirectional and consistent relationship across countries or over economic time periods (Uche et al., 2025). Therefore, an initial understanding of the dynamics and interrelationships between independent variables and carbon emissions in ASEAN-6 can be reviewed thru the movement patterns of each variable over time in Figure 1.

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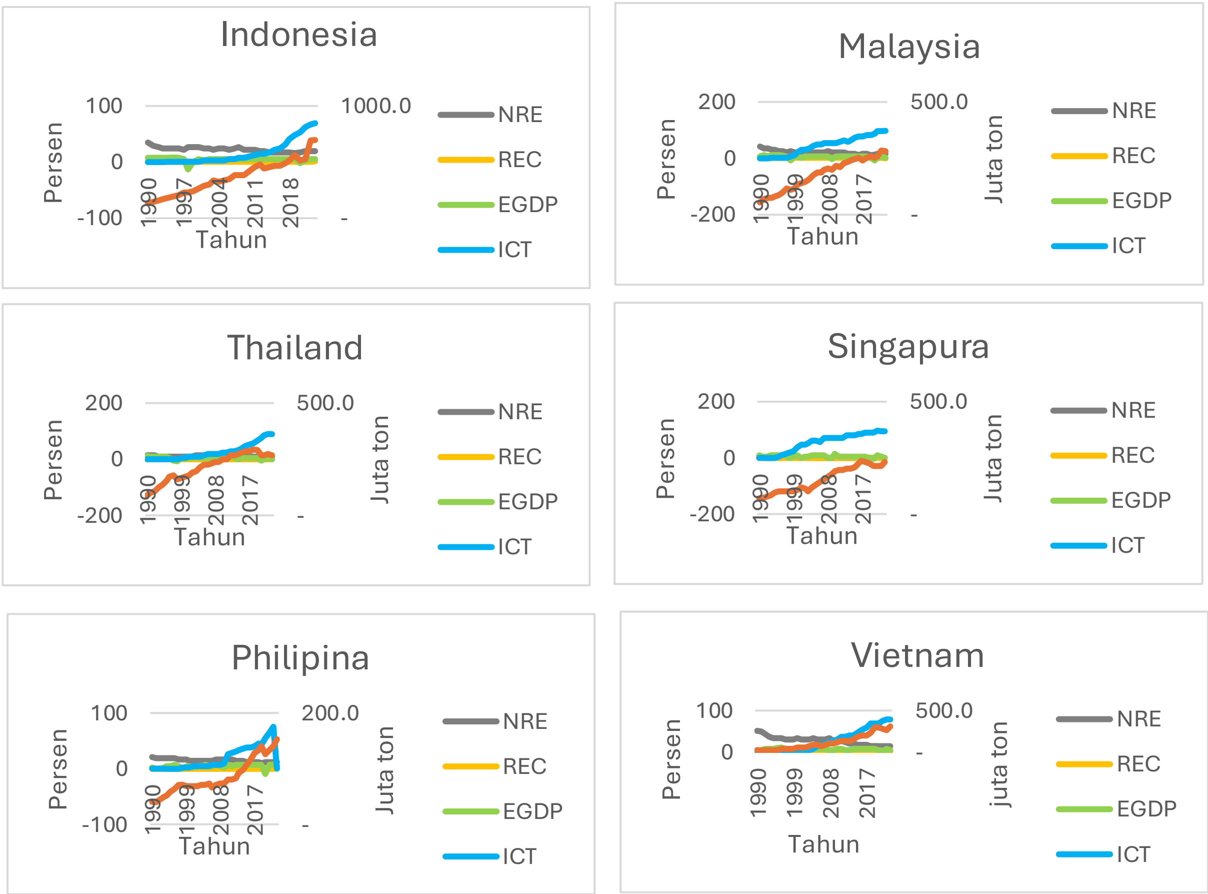

Figure 1 Graph of Natural Resource Efficiency, Renewable Energy, ICT, and Economic Growth Against Carbon Dioxide

Figure 1 shows that all countries experience increases and decreases in CO_2 emissions over time, but the rates and patterns differ. Vietnam and Indonesia stand out the most with a significant increase in emissions due to industrial development and economic growth, while smaller and more developed countries like Singapore show a slower increase and then tend to level off in the later period. The case of Vietnam shows that very rapid economic growth is closely related to the increase in CO_2 emissions, nearly doubling during periods of rapid growth.

Next, in the case of Indonesia in 2006, 2017, and 2020, the increase in natural resource efficiency was actually followed by an increase in CO_2 emissions. A similar phenomenon is also observed in other ASEAN countries such as Malaysia in 1999, 2004, 2007, 2009, and 2020, as well as in Thailand in 1994, 2002, 2004, 2007, and 2010. This condition shows that improvements in efficiency during certain periods do not always reflect a decrease in emissions, but rather can be accompanied by increased economic activity and industrialization that also drive up carbon emissions.

In the context of the relationship between energy and emissions, Figure 1 provides an overview of the dynamics of the energy transition in the ASEAN-6 countries. The increase in the use of renewable energy should lead to a reduction in carbon dioxide emissions, as these clean energy sources replace the role of high-emission fossil fuels. However, based on the empirical data presented, the phenomenon occurring in the ASEAN countries shows a relationship direction that is not entirely consistent with the theory. Although the proportion of renewable energy tends to increase year by year, CO_2 emissions do not always decrease; in fact, in some periods, they even rise simultaneously.

Meanwhile, the role of ICT has shown a very rapid increase since the early 2000s in almost all countries. This increase reflects the growth of digital infrastructure such as data centers and communication networks, which on one hand has the potential to increase energy consumption. However, on the other hand, digitalization also allows production processes and economic activities to become more efficient, replacing some physical activities, and potentially reducing carbon emissions in several sectors. Nevertheless, the increase in ICT shown in Figure 1 has not yet fully managed to curb the rate of carbon emissions increase, as the efficiency gains are still overshadowed by the growth of industrial activities and the overall increase in energy demand (Yu et al., 2023).

In addition to the dynamics of ICT, the economic growth pattern shown in Figure 1 indicates a trend of decreasing energy intensity in several ASEAN-6 countries, which means there is an improvement in terms of efficiency. In other words, each country is able to increase the level of production and economic activity with more efficient energy use compared to the previous period. This is in line with Sakipova's study which reveals that along with economic development and efficiency policies, energy consumption per unit of economy does indeed decrease. However, this decrease does not automatically mean that total emissions also decrease, especially if the scale of the economy and energy consumption broadly continue to increase (Sakipova et al., 2015).

METHODS

The scope of this research is the field of economics. In this study, the researchers analyze the relationship and impact of natural resource efficiency, renewable energy, ICT, and economic growth on carbon dioxide in the ASEAN-6, namely: Indonesia, Malaysia, Thailand, Singapore, the Philippines, and Vietnam. This research is a quantitative study using secondary data. The data used is annual data for the period from 1990 to 2023, totaling 33 years. With a review of all panel data amounting to 198 in six ASEAN countries, namely: Indonesia, Malaysia, Thailand, Singapore, the Philippines, and Vietnam. The data used in this study is panel data, which is a combination of time series data and cross-sectional data obtained from the World Bank.

The quantitative analysis method used in this research is the panel data regression method. Silvia (2019) argues that panel data is a combination of time-series data and cross-section data. This research uses secondary data from the World Bank and Our World In Data websites, from the years 1990-2023. The dependent variable in this study is carbon dioxide, while the independent variables are natural resource efficiency, renewable energy, ICT, and economic

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growth. In analyzing all these variables, this study uses panel regression analysis.With the following model:

$$\Delta CO2_{j,t} = \beta_0 + \sum_{i=1}^{n1} \beta_{1i}\mathrm{CO2}_{i,t-i} + \sum_{i=1}^{n2} \beta_{2i}\mathrm{NRE}_{i,t-i} + \sum_{i=1}^{n3} \beta_{3i}\mathrm{REC}_{i,t-1} + \sum_{i=1}^{n4} \beta_{4i}ICT_{i,t-1} + \sum_{i=1}^{n4} \beta_{5i}EG_{i,t-1} + \theta_1 CO2_{j,t-1} + \theta_2 NRE_{j,t-1} + \theta_3 REC_{j,t-1} + \theta_4 ICT_{j,t-1} + \theta_4 EGDP_{j,t-1} + \varepsilon_t \quad (1)$$

CO2 : Carbon Dioxide
NRE : Natural Resource Efficiency
REC : Renewable Energy
ICT : Information, Communication, and Technology
EG : Economic Growth
$\beta_1, \beta_2, \beta_3, \beta_4$: Short-term Coefficients
$\theta_1, \theta_2, \theta_3, \theta_4$: Long-term Coefficients
t : Year, specifically 1990-2023
j : 6 ASEAN Countries (Indonesia, Malaysia, Thailand, Singapore, the Philippines, and Vietnam)
I : Lag order
ε : Error term

This research uses the Autoregressive Distributed Lag (ARDL) approach model introduced by Pesaran et al. (2001) to test the existence of cointegration among variables and also to estimate the long-term and short-term coefficients of these variables. According to Pesaran (1997), the ARDL model is a neatly stored time series econometric model used in many sources to evaluate the relationship between climate and crops, especially when data is available at the macro level such as national, regional, or other countries (Sharma et al., 2024).

The short-term coefficients $\beta_{1,i}, \beta_{2,i}, \beta_{3,i,}\ \beta_{4,i}$ indicate the impact of changes with Δ of each independent variable on the change in carbon dioxide in the short term. This impact is calculated at a specific lag (i) to accommodate the delayed effects of the variables. The long-term coefficients $\theta_1, \theta_2, \theta_3, \theta_4$ describe the relationship between carbon dioxide and the independent variables in the long term. The independent variables at lag-1 (t-1) are included to observe the long-term effects of each variable on carbon dioxide.

Carbon dioxide data has been logarithmically transformed. This process is carried out to reduce the scale of large data and handle non-normal distributions, making the analysis more stable and the interpretation of coefficients more proportional. With logarithmic transformation, relative changes in air transport infrastructure can be analyzed more comparably against other variables.

This model is designed to identify how changes in various sectors, including natural resource efficiency, renewable energy, technology, and economic growth, affect carbon dioxide

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in six ASEAN countries (Indonesia, Malaysia, Thailand, Singapore, the Philippines, and Vietnam) during the period 1990–2023. The combination of short-term and long-term allows this research to evaluate both the direct impact and the cumulative effects of each variable.

It is very important to understand how much economic components influence each other in an increasingly unstable world. There are several factors, such as transportation infrastructure, urbanization, and ICT, that significantly impact a country's economic situation. This hypothesis is based on research that examines relevant economic facts and theories to test the relationship between short-term and long-term determined variables, the null hypothesis (H0) and alternative hypothesis (H1) can be analyzed as follows:

Table 1 Short-Term Hypotheses

H_0: there is no short-term effect	H_1: there is a short-term effect
$\beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = 0$	$\beta_{11} \neq \beta_{12} \neq \beta_{13} \neq \beta_{14} \neq \beta_{15} \neq 0$
$\beta_{21} = \beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = 0$	$\beta_{21} \neq \beta_{22} \neq \beta_{23} \neq \beta_{24} \neq \beta_{25} \neq 0$
$\beta_{31} = \beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = 0$	$\beta_{31} \neq \beta_{32} \neq \beta_{33} \neq \beta_{34} \neq \beta_{35} \neq 0$
$\beta_{41} = \beta_{42} = \beta_{43} = \beta_{44} = \beta_{45} = 0$	$\beta_{41} \neq \beta_{42} \neq \beta_{43} \neq \beta_{44} \neq \beta_{45} \neq 0$
$\beta_{51} = \beta_{52} = \beta_{53} = \beta_{54} = \beta_{55} = 0$	$\beta_{51} \neq \beta_{52} \neq \beta_{53} \neq \beta_{54} \neq \beta_{55} \neq 0$

However, to test the existence of the long-term influence of the hypothesis H_(0) and H_1, it is formulated as follows:

Table 2 Long-Term Hypotheses

H_0: there is no long-term effect	H_1: there is a long-term effect
$\emptyset_{11} = \emptyset_{12} = \emptyset_{13} = \emptyset_{14} = \emptyset_{15} = 0$	$\emptyset_{11} \neq \emptyset_{12} \neq \emptyset_{13} \neq \emptyset_{14} \neq \emptyset_{15} \neq 0$
$\emptyset_{21} = \emptyset_{22} = \emptyset_{23} = \emptyset_{24} = \emptyset_{25} = 0$	$\emptyset_{21} \neq \emptyset_{22} \neq \emptyset_{23} \neq \emptyset_{24} \neq \emptyset_{25} \neq 0$
$\emptyset_{31} = \emptyset_{32} = \emptyset_{33} = \emptyset_{34} = \emptyset_{35} = 0$	$\emptyset_{31} \neq \emptyset_{32} \neq \emptyset_{33} \neq \emptyset_{34} \neq \emptyset_{35} \neq 0$
$\emptyset_{41} = \emptyset_{42} = \emptyset_{43} = \emptyset_{44} = \emptyset_{45} = 0$	$\emptyset_{41} \neq \emptyset_{42} \neq \emptyset_{43} \neq \emptyset_{44} \neq \emptyset_{45} \neq 0$
$\emptyset_{51} = \emptyset_{52} = \emptyset_{53} = \emptyset_{54} = \emptyset_{55} = 0$	$\emptyset_{51} \neq \emptyset_{52} \neq \emptyset_{53} \neq \emptyset_{54} \neq \emptyset_{55} \neq 0$

- $H_1 : \emptyset_e \neq 0$ (The efficiency of natural resources and renewable energy has a negative impact on carbon dioxide in the long term).
- $H_1 : \emptyset_e \neq 0$ (Information and communication technology and economic growth have a positive impact on carbon dioxide in the long term).

RESULTS AND DISCUSSION

RESULT

The stationarity test ensures that the time series data has a consistent and varying mean over time. Analyzing regression results that contain spurious correlation is very important in ARDL analysis to ensure that the data set is at level I(0) and I(1). This study uses the Phillips-Perron (PP) method for the stationarity test because it is more accurate in addressing issues than the Levin or ADF methods, which are often used as a backup for unit root testing.

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Table 3 Stationarity Test

Variabel	Level		First Difference		Urutan integrasi
	Statistik	P-Value	Statistik	P-Value	
Carbon Dioxide (CO2)	101.012	0.0000	324.836	0.0000	I(1)
Efficiency of natural resources (NRE)	118.910	0.0000	99.4959	0.0000	I(1)
renewable energy (REC)	67.7966	0.0000	71.0174	0.0000	I(1)
ICT	50.9248	0.0000	48.6639	0.0000	I(1)
Economic Growth (EG)	81.4947	0.0000	73.5470	0.0000	I(0)

Source: Processed using Eviews 12 software (2025)

Table 3 shows the results of the stationarity test using the Phillips–Perron (PP) test at the level and first difference. At the level, the test results indicate that only one variable is stationary, namely economic growth. This indicates that the economic growth variable has a relatively constant mean and variance over time without the need for data differencing. Meanwhile, the other variables are not stationary at the level, indicating the presence of long-term trends or fluctuations in the data, which could potentially lead to biased estimation results if directly used in the regression model.

Next, at the first difference level, the results show that four variables have become stationary, namely carbon dioxide (CO_2) emissions transformed into natural logarithm form, natural resource efficiency, renewable energy, and information and communication technology (ICT). The differences in stationarity levels among these variables indicate that the research data consists of a combination of variables integrated at order zero I(0) and order one I(1). This condition meets the requirements for using the ARDL model, as ARDL can accommodate variables with different integration levels as long as there are no variables integrated at order two I(2). Thus, the use of the ARDL model in this study is deemed appropriate for analyzing the short-term and long-term relationships among the variables more comprehensively.

Cointegration Test

After ensuring that the data is statistically significant, the next step is to conduct the Pedroni analysis, which aims to assess the level of cointegration between variables that may not be statistically significant. To test the hypothesis that there is no cointegration, researchers must identify the appropriate regression model and consider the results on the statistical panel.

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Table 4 Cointegration test

Common AR coefs (within-dimension)	**Statistic**	**Prob.**	**Statistic**	**Prob.**
Panel v-statistic	6.629974	0.0000	4.301909	0.0000
Panel rho-statistic	1.303694	0.9038	1.465576	0.9286
Panel PP-statistic	-0.26271	0.3964	-0.03142	0.4875
Panel ADF-statistic	-0.99769	0.1592	-0.59818	0.2749
Common AR coefs (within-dimension)	**Statistic**		**Prob.**	
Panel rho-statistic	2.106097		0.9824	
Panel PP-statistic	-0.40189		0.3439	
Panel ADF-statistic	-1.06015		0.1445	

Source: Processed using Eviews 12 software (2025)

Based on Table 4, the results of the Pedroni cointegration test show that the panel v-statistic value has a probability of 0.0000, which is smaller than the significance level of 0.05. These results indicate that the null hypothesis stating the absence of cointegration can be rejected, thus it can be concluded that there is a long-term relationship between the variables in the research model. These findings affirm that changes in the independent variables have a structural relationship with the dependent variables over a long period.

Furthermore, the presence of cointegration indicates that the imbalances occurring in the short term are temporary and will undergo adjustments toward long-term equilibrium. This means that if there are deviations between the research variables due to economic shocks, policy changes, or other external factors, the adjustment mechanism will work to restore the relationship to long-term equilibrium conditions. Thus, the model used is not only capable of capturing short-term dynamics but also consistently explaining the long-term adjustment process, so that the estimation results can serve as a strong foundation in economic analysis and policy formulation oriented toward sustainability.

Optimal Lag Selection

Finding the optimal lag in the ARDL model is crucial for understanding the dynamic relationships between variables, both in the short term and the long term. In this process, a systematic approach to lag selection helps identify potential weaknesses in the long-term relationship, enhances the validity of cointegration tests, and analyzes the long-term relationship by comparing data with accurate lag selection.

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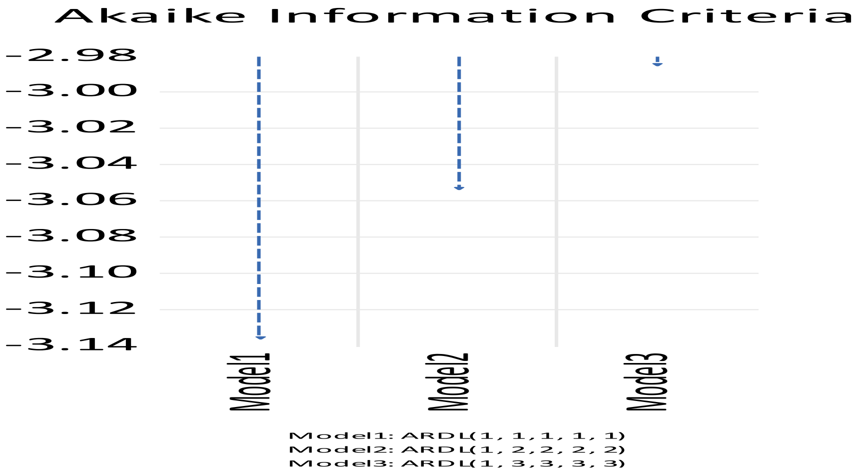

Figure 2 Optimal Lag Selection

Based on Figure 2 it shows the results of optimal lag selection based on three criteria of the Akaike Information Criterion (AIC). The Akaike Information Criterion (AIC) focuses on the model's accuracy in capturing data patterns by applying a relatively light penalty on the number of parameters, allowing for the selection of more complex models if they can significantly improve prediction accuracy. Based on the evaluation results, AIC indicates that Model 3 has the lowest value, meaning Model 3 provides the best balance between the ability to explain the data and the complexity level of the model used.

The lower AIC value in Model 3 confirms that this model is the optimal choice because it achieves superior predictive performance without posing a risk of overfitting, making it more effective than the other tested models. Thus, the selection of Model 3 as the best model based on AIC criteria aligns with the analysis goals that emphasize prediction accuracy and model structure efficiency.

Short-Term ARDL Estimation

The Error Correction Model (ECM) uses the concept of error correction to show how quickly economic variables can return to their initial point after experiencing changes or setbacks. These error elements often have negative coefficients, and their coefficients indicate the speed of adjustment of the variable in question. If the correlation is set to -1, the variable will return to normal faster, whereas if set to 0, the adjustment toward equilibrium will proceed more slowly.

Table 5 Short Term ARDL Estimation

Variabel	Coefficient	Std. Error	t-statistik	Prob.*
COINTEQ01	-0.04231	0.010472	-4.03993	0.0001
NRE	-0.0437	0.042763	-1.02197	0.3083
REC	-0.41944	0.385366	-1.08843	0.278
ICT	0.001355	0.000907	1.492966	0.1374
EG	-0.00017	0.001682	-0.09847	0.9217

*Note: * significance at the 5 percent level*

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Based on the short-term estimation results in Table 5 the value of the Cointeq01 coefficient is -0.042306 with a probability of 0.0001, indicating a valid adjustment mechanism toward long-term equilibrium. This negative and significant coefficient value indicates that any short-term imbalance will be corrected by 4.23 percent in one period, allowing the system to gradually return to long-term equilibrium.

The short-term estimation results show that not all independent variables have a significant impact on changes in carbon dioxide emissions. The efficiency of natural resources has a negative coefficient of -0.043702 with a probability of 0.3083, which means it has a negative but not significant effect on carbon dioxide emissions in the short term. This condition indicates that the utilization of natural resource efficiency in the short term has not yet been able to directly reduce CO_2 emissions, because the transition process requires time, significant investment, and adjustments in technology and supporting infrastructure.

The variable of renewable energy consumption also shows a negative but insignificant effect on carbon dioxide emissions with a coefficient of -0.419444 and a probability of 0.2780. This indicates that the increase in renewable energy consumption in the short term has not yet had a significant impact on reducing carbon emissions, which may be due to the still high dominance of fossil fuels and the limited capacity of clean energy to meet overall energy needs.

Next, information and communication technology (ICT) has a positive coefficient of 0.001355 with a probability of 0.1374, indicating a positive but not significant impact on carbon dioxide emissions in the short term. This condition reflects that the increased use of information and communication technology in the short term tends to raise energy consumption, particularly from data centers, telecommunications networks, and digital devices, potentially leading to an increase in carbon emissions before technological efficiency can be optimally achieved.

Meanwhile, economic growth has a negative coefficient of -0.000166 with a probability of 0.9217, which means it has a negative but not significant impact on carbon dioxide emissions in the short term. This indicates that changes in economic activity in the short term do not directly affect the level of carbon emissions, as the economic structure, energy intensity, and environmental policies take time to show their impact on emissions.

Long-Run ARDL Estimation

The long-run results between the independent variables and the dependent variable based on the ARDL model are as follows:

Table 6 Long Run ARDL Estimation

Variabel	Coefficient	Std. Error	t-statistik	Prob.*
NRE	-0.02767	0.026328	-1.05094	0.2948
REC	-5.24056	1.943895	-2.69591	0.0078
ICT	0.015637	0.003912	3.997382	0.0001
EG	0.183299	0.062837	2.917031	0.004

*Note: * significance at the 5 percent level*

Table 6 shows the long-term estimation results of the ARDL model between the independent variable and the dependent variable of carbon dioxide emissions with a significance level of 5 percent. The estimation results indicate that in the long term, natural resource efficiency has a coefficient of -0.027670 with a probability of 0.2948, which means it has a negative but

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statistically insignificant effect on carbon dioxide emissions. This indicates that an increase in efficiency in the utilization of natural resources tends to reduce carbon emissions in the long term. However, this effect is not yet significant, which may be due to the suboptimal implementation of resource efficiency practices, differences in technology levels between countries, and the still high dependence on carbon-intensive natural resource exploitation activities.

Then, renewable energy consumption shows a negative and significant impact on carbon dioxide emissions in the long term, with a coefficient of -5.240562 and a probability of 0.0078. These results indicate that a consistent increase in renewable energy consumption over the long term is capable of significantly reducing carbon dioxide emissions. These findings are in line with the energy transition theory, which states that the shift from fossil fuels to renewable energy sources such as solar, wind, and hydro can reduce dependence on high-emission energy sources. In the long term, the use of renewable energy also promotes energy efficiency, environmentally friendly technological innovations, and sustainable energy policies that directly impact the reduction of carbon emissions.

Long-term estimation results also show that the information and communication technology (ICT) variable has a positive and significant impact on carbon dioxide emissions, with a coefficient of 0.015637 and a probability of 0.0001. This indicates that the increased use and development of ICT in the long term actually drives an increase in carbon emissions. This condition can be caused by the increased consumption of electrical energy due to the expansion of digital infrastructure such as data centers, telecommunications networks, and electronic devices. Although ICT has the potential to improve economic efficiency, in the long term, the increased scale of technology use without being matched by clean energy sources can increase a country's carbon footprint.

Meanwhile, the economic growth variable shows a positive and significant impact on carbon dioxide emissions in the long term, with a coefficient of 0.183299 and a probability of 0.0040. These findings indicate that an increase in economic activity in the long term tends to raise carbon emissions. This is in line with the Environmental Kuznets Curve (EKC) theory in the early and middle stages of economic development, where economic growth is still dominated by energy-intensive and fossil fuel-based sectors. The increase in production, consumption, and industrial activities accompanying economic growth contributes to rising carbon emissions if not balanced by strict environmental policies and the use of environmentally friendly technologies.

Overall, the long-term estimation results show that the consumption of renewable energy plays an important role in reducing carbon dioxide emissions, while economic growth and ICT development tend to increase emissions. On the other hand, natural resource efficiency has the potential to reduce carbon emissions, although its impact has not yet been statistically significant. This underscores the importance of sustainable development policies that not only promote economic growth and technological advancement but also strengthen resource efficiency and the transition to clean energy in the long term.

CONCLUSION

Based on the analysis results using the Autoregressive Distributed Lag (ARDL) method, this study found that there is a long-term relationship between natural resource efficiency, renewable energy, information and communication technology (ICT), and economic growth on carbon dioxide (CO_2) emissions in ASEAN countries. The cointegration test results indicate that the variables in this study move together in the long term, so changes in one variable will affect the balance of carbon dioxide emissions over a longer period.

The estimation results show that natural resource efficiency has a negative but insignificant effect on carbon dioxide emissions both in the short term and the long term. This indicates that improvements in the efficiency of natural resource utilization have the potential to reduce carbon emissions, but the impact has not yet been statistically significant. This condition may be caused by differences in the capacity to manage natural resources among ASEAN countries, as well as the dominance of energy- and emission-intensive economic activities based on the exploitation of natural resources.

Furthermore, renewable energy shows a negative and significant impact on carbon dioxide emissions in the long term, although its short-term impact has not yet been significant. These findings indicate that the transition to renewable energy usage requires time before having a tangible impact on reducing carbon emissions. In the long term, the increase in renewable energy consumption has proven effective in reducing dependence on fossil fuels and lowering carbon dioxide emission levels in the ASEAN region.

The research results also show that information and communication technology (ICT) has a positive and significant impact on carbon dioxide emissions in the long term, while in the short term its impact is positive but not significant. This indicates that the rapid development of ICT can increase energy consumption, especially thru the use of digital infrastructure and data centers that still rely on fossil fuels. Thus, without support from clean energy, the development of ICT has the potential to increase carbon emissions in the long term.

Meanwhile, economic growth has a positive and significant impact on carbon dioxide emissions in the long term, although its impact is not significant in the short term. These findings indicate that the sustained increase in economic activity in ASEAN countries still tends to raise carbon emissions, in line with the Environmental Kuznets Curve (EKC) theory, where in the early and middle stages of development, economic growth contributes to increased environmental degradation.

REFERENCES

Albaker, A., Abbasi, K. R., Haddad, A. M., Radulescu, M., Manescu, C., & Bondac, G. T. (2023). Analyzing the Impact of Renewable Energy and Green Innovation on Carbon Emissions in the MENA Region. *Energies*, *16*(16). https://doi.org/10.3390/en16166053

Bach, P. X., & Cong, P. T. (2024). Toward sustainable development: Green economy with economic growth and carbon emission in Vietnam. *Journal of Infrastructure, Policy and Development*, *8*(3). https://doi.org/10.24294/jipd.v8i3.3111

Balsalobre-Lorente, D., Topaloglu, E. E., Nur, T., & Pilař, L. (2025). The management of environmental taxation, ICT, and financial development over the load capacity in advanced economies. *Journal of Environmental Management*, *392*. https://doi.org/10.1016/j.jenvman.2025.126878

Buehler, R., Pucher, J., White, P., & Currie, G. (2025). Public transport and the COVID-19 pandemic: A comparative analysis of trends and policies in Great Britain, Germany, the

USA, Canada, and Australia. *Transportation Research Part A: Policy and Practice*, *199*. https://doi.org/10.1016/j.tra.2025.104549

Bui Minh, T., Nguyen Ngoc, T., & Bui Van, H. (2023). Relationship between carbon emissions, economic growth, renewable energy consumption, foreign direct investment, and urban population in Vietnam. *Heliyon*, *9*(6). https://doi.org/10.1016/j.heliyon.2023.e17544

Chang, K., Liu, L., Luo, D., & Xing, K. (2023). The impact of green technology innovation on carbon dioxide emissions: The role of local environmental regulations. *Journal of Environmental Management*, *340*. https://doi.org/10.1016/j.jenvman.2023.117990

Chen, C., Pinar, M., & Stengos, T. (2022). Renewable energy and CO2 emissions: New evidence with the panel threshold model. *Renewable Energy*, *194*, 117–128. https://doi.org/10.1016/j.renene.2022.05.095

Chen, X., & Ding, H. (2023). Assessment of green economic development through the impacts of fossil fuels resources and education in China. *Resources Policy*, *85*. https://doi.org/10.1016/j.resourpol.2023.103910

Cheng, Q., Lin, A. P., & Yang, M. (2025). Green innovation and firms' financial and environmental performance: The roles of pollution prevention versus control. *Journal of Accounting and Economics*, *79*(1). https://doi.org/10.1016/j.jacceco.2024.101706

Daeli, I. S. (2024). Strategi mengurangi emisi gas rumah kaca untuk mengatasi konflik global akibat perubahan iklim. *Environment Conflict*, *1*(2), 72–82. https://doi.org/10.61511/environc.v1i2.2024.1176

Dash, A. K., Panda, S. P., Sahu, P. K., & Jóźwik, B. (2024). Do green innovation and governance limit CO2 emissions: evidence from twelve polluting countries with panel data decision tree model. *Discover Sustainability*, *5*(1). https://doi.org/10.1007/s43621-024-00418-9

Dong, F., Qin, C., Zhang, X., Zhao, X., Pan, Y., Gao, Y., Zhu, J., & Li, Y. (2021). Towards carbon neutrality: The impact of renewable energy development on carbon emission efficiency. *International Journal of Environmental Research and Public Health*, *18*(24). https://doi.org/10.3390/ijerph182413284

El Hafdaoui, H., Khallaayoun, A., & Al-Majeed, S. (2025). Renewable energies in Morocco: A comprehensive review and analysis of current status, policy framework, and prospective potential. In *Energy Conversion and Management: X* (Vol. 26). Elsevier Ltd. https://doi.org/10.1016/j.ecmx.2025.100967

Gholipour, H. F., Arjomandi, A., Andargoli, A. E., & Bennett, R. (2023). On real estate market transparency: The relationship with ICT trade and investment. *Land Use Policy*, *133*. https://doi.org/10.1016/j.landusepol.2023.106846

González, M. E., Barrios, N., Venditti, R. A., & Pal, L. (2025). Advancing sustainability in the U.S. pulp and paper industry: Decarbonization through energy efficiency, electrification, low-carbon fuels, and the social cost of emissions. *Journal of Cleaner Production*, *522*. https://doi.org/10.1016/j.jclepro.2025.146196

He, J., Zhang, P., & Lu, X. (2025). The risk-based environmental footprints and sustainability deficits of nations. *Ecological Economics*, *230*. https://doi.org/10.1016/j.ecolecon.2024.108501

Idroes, G. M., Hardi, I., Noviandy, T. R., Sasmita, N. R., Hilal, I. S., Kusumo, F., & Idroes, R. (2023). A Deep Dive into Indonesia's CO2 Emissions: The Role of Energy Consumption, Economic Growth and Natural Disasters. *Ekonomikalia Journal of Economics*, *1*(2), 69–81. https://doi.org/10.60084/eje.v1i2.115

Ju, W., & Jin, S. (2024). The impact of green innovation on the carbon performance of Chinese manufacturing enterprises: Moderating role of internal governance. *Heliyon*, *10*(10). https://doi.org/10.1016/j.heliyon.2024.e31272

Kafeel, K., Zhou, J., Phetkhammai, M., Heyan, L., & Khan, S. (2024). Green innovation and environmental quality in OECD countries: the mediating role of renewable energy and carbon taxes. *Environmental Science and Pollution Research International*, *31*(2), 2214–2227. https://doi.org/10.1007/s11356-023-31111-5

khaoula Aliani, Borgi, H., Alessa, N., Hamza, F., & Albitar, K. (2024). The impact of green innovation and renewable energy on CO2 emissions in G7 nations. *Heliyon*, *10*(10). https://doi.org/10.1016/j.heliyon.2024.e31142

Kumar Sharma, R., Dhillon, J., Kumar, P., Raja Reddy, K., Reed, V., Dodds, D. M., & Reddy, K. N. (2024). Modelling the climate change and cotton yield relationship in Mississippi: Autoregressive distributed lag approach. *Ecological Indicators*, *166*. https://doi.org/10.1016/j.ecolind.2024.112573

Li, J., Ji, L., Zhang, S., & Zhu, Y. (2024). Digital technology, green innovation, and the carbon performance of manufacturing enterprises. *Frontiers in Environmental Science*, *12*. https://doi.org/10.3389/fenvs.2024.1384332

Lim, K. Y., & Liu, C. (2024). Aid and developing regional integration. *International Review of Economics and Finance*, *93*, 756–776. https://doi.org/10.1016/j.iref.2024.05.002

Makhoukh, A., Redouane, A., Oubouch, N., & Hasnaoui, A. El. (2025). Optimizing off-grid energy solutions: a hybrid approach leveraging solar, wind, and biomass for sustainable development. *Global Energy Interconnection*. https://doi.org/10.1016/j.gloei.2025.05.008

Mehmood, F., Rehman, J., & Wasif, M. (n.d.). *Munich Personal RePEc Archive Impact of Energy Efficiency on CO2 Emissions: Empirical Evidence from Developing Countries*.

Regina Citra Kurnia Pangestu, & Anak Agung Ketut Ayuningsasi. (2024). Pengaruh Konsumsi Energi Sektor Industri, Rumah Tangga, dan Transportasi terhadap Emisi Karbon di Indonesia. *Inisiatif: Jurnal Ekonomi, Akuntansi Dan Manajemen*, *3*(4), 297–311. https://doi.org/10.30640/inisiatif.v3i4.3154

Sakipova, S., Jakovics, A., & Gendelis, S. (2015). Studies energy efficiency of the renewable sources use considering climate in Latvia. *Energy Procedia*, *78*, 1980–1984. https://doi.org/10.1016/j.egypro.2015.11.388

Szetela, B., Majewska, A., Jamroz, P., Djalilov, B., & Salahodjaev, R. (2022). Renewable Energy and CO2 Emissions in Top Natural Resource Rents Depending Countries: The Role of Governance. *Frontiers in Energy Research*, *10*. https://doi.org/10.3389/fenrg.2022.872941

Tian, J., & Qiu, W. (2025). Can green location-oriented policies promote substantive green innovation by enterprises? Evidence from China's National Eco-Industrial Demonstration Parks. *PLOS ONE*, *20*(6 June). https://doi.org/10.1371/journal.pone.0325666

Wang, C., Abbasi, K. R., Irfan, M., Ben-Salha, O., & Bandyopadhyay, A. (2024). Navigating sustainability in the US: A comprehensive analysis of green energy, eco-innovation, and economic policy uncertainty on sectoral CO2 emissions. *Energy Reports*, *11*, 5286–5299. https://doi.org/10.1016/j.egyr.2024.05.014

Wang, Y., Su, Z., Cai, X., & Yu, J. (2025). The dual carbon emission effects of digital economy: Evidence from China. *Heliyon*, *11*(4). https://doi.org/10.1016/j.heliyon.2025.e42554

Wei, W., & Ma, Y. (2024). The impact of green technology innovation on carbon emission reduction capacity in China: Based on spatial econometrics and threshold effect analysis. *PLoS ONE*, *19*(12 December). https://doi.org/10.1371/journal.pone.0310208

Xu, W., Sun, Z., & Ni, H. (2024). Transparency pays: How carbon emission disclosure lowers cost of capital. *Economic Analysis and Policy*, *83*, 165–177. https://doi.org/10.1016/j.eap.2024.05.020

Yu, M., Jin, H., Zhang, H., & Chong, A. Y. L. (2023). ICT, Financial Development and Renewable Energy Consumption. *Journal of Computer Information Systems*, *63*(1), 190–203. https://doi.org/10.1080/08874417.2022.2049017