Available online at
www.heca-analitika.com/eje

**Ekonomikalia
Journal of Economics**

Vol. 3, No. 1, 2025

CO_2 Emissions in ASEAN-5: The Role of Labor, Investment, Inflation, Exchange Rate, and Economic Growth

Sanny F. Lubis [1], Vivi Silvia [1,*] and Taufiq Carnegie Dawood [1]

[1] Department of Economics, Faculty of Economics and Business, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; sannylubis9@gmail.com (S.F.L.); vivisilvia@usk.ac.id (V.S.); taufiq.dawood@usk.ac.id (T.C.D.)

* Correspondence: vivisilvia@usk.ac.id

Article History

Received 10 February 2025
Revised 8 April 2025
Accepted 17 April 2025
Available Online 25 April 2025

Keywords:
Carbon emissions
Labor
Investment
Inflation
Exchange rate
Economic growth
ASEAN-5

Abstract

Labor and investment can raise emissions in the short term but may reduce them in the long term if energy efficiency improves. Inflation influences emissions through changes in energy prices and production costs. The exchange rate affects emissions by altering the cost of imported energy and green technologies. Economic growth generally increases emissions, especially in early development stages, as described by the Environmental Kuznets Curve (EKC) hypothesis. Given these linkages, this study examines the effects of labor, investment, inflation, exchange rate, and economic growth on CO_2 emissions in ASEAN-5 countries. To ensure robust findings, the study uses the Autoregressive Distributed Lag (ARDL) model and applies Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS) for dynamic estimations. Results show that labor, exchange rate, and economic growth do not significantly impact CO_2 emissions in the short term. However, investment and inflation have significant positive effects, indicating they contribute to short-term emission increases. In the long term, labor, investment, and inflation significantly reduce emissions, while the exchange rate remains insignificant. Economic growth, however, significantly increases emissions over time. This suggests that without strong environmental policies, continued economic expansion may lead to higher emissions. Overall, the findings highlight that structural factors like investment and economic growth are crucial in shaping CO_2 emissions. Policies such as carbon taxes or emissions trading systems can help internalize the environmental costs of emissions, encouraging a shift to cleaner energy and reducing fossil fuel dependence.

1. Introduction

The problem of industrial CO_2 emissions began when the use of fossil fuels such as coal and oil rapidly increased to support mass production [1]. As industries expanded, the environmental impact of CO_2 emissions became more apparent, prompting the introduction of regulatory policies like carbon taxes and emissions trading schemes [2]. These policies affect various aspects of economic activity, from labor markets to overall economic growth. Industries heavily reliant on fossil fuels face higher production costs, which may lead to workforce reductions as companies attempt to cut expenses. Conversely, investment is likely to shift toward the renewable energy sector, generating new job opportunities in green industries [3, 4]. Rising energy and production costs could also contribute to inflation, potentially eroding consumer purchasing power and placing additional financial strain on households [5].

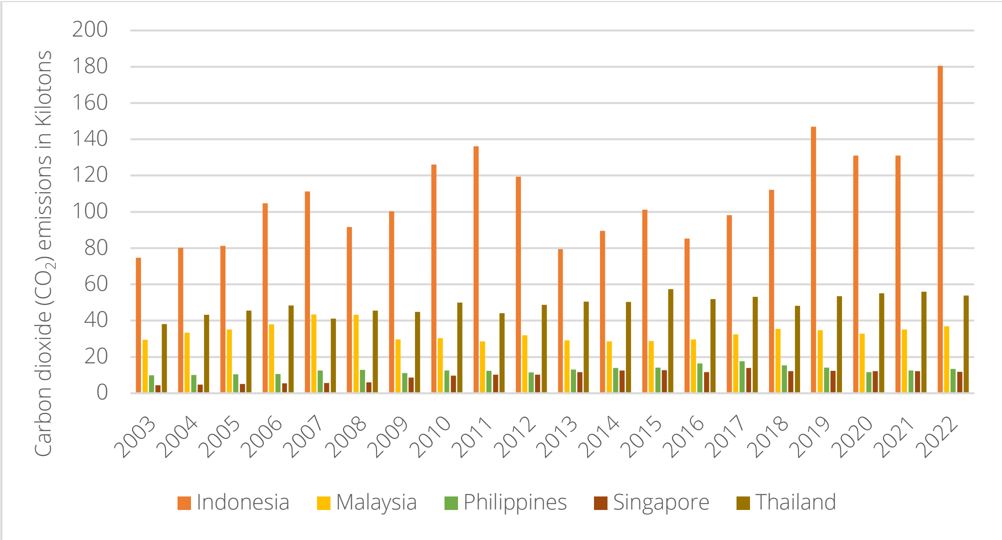

Figure 1. CO_2 emissions in ASEAN-5, 2003–2022.
Source: World Bank [6]

Additionally, the exchange rates of countries dependent on fossil fuel exports may weaken if global demand declines due to the transition to green energy [7]. However, in the long run, transitioning to a low-carbon economy can support more sustainable growth through technological innovation and improved energy efficiency. Energy use has diverse impacts, as its extraction and processing invariably cause environmental disturbances, including geomorphological and ecological damage, as well as pollution [8, 9]. Since all human activities rely on energy, all environmental impacts caused by humans can ultimately be traced back to energy use [10, 11]. The industrial sector, in particular, is linked to increased goods production, which frequently involves burning fossil fuels like oil, coal, and natural gas, which are major sources of CO2 emissions [12, 13].

An increase in the labor force often reflects greater production capacity, which in turn leads to higher energy consumption and carbon emissions. Foreign direct investment (FDI) is frequently directed toward the industrial sector, including plant construction, technology investment, and production expansion [14]. High inflation rates can reduce the competitiveness of the industrial sector, resulting in decreased production activity and lower emissions. Conversely, low inflation can stimulate increased production and energy consumption [15, 16]. Exchange rate depreciation may enhance export competitiveness but can also raise the cost of importing raw materials and green technologies, potentially slowing the adoption of low-carbon technologies [17]. Developing and industrializing countries typically experience rising CO_2 emissions as their economies grow [18, 19], with infrastructure development, increased industrial output, and greater energy consumption being the primary drivers [20, 21].

Figure 1 illustrates the trend of CO_2 emissions (in kilotons) from five Southeast Asian countries—Indonesia, Malaysia, the Philippines, Singapore, and Thailand—over the period from 2003 to 2022. Indonesia exhibits the most volatile and significantly increasing trend, particularly after 2015, with a sharp spike in 2022. Thailand shows a relatively stable but gradually rising pattern, while Malaysia experienced an increase up to 2008, followed by a gradual decline and stabilization. The Philippines displays a slow yet consistent upward trend. Singapore, with the lowest emissions among the five, has maintained a relatively flat trend, showing minimal improvement over the past two decades. Overall, Indonesia dominates the region's emissions in ASEAN-5, with a pronounced and persistent upward trend, likely due to its rapid industrialization and reliance on fossil fuels for energy production [22, 23].

The Philippines has experienced growth in capital stock, largely driven by increased foreign direct investment in recent years, particularly in the business process outsourcing (BPO), manufacturing, and real estate sectors. Despite these gains, the country's infrastructure remains underdeveloped. Initiatives such as the "Build, Build, Build" program aim to enhance infrastructure capital stock and support long-term economic growth. In contrast, Singapore, one of the wealthiest countries in ASEAN, has a high capital stock per capita. Major investments in modern infrastructure, information technology, and the financial services sector have significantly strengthened its productive capacity [24, 25]. As a regional hub for technology and innovation, Singapore has also made substantial investments in research and development, especially in high-tech, biotechnology, and finance. Thailand, with a well-established capital stock base, benefits from a robust manufacturing sector, particularly in automotive and electronics, and ongoing improvements in infrastructure through both public and private investments [15]. Additionally, investments in tourism and industrial infrastructure have reinforced Thailand's position as one of the largest economies in ASEAN [13, 26, 27].

From 2013 to 2022, average emissions from land use in Indonesia reached 930 million tons, accounting for 19.9 percent of total global land use change emissions [28, 29]. As a small but developed economy, Singapore has high per capita CO_2 emissions, primarily stemming from industry, transportation, and power generation using natural gas [5, 30]. Its role as a major trading and shipping hub further contributes to its emissions. Singapore has set a target to peak CO_2 emissions by 2030 and achieve carbon neutrality in the second half of the century. Its mitigation strategies include enhancing energy efficiency, investing in green technologies, and expanding solar energy use. Thailand, meanwhile, has increased investment in renewable energy, particularly solar and wind power. To boost the share of renewables in its energy mix, the country has committed to reducing greenhouse gas emissions by 20 percent from business-as-usual levels [31].

The economic growth theory developed by Solow [32] is a refinement of classical theory, with a primary focus on capital accumulation. The Solow growth model with environmental considerations is an extension of the original model that incorporates environmental variables as key factors in the long-term economic growth process [33]. In essence, this extended model recognizes that output growth (GDP) depends not only on capital, labor, and technology, but also on environmental degradation resulting from production activities—particularly carbon emissions.

In growth theory, the emphasis has traditionally been placed on primary inputs, particularly capital and land, while the role of energy in the growth process has received limited and often indirect attention. Primary energy inputs, such as oil reserves, are considered stock resources; however, they are not explicitly integrated into standard growth models, which primarily focus on labor and capital. Unlike capital and labor, which are reproducible, energy represents a non-reproducible factor of production. Although the energy vector (i.e., fuel) can be reproduced, the fundamental energy sources themselves are finite [34].

Environmental scientists and ecological economists have long emphasized the critical role of energy availability in driving production and economic growth. The first law of thermodynamics, or the law of conservation, underpins the principle of mass balance, asserting that producing a given material output requires at least an equivalent amount of material input, with any excess resulting in waste or pollution [35]. This highlights the unavoidable threshold of material inputs necessary to maintain output quality and quantity. Furthermore, the second law of thermodynamics, the law of efficiency, suggests that a minimum amount of energy is essential for transforming matter, as all production processes involve such transformations. As a result, the extent to which other production factors can substitute for energy is fundamentally limited. While some service-based activities may not involve direct material processing [36], this is largely a micro-level phenomenon; at the macroeconomic level, all economic activity requires indirect use of materials and energy, whether in sustaining labor or producing capital goods.

Capital and labor are treated as flows, representing the consumption of capital and labor services, rather than as stocks [37]. These flows are measured in terms of the energy use associated with them, and the total value added in the economy is viewed as the rent earned from the energy utilized within it [38]. Accordingly, the owners of labor, capital, and land are entitled to a share of the surplus energy generated [34, 39]. The overall production process in the economy can be modeled using an input-output framework, which determines the required quantity of each input needed to produce a given output, with each output potentially serving as an input in another production process [35].

Analyzing data on CO_2 emissions, inflation, investment, and other economic indicators provides a clearer picture of their direct and indirect impacts. Some investors may choose to withdraw from ASEAN markets if they perceive political risks or uncertainties that could hinder economic growth. Conversely, investors from countries supporting economic boycotts may find new opportunities. This could lead to the emergence of new projects aimed at strengthening economic independence across various sectors [40].

Shaari et al. [10] examined the impact of energy use, tourism, and foreign labor on environmental pollution in Malaysia, finding that the presence of foreign workers significantly affects carbon emissions. Similarly, Nguyen et al. [41] found that while FDI has a positive and significant effect on economic growth, while Sari & Dawood [14] economic growth itself negatively and significantly affects carbon emissions. In contrast,

Table 1. Variable description.

Status	Variable Name	Symbol	Variable Definition	Units	Data Sources
Dependent	Carbon Emissions	CO2	Carbon dioxide emissions, calculated using Global Warming Potential (GWP) factors, from industrial combustion (including energy sector subsectors), as well as from the manufacturing and construction industries.	Kiloton	World Bank [6]
Independent	Labor	L	Labor refers to the economically active population aged 15 to 64, encompassing all individuals who contribute labor to the production of goods and services.	Percent	World Bank [6]
	FDI	INV	Foreign direct investment (FDI) comprises the total of equity capital, reinvested earnings, long-term capital, and short-term capital.	Percent	World Bank [6]
	Inflation	INF	Inflation is measured as the annual percentage change in the average cost of consumer goods and services.	Percent	World Bank [6]
	Exchange Rate	EXR	The exchange rate refers to the value of a country's currency as determined by the foreign exchange market.	Dollars	World Bank [6]
	Economic Growth	EG	GDP at constant 2015 prices represents the sum of gross value added generated by all producers in the economy, adjusted for inflation.	Percent	World Bank [6]

research by Kambono & Marpaung [27] and Fitriady et al. [42] indicated that FDI has a positive and significant effect on GRDP, whereas domestic investment has a positive but statistically insignificant impact. Supporting this, Fathia et al. [43] concluded that foreign investment has no significant effect on CO_2 emissions in eight ASEAN countries, possibly because such investments already adopt environmentally friendly technologies and utilize renewable energy, thereby minimizing their environmental impact.

Yuliadi & Wardani [44] used panel data from 2010 to 2019 to analyze the social and economic factors influencing CO_2 emissions in selected ASEAN Economic Community (AEC) member countries. Their findings indicate that inflation has no significant effect on CO_2 emissions. In contrast, Suwandaru et al. [45] suggest that inflation can influence consumption patterns and economic activity, which may indirectly affect carbon emissions. However, the specific causal relationship between inflation and CO_2 emissions remains inconclusive and warrants further investigation. Wefielananda & Soetjipto [2] examined the indirect effects of exchange rate volatility on CO_2 emissions in eight ASEAN countries over the period 1990–2016. Research by Shi et al. [46], Infante-Amate et al. [28], and Suroso et al. [47] collectively shows that the pursuit of economic growth targets significantly increases total fossil fuel consumption and reduces energy efficiency at both the firm and industry levels. On the other hand, Balsalobre-Lorente & Leitão [48] found that renewable energy positively contributes to economic growth. Similarly, Amalina & Silvia [49] demonstrated that economic growth has a negative and significant effect on carbon emissions.

Most previous studies have primarily focused on one or two variables—such as the relationship between economic growth and carbon emissions—while overlooking the broader interplay of other critical factors. In particular, limited attention has been given to the roles of foreign labor and exchange rate dynamics. The research gap addressed in this study lies in the lack of comprehensive analyses that integrate the effects of labor, investment, inflation, exchange rates, and economic growth on CO_2 emissions, especially in the context of developing countries such as the ASEAN-5.

This study aims to examine the dynamic relationship between labor, investment, inflation, exchange rates, and economic growth with carbon emissions. Specifically, it tests the validity of the Environmental Kuznets Curve (EKC) hypothesis, which posits a non-linear relationship between economic growth and environmental degradation, and the Pollution Haven Hypothesis (PHH), which suggests that foreign investment may exacerbate pollution in countries with lax environmental regulations. This study contributes empirically by investigating whether economic growth in the ASEAN-5 follows the EKC pattern—where emissions initially rise with growth but decline after reaching a certain income threshold—and whether foreign investment leads to environmental degradation or facilitates the adoption of cleaner technologies. Based on the findings, this study also provides policy recommendations for achieving sustainable economic development without compromising environmental quality.

2. Materials and Methods

2.1. Data and Variables

This study employs time series data spanning from 2003 to 2022. The choice of this period reflects the availability of relatively complete and consistent data, which enhances the accuracy and representativeness of the model estimation results for economic and environmental conditions in the ASEAN region. Moreover, this time frame enables a long-term analysis of CO_2 emission trends, investment, and key factors such as inflation, exchange rates, and economic growth, all of which are relevant in the context of sustainable development policies. The study also utilizes cross-sectional data from five ASEAN countries: Indonesia, Malaysia, the Philippines, Singapore, and Thailand. As seen in Table 1, the variables examined include the labor force participation rate, total investment or foreign direct investment, inflation rate, exchange rate, CO_2 emissions, and economic growth. All data are sourced from the World Bank.

2.2. Research Framework

The foundational model of economic growth, developed by Solow [50], initially excluded natural resources entirely. Subsequent extensions incorporated non-renewable and renewable resources, as well as waste assimilation services. However, these extended versions have primarily been used in discussions of environmental sustainability rather than in mainstream macroeconomic applications. This study begins with the neoclassical perspective of the production function to examine the factors that may either weaken or strengthen the relationship between energy use and economic activity over time. The production function is generally represented in Equation 1.

$$(Q_1 \ldots, Q_M)' = f(A, X_1, \ldots, X_n, E_1, \ldots, E_P) \quad (1)$$

The relationship between energy and aggregate output—such as gross domestic product—can be influenced by various factors: substitution between energy and other inputs, technological advancements (i.e., changes in A), shifts in the composition of energy sources, and changes in the composition of output. Additionally, transitions in the mix of inputs, such as moving from a labor-intensive to a capital-intensive economy, can alter the relationship between energy consumption and output. While input variables can potentially affect total factor productivity (TFP), models that assume exogenous technological change typically exclude this interaction.

Schurr [51] was among the first to recognize the economic significance of energy quality, observing that the composition of energy use has shifted considerably over time. He argued that a transition toward higher-quality fuels reduces the energy required to generate a dollar of GDP. Ignoring this shift can lead to overestimating growth in TFP. Many scholars have further analyzed how much of the decline in energy intensity can be attributed to structural economic changes and a move toward higher-quality fuels.

In this study, the authors hypothesize that each independent variable may influence CO_2 emissions depending on the structural and policy context in ASEAN countries. Labor is expected to have a positive influence, as increased economic activity involving labor tends to drive energy consumption and emissions [52]. Investment is assumed to have a negative effect if directed toward green sectors and environmentally friendly technologies, but may have a positive effect if concentrated in energy-intensive industries [53]. Inflation can have a dual impact: high inflation may reduce energy consumption by weakening purchasing power [54], but it may also increase emissions if it stimulates domestic production of energy-inefficient import substitutes. The exchange rate could negatively impact emissions if depreciation encourages exports from emissions-intensive industries [55], but it may also reduce emissions by decreasing fuel imports. Economic growth is generally expected to increase emissions, consistent with the Environmental Kuznets Curve (EKC) hypothesis, which suggests that emissions initially rise with growth but decline after reaching a certain development threshold [56]. Based on these considerations, the authors developed a model to test the direction and magnitude of each variable's influence on CO_2 emissions.

2.3. Model Specification

Equation 2 applies the Autoregressive Distributed Lag (ARDL) method to analyze the short- and long-term effects of labor, investment, inflation, exchange rate, and economic growth on CO_2 emissions. In this model, the symbol Δ denotes the first difference of the variables, capturing short-run dynamics, while the coefficients denoted by φ represent long-term relationships. The Error Correction Term (ECT) is included to reflect the speed at which the dependent variable adjusts to restore equilibrium after a short-term disturbance. A significantly negative ECT coefficient confirms the presence of a long-run relationship among the variables and indicates how quickly the system corrects deviations from equilibrium.

$$\Delta CO2_{it} = \beta_0 + \sum_{j=1}^{q} \beta_1 \Delta CO2_{it-j} + \sum_{j=0}^{p} \beta_2 \Delta L_{it-j} + \sum_{j=0}^{p} \beta_3 \Delta INV_{it-j} + \sum_{j=0}^{p} \beta_4 \Delta INF_{it-j} + \sum_{j=0}^{p} \beta_5 \Delta EXR_{it-j} + \sum_{j=0}^{p} \beta_6 \Delta EG_{it-j} + \lambda ECT_{it-1} + \varphi_1 CO2_{it-1} + \varphi_2 L_{it-1} + \varphi_3 INV_{it-1} + \varphi_4 INF_{it-1} + \varphi_5 EXR_{it-1} + \varphi_6 EG_{it-1} + \varepsilon_{it} \quad (2)$$

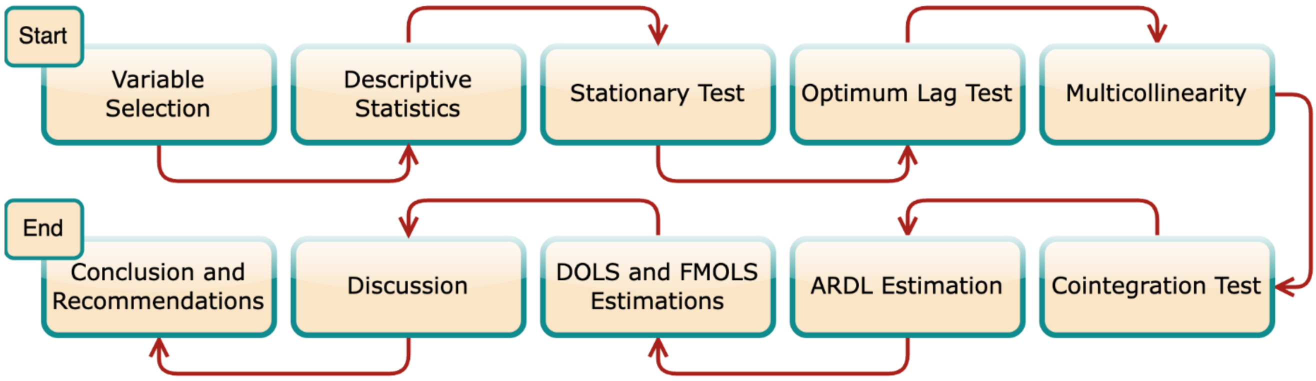

Figure 2. Research flow.

To complement the ARDL analysis, this study also employs Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS) methods to estimate long-run relationships, while addressing potential issues such as endogeneity and serial correlation. Both methods are applied to the following linear model, which is used to test the Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis, as shown in Equation 3.

$$CO2_{it} = \beta_0 + \beta_1 L_{it} + \beta_2 INV_{it} + \beta_3 INF_{it} + \beta_4 EXR_{it} + \beta_5 EG_{it} + \varepsilon_{it} \quad (3)$$

This equation captures the impact of labor, investment, inflation, exchange rate, and economic growth on CO_2 emissions, and is estimated using both DOLS and FMOLS techniques to ensure robustness and consistency of the long-run results.

2.4. Methods

The ARDL (Autoregressive Distributed Lag) model accommodates varying lag lengths between the dependent and independent variables. This approach is well-suited for estimating linear regression models and allows for the analysis of both short-run and long-run relationships among the variables considered in this study [4].

To complement this, the study also employs the DOLS (Dynamic Ordinary Least Squares) method, which enhances long-run estimation by incorporating lead and lag differences of the independent variables as additional regressors. This technique helps ensure consistent estimation of long-run coefficients, even in the presence of short-term disturbances [57]. Moreover, DOLS effectively addresses endogeneity issues—often present when explanatory variables are correlated with the error term—thereby reducing potential estimation bias [58, 59]. These adjustments make DOLS a robust method for producing reliable long-term results [36].

Additionally, the Fully Modified Ordinary Least Squares (FMOLS) method is applied to estimate the long-run relationship between the independent variables and CO_2 emissions within a cointegrated framework. FMOLS is specifically designed to correct for simultaneity bias and autocorrelation in cointegration regressions, yielding more consistent and efficient parameter estimates [60]. By addressing heteroskedasticity and serial correlation in the error terms, FMOLS offers greater robustness and reliability than conventional OLS methods in long-run estimations.

2.5. Research Flow

Figure 2 shows that the study begins by identifying the main variables: CO_2 emissions as the dependent variable, and labor (L), investment (INV), inflation (INF), exchange rate (EXR), and economic growth (EG) as independent variables. Annual data from 2003 to 2022 were collected from official sources such as the World Bank. Descriptive statistical analysis was first conducted to examine the basic characteristics of each variable, including the mean, standard deviation, and minimum and maximum values. Stationarity of the data was then tested using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, followed by lag selection based on the Akaike Information Criterion (AIC). A cointegration test was conducted to determine the existence of long-term relationships among the variables. The ARDL model was applied to estimate both short-run and long-run effects, and to ensure robustness, the study also employed Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS). The results from all three models were compared and interpreted, with particular attention to the magnitude and direction of each variable's effect on the dependent variable. The study concludes by presenting policy recommendations grounded in the empirical findings, aiming to inform decision-making and future research.

Table 2. Descriptive statistics.

Stat.	CO2 (Kiloton)	L (Percent)	INV (Percent)	INF (Percent)	EXR (Dollars)	EG (Percent)
Mean	42.7766	42.5778	6.21098	3.1325	2291.472	4.3857
Median	32.6239	42.1770	2.77718	2.8384	33.6266	5.0783
Max.	180.4691	52.2100	31.6207	13.1087	14849.85	9.7084
Min.	4.36360	30.1320	-0.9886	-1.1387	1.2497	-9.5183
Std. Dev.	38.3074	4.5737	8.3316	2.5414	4677.650	3.0348
Obs.	100	100	100	100	100	100

Table 3. Results of stationarity test.

Variables	*Level*		Conclusion	*1st Difference*		Conclusion
	Stat. ADF	*P-Value*		Stat. ADF	*P-Value*	
CO2	8.3188	0.5977	Non Stationary	65.705	0.0000*	Stationer
L	14.594	0.1476	Non Stationary	71.939	0.0000*	Stationer
INV	40.123	0.0000*	Stationer	67.309	0.0000*	Stationer
INF	28.086	0.0017*	Stationer	85.108	0.0000*	Stationer
EXR	9.8976	0.4495	Non Stationary	25.077	0.0052*	Stationer
EG	38.065	0.0000*	Stationer	68.772	0.0000*	Stationer

Note: * denotes significance level at 1%.

3. Results and Discussion

3.1. Descriptive Statistics

Based on Table 2, the descriptive statistics reveal that each variable in this study comprises 100 observations. The average CO_2 emission is 42,776 kilotons, with a median of 32,623 kilotons. The minimum value, recorded in Singapore, is 4,363 kilotons, while the maximum value, found in Indonesia, reaches 180,469 kilotons. The standard deviation of 38,307, which is lower than the mean, indicates relatively low variation in CO_2 emissions across the ASEAN-5 countries, suggesting that emissions levels are relatively similar. In terms of investment, Singapore records the highest rate at 31.62 percent, reflecting its dynamic economic environment and focus on productive sectors, whereas Thailand shows the lowest investment rate at -0.98 percent. The average labor force participation rate across ASEAN-5 is 42.57 percent, with Thailand having the highest at 52.21 percent and the Philippines the lowest at 30.13 percent. Inflation is highest in Indonesia at 13.1 percent, pointing to significant price increases that may affect purchasing power and the cost of living. Malaysia, on the other hand, recorded the lowest inflation rate at -1.13 percent. Regarding exchange rates, Indonesia had the weakest currency with 14,849 rupiah per USD, while Singapore had the strongest at 1.24 dollars per USD. Lastly, Singapore experienced the highest economic growth at 9.70 percent, whereas the Philippines recorded the lowest growth at -9.51 percent, particularly impacted by economic disruptions during the study period.

The proportion of jobs in the agricultural sector is declining in countries like Thailand and Indonesia due to increasing industrialization and urbanization. In contrast, Singapore and Malaysia are experiencing significant growth in the information and communication technology (ICT) sector, which is creating new employment opportunities. Investment in the ASEAN-5 region, primarily in physical capital, has contributed to increased emissions, indicating that foreign investment activity continues to grow each year and positively impacts production capacity. Singapore, with the highest level of investment, reflects the characteristics of a rapidly expanding economy, particularly through substantial investment in the production sector. Conversely, Thailand recorded the lowest investment level in 2020, largely due to the COVID-19 pandemic, which severely disrupted the tourism industry—a sector contributing around 12–15 percent of the country's GDP—resulting in reduced investment in hotels, restaurants, and related infrastructure.

Inflation across ASEAN-5 shows a general upward trend in prices, which is considered stable for emerging economies: not excessively high to erode purchasing power, yet not so low as to indicate weak demand. Indonesia experienced the highest inflation rate, signaling significant price increases above the regional average. Regarding exchange rates, Indonesia recorded the weakest currency at 14,849 rupiah per USD, while Singapore had the strongest at 1.24 Singapore dollars per USD. This disparity reflects the differing values of local currencies relative to the U.S. dollar, with Singapore's strong exchange rate typically associated with economic stability and low inflation. However, exchange rates alone do not directly reflect a country's prosperity. Finally, economic growth across ASEAN-5 peaked in Singapore and was lowest in the Philippines. The sharpest decline occurred in 2020, when the COVID-19 pandemic led to economic contractions across all five countries, with several recording negative growth rates that year.

Table 4. ARDL optimum lag.

Model	LogL	AIC	BIC	HQ	Specifications
4	-131.4275	4.6607	6.2983	5.3173	ARDL(4, 1, 1, 1, 1, 1, 1)
3	-150.9633	5.0241	6.5128	5.6209	ARDL(3, 1, 1, 1, 1, 1, 1)
2	-159.3764	5.1094	6.4493	5.6466	ARDL(2, 1, 1, 1, 1, 1, 1)
1	-169.1406	5.2285	6.4195	5.7060	ARDL(1, 1, 1, 1, 1, 1, 0)

Table 5. Results of cointegration test.

Test	Hypothesized No. of CE(s)	Fisher Stat. (from trace test)	Prob.	Conclusion
Johansen	None	75.07	0.0000*	Co-integrated
	At most 1	167.6	0.0000*	Co-integrated
	At most 2	80.65	0.0000*	Co-integrated
	At most 3	36.45	0.0001*	Co-integrated
	At most 4	22.14	0.0144**	Co-integrated
	At most 5	19.22	0.0375**	Co-integrated
Kao			0.0041*	Co-integrated

Note: * and ** denote significance levels at 1% and 5%, respectively.

Table 6. Correlation coefficient matrix.

Independent Variable	L	INV	INF	EXR	EG
L	1				
INV	0.462	1			
INF	0.322	0.262	1		
EXR	0.509	0.261	0.412	1	
EG	0.189	0.075	0.314	0.064	1

3.2. Stationarity Test

The stationarity test is conducted to determine whether the time series data used in the study have constant mean, variance, and covariance over time. This step is crucial because econometric models such as regression and cointegration rely on stationary data to ensure valid, consistent, and unbiased estimation results. If the data are non-stationary, regression analysis may yield spurious results. Therefore, non-stationary variables must be differenced or transformed to achieve stationarity before being included in the model. Based on the results presented in Table 3, the six variables in this study exhibit stationarity at different levels. Specifically, economic growth, investment, and inflation are stationary at level, whereas labor, exchange rate, and CO_2 emissions become stationary after first differencing.

3.3. Determination of Optimum Lag

Lag optimization is carried out to identify the appropriate number of lags for each variable in the model, ensuring that the resulting estimates are both accurate and efficient. Selecting an optimal lag length is essential, as too few lags may result in model misspecification, while too many can lead to overfitting and a loss of degrees of freedom. To address this, information criteria such as the Akaike Information Criterion (AIC) or the Schwarz Bayesian Criterion (SBC) are commonly used to guide the selection process. These criteria help ensure that the ARDL model effectively captures both short-run and long-run dynamics.

Based on the results presented in Table 4, the optimum lag structure selected using the AIC is ARDL (4, 1, 1, 1, 1), which corresponds to the lowest AIC value among the evaluated specifications. This means the dependent variable (CO_2 emissions) is lagged by four periods, while each independent variable—labor, investment, inflation, exchange rate, and economic growth—is lagged by one period. These selected lag lengths are applied in the ARDL estimation to accurately model the dynamic relationships among the variables.

3.4. Cointegration Test

The cointegration test is conducted to determine whether there is a long-term equilibrium relationship among the variables in the study. In this context, cointegration implies that while the variables may exhibit short-term fluctuations, they move together over time, maintaining a stable long-run relationship. A cointegration relationship is confirmed when the probability value obtained from the test is lower than the chosen level of significance, typically 5% (or 0.05).

As presented in Table 5, the results of the Johansen and Kao tests show that the probability value is below the 5% significance threshold ($p < 0.05$), leading to the rejection of the study's null hypothesis of no

Table 7. Results of ARDL estimation.

Variable	Coeff.	Std. Err.	t-Stat.	Prob.
Short Term				
COINTEQ01 (ECT_{-1})	-0.7555	0.2722	-2.7761	0.0080*
ΔCO2(-1)	0.5227	0.2530	2.0656	0.0447**
ΔCO2(-2)	0.0359	0.1803	0.1993	0.8429
ΔCO2(-3)	0.1792	0.1783	1.0049	0.3203
ΔL	0.2249	0.8803	0.2555	0.7995
ΔINV	1.2616	0.6363	1.9825	0.0535***
ΔINF	0.2889	0.1248	2.3156	0.0252**
ΔEXR	0.6774	2.7616	0.2453	0.8073
ΔEG	0.3322	0.3246	1.0235	0.3115
C	40.869	20.289	2.0144	0.0501***
Long Term				
L	-0.5033	0.0450	-11.178	0.0000*
INV	-0.9459	0.1498	-6.3152	0.0000*
INF	-0.5497	0.0779	-7.0540	0.0000*
EXR	0.0145	0.0250	0.5804	0.5645
EG	0.2949	0.0462	6.3797	0.0000*

Note: *, ** and *** denote significance levels at 1%, 5% and 10%, respectively.

cointegration. This indicates that the variables—labor, investment, inflation, exchange rate, economic growth, and CO_2 emissions—are cointegrated. In other words, the study finds statistical evidence of a long-term relationship among these variables.

The presence of cointegration is critical, as it suggests that despite short-term volatility, these variables are linked in the long run. This finding has important implications for policy-making, particularly in designing integrated economic and environmental strategies. It supports the formulation of long-term policies that aim to control carbon emissions while sustaining economic growth, ensuring that efforts to improve environmental quality are not made at the expense of development.

3.5. Multicollinearity Test

To detect the presence of a strong linear relationship between independent variables in the regression model, a multicollinearity test is necessary. High multicollinearity can cause the estimated regression coefficients to become unstable, leading to biased or unreliable results. This test is crucial to ensure that each independent variable makes a unique contribution to the dependent variable, making the interpretation of regression results more accurate and policies based on the model more effective. In Table 6, the correlation matrix shows that the correlation coefficient values are all below 0.85, indicating that there is no strong relationship between the independent variables and that multicollinearity is not a concern.

3.6. ARDL Estimation

The short-term ARDL estimation results aim to identify how changes in independent variables—such as labor, investment, inflation, and exchange rates—affect CO_2 emissions over shorter periods. This helps to understand the temporary dynamics and potential effects of economic policy volatility. In contrast, the long-term ARDL estimation results aim to analyze the equilibrium relationship between these variables over a longer period. By understanding this long-term relationship, policymakers can design more sustainable strategies to control carbon emissions without hindering economic growth.

The estimation results in Table 7 show that, in the short term, the adjustment mechanism (COINTEQ01) is significant, with a correction speed of 75.56% towards the long-term equilibrium. The CO_2 emissions variable in the first lag has a positive and significant relationship with current emissions, indicating that CO_2 emissions from the previous period positively influence emissions in the current period. Changes in CO_2 emissions from the previous two or three periods, however, do not have a strong enough relationship with changes in current emissions.

On the other hand, short-term changes in independent variables, such as investment and inflation, have a positive and significant relationship with CO_2 emissions. Specifically, a 1 percent increase in investment increases emissions by 1.2616 kilotons, and a 1 percent increase in inflation increases emissions by 0.2889 kilotons. Meanwhile, labor, exchange rate, and economic growth have no significant influence on current CO_2 emissions, with significance greater than 0.05 for each variable.

In the long run, labor has a negative and significant effect on CO_2 emissions. A 1 percent increase in labor reduces CO_2 emissions by 0.5033 kilotons, reflect greater labor

Table 8. Results of DOLS and FMOLS estimation.

Method	Variable	Coeff.	Std. Err.	t-Stat.	Prob.
DOLS	L	1.5786	0.1221	12.934	0.0000*
	INV	-1.3802	0.1465	-9.4197	0.0002*
	INF	-2.3240	1.3593	-1.7097	0.1480
	EXR	0.0072	0.0006	11.248	0.0001*
	EG	-4.8055	1.5417	-3.1170	0.0263**
FMOLS	L	1.0321	0.0241	42.843	0.0000*
	INV	-0.5099	0.0426	-11.964	0.0000*
	INF	-2.0586	0.0436	-47.205	0.0000*
	EXR	-0.0677	0.0239	-2.8294	0.0057*
	EG	-0.3419	0.0419	-8.1428	0.0000*

Note: * and ** denote significance levels at 1% and 5%, respectively.

efficiency or a shift towards more environmentally friendly sectors. Investment also has a negative and significant effect. A 1 percent increase in investment reduces emissions by 0.9459 kilotons, which may occur if investment is directed towards clean technology or green energy. Inflation has a negative and significant impact, with a 1 percent increase in inflation reducing CO_2 emissions by 0.5497 kilotons. This could be due to a decrease in production or consumption activity resulting from inflationary pressures. The exchange rate has no significant effect on emissions, with a small and insignificant coefficient ($p = 0.5645$). Economic growth has a positive and significant effect. A 1 percent increase in economic growth increases emissions by 0.2949 kilotons, reflecting the general pattern that economic growth drives emissions.

3.7. DOLS and FMOLS Estimation

In Table 8, the results from the DOLS and FMOLS analysis show that, in the DOLS analysis, an increase in the number of workers contributes to an increase in emissions by 1.579 kilotons. This can occur because production activities rise as labor increases. An increase in investment decreases emissions by 1.3802 kilotons, which may indicate that investment is directed towards environmentally friendly sectors or energy-efficient technologies. Inflation tends to reduce emissions by 2.3240 kilotons, likely due to price pressures that reduce consumption and production, although this effect is not statistically strong. An increase in the exchange rate (a weakening of the local currency) increases emissions by 0.0072 kilotons, possibly due to the encouragement of exports from carbon-intensive industries. Economic growth reduces emissions by 4.8055 kilotons, which may indicate a decoupling between economic growth and environmental degradation, possibly because the country is adopting cleaner technologies.

On the other hand, the FMOLS analysis concluded that an increase in labor increases emissions by 1.0321 kilotons, suggesting that economic activity involving labor remains carbon-intensive. Investment reduces emissions by 0.5099 kilotons, indicating that investment could support energy efficiency or the green sector. Rising inflation reduces emissions by 2.0586 kilotons, possibly because inflation suppresses production and consumption activities contributing to pollution. An appreciating exchange rate decreases emissions by 0.0677 kilotons, possibly because imports of clean technologies become cheaper or exports of carbon-intensive goods decrease. Economic growth leads to a 0.3419 kiloton decrease in emissions, indicating that countries may have reached a stage of cleaner or more sustainable growth (decoupling).

The estimation results from the long-term ARDL model, compared to the DOLS and FMOLS models, show a combination of consistency and inconsistency in the direction and significance of each variable's effect on CO_2 emissions. The L variable shows inconsistent coefficient directions. The difference in direction suggests that the ARDL model finds a significant negative impact, reflecting the role of labor in more environmentally friendly sectors or production efficiency, while the DOLS/FMOLS models show a significant positive impact, indicating that an increase in labor generally drives economic activity and energy consumption, which generates emissions.

INV shows a consistent negative and significant direction, suggesting that investments are being directed towards more energy-efficient or environmentally friendly technologies. INF consistently shows negative results but is only significant in the ARDL and FMOLS models, while in DOLS, it is insignificant, possibly due to the method's sensitivity to short-term fluctuations or multicollinearity. The EXR shows an inconsistent direction: insignificant in the ARDL model but positively significant in DOLS and negatively significant in FMOLS. This may reflect differences in how emissions respond to exchange rate depreciation in nominal versus real terms, or variations across countries. Meanwhile, EG shows inconsistent coefficient directions. The difference suggests that the ARDL model finds a significant positive impact, while DOLS and FMOLS show a significant negative impact. This is likely due to the different focuses of the models: ARDL is more sensitive to short-term dynamics and lag structures, capturing the early effects of economic expansion that increase emissions. In contrast, DOLS and FMOLS, which focus on the long term, show that over a longer horizon, economic growth actually reduces emissions, in line with the transition to cleaner technologies and production structures, as per the EKC pattern.

3.8. Discussion

The results show significant long-term and short-term relationships between CO_2 emissions and several economic activity variables. In the short term, the first lag of CO_2 emissions shows a significant positive effect on CO_2 emissions, while the second and third lags are insignificant. Investment has a positive and significant relationship, while inflation shows a significant positive effect on CO_2 emissions. Other variables, such as labor changes, exchange rates, and economic growth, have no significant influence in the short term. The constant in the model is significant at 5 percent, with a value of 40.86951, indicating the baseline value of CO_2 emissions under ceteris paribus conditions. This is similar to research by Jawad Sajid et al. [61], which shows that the labor force has a positive effect on CO_2 emissions, meaning that an increase in the number of workers tends to increase emissions. Arsyah & Yuwono [62] found that carbon emissions from increasing labor amounted to 1,610.635 kg CO_2 per job.

The study Cui et al. [63] found that a decrease in the unemployment rate, which reflects an increase in the labor force, is associated with an increase in carbon emissions. This is because less-skilled labor tends to work in high-emission sectors, thus increasing total carbon emissions. Research shows that firms with high emissions intensity tend to reduce labor demand in response to stricter environmental policies, while firms with low emissions intensity increase labor demand. This suggests a reallocation of labor that could affect overall carbon emissions [64, 65]. Research found that carbon emission reductions generally lead to significant job losses, suggesting that high-emitting sectors are still major employers. Therefore, an increase in employment in these sectors could increase carbon emissions. The study by Zheng et al. [66] analyzed data from 1960 to 2022 in China and found that inflation has a positive and significant impact on CO_2 emissions in the short term, meaning that an increase in inflation is associated with an increase in CO_2 emissions. However, this effect tends to diminish over time. This study by Musarat et al. [67] examined the Malaysian construction industry and found that a decrease in the inflation rate leads to a decrease in building material prices, which then increases construction activity and ultimately raises CO_2 emissions.

In the short run, the adjustment mechanism (COINTEQ01) is significant toward the long-run equilibrium when shocks occur. The CO_2 emissions variable in the first lag has a positive and significant relationship with current emissions, indicating emissions inertia, where past emissions patterns affect current emission levels. Investment shows a significant result, indicating the role of investment in economic activity that tends to increase emissions. This result is consistent with research by Santana & Maria [15] that finds foreign investment has a significant influence on carbon emissions in the ASEAN region. An increase in foreign investment by 1 billion dollars can reduce carbon emissions by 1.82 Mton, assuming other factors remain constant. This finding supports the Pollution Haven Hypothesis, which states that firms with foreign investment can move polluting technologies to countries with weaker environmental regulations. The same research by Jufri & Bahri [26] shows that an increase in Foreign Direct Investment (FDI) has a positive and significant effect on CO_2 emissions in the long run in ASEAN. Research by Munir & Ameer [68] states that an increase in foreign direct investment (FDI) has a positive and significant effect on CO_2 emissions in the long run. The results are similar to the findings of Pazienza [69], which show a positive relationship between FDI and CO_2 emissions in the manufacturing sector in the Organization for Economic Co-operation and Development (OECD).

Inflation shows a significant positive relationship with CO_2 emissions, which may reflect an increase in less efficient economic activity during periods of price pressure. This result is consistent with the study by Trianto & Pirwanti [70], which proves that inflation has a positive and statistically significant effect on CO_2 emissions. This result is also in accordance with the hypothesis supported by Faizah et al. [5], which states that if the state fails to maintain macroeconomic stability due to inflation, it will further exacerbate environmental damage. In addition, aggregate supply will fall due to an unstable economy, putting more pressure on natural preservation. Exchange rates have a positive and significant relationship, as supported by Wefielananda & Soetjipto [2], which found that trade between countries, influenced by exchange rates, plays a role in economic movement and impacts the environment. Their study revealed that while exchange rate volatility can reduce the value of both imports and exports, only a decline in imports has a significant impact on increasing CO2 emissions, likely due to a shift toward more emission-intensive production.

The results of the regression analysis show that, in the long run, labor, investment, inflation, and economic growth have a significant relationship with CO_2 emissions, while the exchange rate shows no significant effect. Labor shows a negative and significant relationship. This result may indicate that a larger labor force could support the transition to more environmentally friendly sectors or increased work efficiency. Investment shows a negative and significant relationship, suggesting that investment, especially in green sectors, plays an important role in reducing carbon emissions. The coefficient of inflation shows a negative and significant relationship, meaning that high inflation may reduce certain economic activities that contribute to carbon emissions, such as energy consumption. The exchange rate shows a positive and insignificant coefficient. Economic growth shows a positive and significant effect, in accordance with the research hypothesis and supported by Candra [71], which found that Gross Domestic Product and foreign investment have no significant effect on CO_2 emissions.

Labor has a positive and significant effect on carbon emissions in both methods (DOLS and FMOLS), indicating that an increase in labor goes hand in hand with an increase in carbon emissions. Investment has a negative and significant effect, indicating that an increase in investment decreases carbon emissions, possibly because investment is directed toward more environmentally friendly technologies. Inflation shows a negative coefficient in both methods, but in DOLS, it is not significant. In FMOLS, it is significant, suggesting that higher inflation may suppress carbon emissions, possibly through reduced economic activity. The exchange rate in DOLS has a positive and significant effect, while in FMOLS, it is negative and significant, indicating that the impact of exchange rates on emissions depends on the estimation method used. Economic growth has a negative and significant effect, supporting the Environmental Kuznets Curve (EKC) hypothesis, which suggests that after a certain point, economic growth can reduce carbon emissions.

4. Conclusions and Policy Recommendations

In the long run, labor in the ASEAN-5 has a significant negative effect on CO_2 emissions, but in the short run, labor does not show a significant effect on CO_2 emissions. Investment has a significant negative effect in the long run. Meanwhile, in the short term, investment shows a nearly significant effect. Inflation has a significant negative effect on CO_2 emissions in the long run. In contrast, in the short term, inflation has a positive and significant effect. The exchange rate in the long run has a positive but insignificant effect on CO_2 emissions. Meanwhile, neither the exchange rate nor economic growth shows a significant effect on CO_2 emissions in the short term. Economic growth in the long term has a significant positive effect on CO_2 emissions.

To reduce the negative impact of CO_2 emissions caused by economic activity, an integrated and sustainable policy approach is needed. First, the government can encourage labor efficiency by adopting low-carbon technologies in the production sector, thereby reducing the intensity of energy use without reducing productivity. In addition, green investment policies need to be strengthened, such as fiscal incentives for companies that adopt environmentally friendly practices or invest in renewable energy infrastructure. In the face of inflation, stable monetary policy should be accompanied by incentives for sectors supporting the circular economy, such as recycling and waste management, to reduce pressure on natural resources. On the other hand, economic growth should be directed towards environmentally friendly sectors by encouraging the transition to renewable energy and diversifying the economy into cleaner service sectors.

To ensure that economic activity does not exacerbate CO_2 emissions, governments can enact effective carbon taxes and establish carbon market mechanisms, where emissions can be traded as a commodity with strict maximum limits. In addition, exchange rate stability can be utilized to increase the export competitiveness of environmentally friendly products, thereby encouraging businesses to switch to more sustainable production methods.

The type of policy needed to explain and manage the relationship between variables in reducing CO_2 emissions must be multidimensional, encompassing interventions across different aspects of the economy. For example, the long-term negative relationship between labor and CO_2 emissions suggests the need for policies that promote labor efficiency improvements through green technology training and automation, which reduce reliance on carbon-intensive energy. Meanwhile, the negative influence of investment on emissions indicates the need for regulations that encourage investment in renewable energy and green technologies.

Fiscal policies, such as subsidies for clean energy or tax exemptions for companies innovating in emissions reduction, could amplify this effect. On the other hand, the positive relationship between economic growth and CO_2 emissions suggests the need for policies that direct growth to low-carbon sectors, such as information technology or financial services, which have smaller carbon footprints than heavy industry. To address the effect of inflation, price stabilization policies can be directed at controlling fossil energy consumption by raising the price of carbon-based energy, while providing incentives for the adoption of renewable energy. In addition, the exchange rate, which is insignificant to emissions in the long run, can be utilized as a tool to increase exports of green products through trade policies that support green innovation.

5. Study Limitations and Future Research

While this study provides valuable insights into the factors influencing CO_2 emissions in the ASEAN-5, there are several limitations that must be acknowledged. One key limitation is the exclusion of certain variables that are known to have a significant effect on CO_2 emissions, such as energy consumption, deforestation, and urbanization rates. Data limitations, including the availability and consistency of these variables across the study period, may have restricted their inclusion in the analysis. To gain a more comprehensive understanding of the factors affecting CO_2 emissions, future research should incorporate additional variables such as energy consumption, urbanization, and fiscal policy indicators. The inclusion of these variables could provide a more complete picture of the determinants of carbon emissions in the ASEAN region. Furthermore, expanding the time span of the study and using more recent data will allow for a more accurate analysis of long-term trends and the evaluation of policy impacts. This would also help in understanding the structural changes that may have occurred in the economy and environment over the period.

Author Contributions: Conceptualization, S.F.L., V.S., T.C.D.; methodology, S.F.L., T.C.D., V.S.; software, S.F.L., T.C.D., V.S.; validation, S.F.L., V.S., T.C.D.; formal analysis, S.F.L., V.S., T.C.D.; investigation, S.F.L. and T.C.D.; resources S.F.L., T.C.D., V.S.; data curation, S.F.L.; preparation of original draft, S.F.L.; review and editing, S.F.L., T.C.D., V.S.; visualization, S.F.L., V.S., T.C.D.; supervision, S.F.L., V.S., T.C.D.; project administration, S.F.L., V.S., T.C.D.; All authors have read and approved the published version of the manuscript.

Funding: This study does not receive external funding.

Data Availability Statement: Data is available upon request.

Acknowledgments: The authors gratefully acknowledge the support of Universitas Syiah Kuala.

Conflicts of Interest: All the authors declare that there are no conflicts of interest.

References

1. Hou, H., Lu, W., Liu, B., Hassanein, Z., Mahmood, H., and Khalid, S. (2023). Exploring the Role of Fossil Fuels and Renewable Energy in Determining Environmental Sustainability: Evidence from OECD Countries, *Sustainability*, Vol. 15, No. 3, 2048. doi:10.3390/su15032048.
2. Wefielananda, R. A., and Soetjipto, W. (2023). Analisis Pengaruh Hubungan Tidak Langsung Volatilitas Nilai Tukar terhadap EmisI CO2 di ASEAN, *Cakrawala Repositori IMWI*, Vol. 6, No. 4, 669–682. doi:10.52851/cakrawala.v6i4.406.
3. Hardi, I., Idroes, G. M., Márquez-Ramos, L., Noviandy, T. R., and Idroes, R. (2025). Inclusive Innovation and Green Growth in Advanced Economies, *Sustainable Futures*, Vol. 9, 100540. doi:10.1016/j.sftr.2025.100540.
4. Idroes, G. M., Hardi, I., Hilal, I. S., Utami, R. T., Noviandy, T. R., and Idroes, R. (2024). Economic Growth and Environmental Impact: Assessing the Role of Geothermal Energy in Developing and Developed Countries, *Innovation and Green Development*, Vol. 3, No. 3, 100144. doi:10.1016/j.igd.2024.100144.
5. Faizah, N., Laut, L. T., and Jalunggono, G. (2021). Analisis Determinan Degradasi Lingkungan: Pengujian EKC di 9 Negara ASEAN Periode 2000-2017, *DINAMIC : Directory Journal of Economic*, Vol. 3, No. 2, 463–480. doi: 10.31002/dinamic.v3i2.2661.
6. World Bank. (2023). World Development Indicators, from https://databank.worldbank.org/source/world-development-indicators.
7. Maulana, A., Dawood, T. C., and Zulham, T. (2021). Asymmetrical Exchange Rates Effect on Indonesia's Trade Balance in Tourism, *JEJAK*, Vol. 14, No. 1, 102–122. doi:10.15294/jejak.v14i1.27234.
8. Helda, N. P., Jamal, A., and Dawood, T. C. (2018). Pengaruh Urbanisasi, Pertumbuhan PDB Sektor Industri dan Pertumbuhan PDB Sektor Transportasi terhadap Polusi Lingkungan di Indonesia, *Jurnal Ekonomi Dan Kebijakan Publik Indonesia*, Vol. 5, No. 2, 168–183.
9. Hardi, I., Idroes, G. M., Hamaguchi, Y., Can, M., Noviandy, T. R., and Idroes, R. (2025). Business Confidence in the Shift to Renewable Energy: A Country-Specific Assessment in Major Asian Economies, *Journal of Economy and Technology*, Vol. 3, 44–68. doi:10.1016/j.ject.2024.08.002.
10. Shaari, M. S., Lee, W. C., Ridzuan, A. R., Lau, E., and Masnan, F. (2022). The Impacts of Energy Consumption by Sector and Foreign Direct Investment on CO2 Emissions in Malaysia, *Sustainability*, Vol. 14, No. 23, 16028. doi:10.3390/su142316028.
11. Naz, F., Tanveer, A., Karim, S., and Dowling, M. (2024). The Decoupling Dilemma: Examining Economic Growth and Carbon Emissions in Emerging Economic Blocs, *Energy Economics*, Vol. 138, 107848. doi:10.1016/j.eneco.2024.107848.
12. Li, X., and Wang, C. (2024). Clean Energy's Influence on the Mineral Resource Market in the ASEAN Region, *Resources Policy*, Vol. 91, 104781. doi:10.1016/j.resourpol.2024.104781.
13. Koirala, B. S., and Pradhan, G. (2020). Determinants of Sustainable Development: Evidence from 12 Asian Countries, *Sustainable Development*, Vol. 28, No. 1, 39–45. doi:10.1002/sd.1963.
14. Sari, F., and Dawood, T. C. (2022). Pengaruh Foreign Direct Investment, Remitansi, Kredit, Keterbukaan Perdagangan dan Pengeluaran Konsumsi Pemerintah terhadap PDB ASEAN, *Jurnal Ilmiah Mahasiswa Ekonomi Pembangunan*, Vol. 7, No. 4, 287–296.
15. Santana, F. R., and Maria, N. S. B. (2024). Determinan Emisi CO2 pada Negara Anggota ASEAN Tahun 2015-2022, *Diponegoro Journal of Economics*, Vol. 13, No. 2, 53–68. doi:10.14710/djoe.44589.
16. Kusuma, A. C., Kurniawan, R., Wongsonadi, S. K., Gio, P. U., Dalimunthe, H. H. B., and Sutisna, A. (2025). Relation of Energy Use to Price Inflation for Sustainable Development Policy: Does Fossilflation Occur in Indonesia?, *International Journal of Energy Sector Management*, Vol. 19, 85. doi:10.1108/IJESM-09-2024-0026.
17. Salari, M., Javid, R. J., and Noghanibehambari, H. (2021). The Nexus between CO2 Emissions, Energy Consumption, and

Economic Growth in the U.S., *Economic Analysis and Policy*, Vol. 69, 182–194. doi:10.1016/j.eap.2020.12.007.

18. Zulham, T., Dawood, T. C., Farlian, T., Saputra, J., Juliansyah, R., and Hadi, F. (2021). The Nexus of Human Development Index, Economic and Population Growth on Environmental Degradation in Aceh Province, Indonesia, *WSEAS Transactions on Environment and Development*, Vol. 17, 314–320. doi:10.37394/232015.2021.17.31.

19. Idroes, G. M., Rahman, H., Uddin, I., Hardi, I., and Falcone, P. M. (2024). Towards Sustainable Environment in North African Countries: The Role of Military Expenditure, Renewable Energy, Tourism, Manufacture, and Globalization on Environmental Degradation, *Journal of Environmental Management*, Vol. 368, 122077. doi:10.1016/j.jenvman.2024.122077.

20. Umar, M., Ji, X., Kirikkaleli, D., Shahbaz, M., and Zhou, X. (2020). Environmental Cost of Natural Resources Utilization and Economic Growth: Can China Shift Some Burden through Globalization for Sustainable Development?, *Sustainable Development*, Vol. 28, No. 6, 1678–1688. doi:10.1002/sd.2116.

21. Idroes, G. M., Afjal, M., Khan, M., Haseeb, M., Hardi, I., Noviandy, T. R., and Idroes, R. (2024). Exploring the Role of Geothermal Energy Consumption in Achieving Carbon Neutrality and Environmental Sustainability, *Heliyon*, Vol. 10, No. 23, e40709. doi:10.1016/j.heliyon.2024.e40709.

22. Hardi, I., Afjal, M., Can, M., Idroes, G. M., Noviandy, T. R., and Idroes, R. (2024). Shadow Economy, Energy Consumption, and Ecological Footprint in Indonesia, *Sustainable Futures*, Vol. 8, 100343. doi:10.1016/j.sftr.2024.100343.

23. Idroes, G. M., Hardi, I., Rahman, M. H., Afjal, M., Noviandy, T. R., and Idroes, R. (2024). The Dynamic Impact of Non-renewable and Renewable Energy on Carbon Dioxide Emissions and Ecological Footprint in Indonesia, *Carbon Research*, Vol. 3, No. 1, 35. doi:10.1007/s44246-024-00117-0.

24. Nasir, M. S., Wibowo, A. R., and Yansyah, D. (2021). The Determinants of Economic Growth: Empirical Study of 10 Asia-Pacific Countries, *Signifikan: Jurnal Ilmu Ekonomi*, Vol. 10, No. 1, 149–160.

25. Nguyen, D. B., Nong, D., Siriwardana, M., and Pham, H. T. (2023). Insights from ASEAN-Wide Emissions Trading Schemes (ETSs): A General Equilibrium Assessment, *Energy Policy*, Vol. 178, 113583. doi:10.1016/j.enpol.2023.113583.

26. Jufri, A., and Bahri. (2022). Pengaruh Investasi Asing Langsung terhadap Emisi CO2 dan Produk Domestik Bruto di Malta, *Entrepreneurship Bisnis Manajemen Akuntansi (E-BISMA)*, Vol. 3, No. 2, 94–101. doi:10.37631/ebisma.v3i2.524.

27. Kambono, H., and Marpaung, E. I. (2020). Pengaruh Investasi Asing dan Investasi Dalam Negeri terhadap Perekonomian Indonesia, *Jurnal Akuntansi Maranatha*, Vol. 12, No. 1, 137–145. doi:10.28932/jam.v12i1.2282.

28. Infante-Amate, J., Travieso, E., and Aguilera, E. (2024). Unsustainable Prosperity? Decoupling Wellbeing, Economic Growth, and Greenhouse Gas Emissions over the past 150 Years, *World Development*, Vol. 184, 106754. doi:10.1016/j.worlddev.2024.106754.

29. Hardi, I., Afjal, M., Khan, M., Idroes, G. M., Noviandy, T. R., and Utami, R. T. (2024). Economic Freedom and Growth Dynamics in Indonesia: An Empirical Analysis of Indicators Driving Sustainable Development, *Cogent Economics & Finance*, Vol. 12, No. 1, 2433023. doi:10.1080/23322039.2024.2433023.

30. Sumarno, T. B., Yusgiantoro, I. B., Fitriyanti, V., and Khusna, V. A. (2024). Challenges in Increasing Women's Participation in the Energy Transition in ASEAN and G7 Countries: A Qualitative Approach Based on the Three Tenets of Justice, *Energy Policy*, Vol. 191, 114163. doi:10.1016/j.enpol.2024.114163.

31. Rahmi, N., and Aliasuddin, A. (2020). The Effect of Good News and Bad News on Exports and Imports in Indonesia, *Advances in Natural and Applied Sciences*, Vol. 14, No. 1, 217–223.

32. Mankiw, N. G. (2021). *Principles of Economics*, Cengage Learning.

33. Ogbeifun, L., and Shobande, O. A. (2022). A Reevaluation of Human Capital Accumulation and Economic Growth in OECD, *Journal of Public Affairs*, Vol. 22, No. 4. doi:10.1002/pa.2602.

34. Jemiluyi, O. O., and Jeke, L. (2024). The Role of Human Capital Development in Urbanization-Economic Growth Nexus: A New Insight on Nigeria, *Sustainable Futures*, Vol. 8, 100266. doi:10.1016/j.sftr.2024.100266.

35. Chakraborty, P., Mitra, D., and Sundaram, A. (2024). Import Competition, Labor Market Regulations, and Firm Outsourcing, *Journal of Development Economics*, Vol. 168, 103272. doi:10.1016/j.jdeveco.2024.103272.

36. Noor, M. A., and Saputra, P. M. A. (2020). Emisi Karbon dan Produk Domestik Bruto: Investigasi Hipotesis Environmental Kuznets Curve (EKC) pada Negara Berpendapatan Menengah di Kawasan ASEAN, *Jurnal Wilayah dan Lingkungan*, Vol. 8, No. 3, 230–246. doi:10.14710/jwl.8.3.230-246.

37. Bradley, J., and Mann, L. (2024). Learning about Labor Markets, *Journal of Monetary Economics*, Vol. 148, 103612. doi:10.1016/j.jmoneco.2024.103612.

38. Raihan, A., Hasan, M. A., Voumik, L. C., Pattak, D. C., Akter, S., and Ridwan, M. (2024). Sustainability in Vietnam: Examining Economic Growth, Energy, Innovation, Agriculture, and Forests' Impact on CO2 Emissions, *World Development Sustainability*, Vol. 4, 100164. doi:10.1016/j.wds.2024.100164.

39. AG, M., Syechalad, M. N., and Silvia, V. (2018). The Effect of Government Expenditures, Private Investment and Labor on Economic Growth in Pidie District, *Sriwijaya International Journal of Dynamic Economics and Business (SIJDEB)*, Vol. 1, No. 4, 357–374. doi:10.29259/sijdeb.v1i4.357-374.

40. Pejović, B., Karadžić, V., Dragašević, Z., and Backović, T. (2021). Economic Growth, Energy Consumption and CO2 Emissions in the Countries of the European Union and the Western Balkans, *Energy Reports*, Vol. 7, 2775–2783. doi:10.1016/j.egyr.2021.05.011.

41. Nguyen, H. T., Le, A. N. N., Le, H. V., and Duong, K. D. (2024). Foreign Direct Investment and Employments in Asia Pacific Nations: The Moderating Role of Labor Quality, *Heliyon*, Vol. 10, No. 9, e30133. doi:10.1016/j.heliyon.2024.e30133.

42. Fitriady, A., Silvia, V., and Suriani, S. (2022). The Impact of Macroeconomic Variables on the Real Economic Growth in Indonesia, *International Journal of Global Optimization and Its Application*, Vol. 1, No. 2, 70–79. doi:10.56225/ijgoia.v1i2.16.

43. Fathia, N., Silvia, V., and Gunawan, E. (2021). Analysis of Foreign Investment Determinants in Indonesia, *Economics Development Analysis Journal*, Vol. 10, No. 3, 338–350. doi:10.15294/edaj.v10i3.45375.

44. Yuliadi, I., and Wardani, D. T. K. (2023). Macroeconomic Variables and Its Impact on CO2 Emissions: An Empirical Study on Selected ASEAN Economic Community (AEC) Countries, *International Journal of Sustainable Development and Planning*, Vol. 18, No. 1, 139–144. doi:10.18280/ijsdp.180114.

45. Suwandaru, A., Sudiyono, W., Shawdari, A., and Fristin, Y. (2024). Understanding the Economic Drivers of Climate Change in Southeast Asia: An Econometric Analysis, *Economies*, Vol. 12, No. 8, 200. doi:10.3390/economies12080200.

46. Shi, B., Zhu, G., and Li, N. (2024). Does Economic Growth Targets Setting Lead to Carbon Emissions? An Empirical Study from China, *Journal of Environmental Management*, Vol. 368, 122084. doi:10.1016/j.jenvman.2024.122084.

47. Suroso, D. S. A., Setiawan, B., Pradono, P., Iskandar, Z. S., and Hastari, M. A. (2022). Revisiting the Role of International Climate Finance (ICF) Towards Achieving the Nationally Determined Contribution (NDC) Target: A Case Study of the Indonesian Energy Sector, *Environmental Science & Policy*, Vol. 131, 188–195. doi:10.1016/j.envsci.2022.01.022.

48. Balsalobre-Lorente, D., and Leitão, N. C. (2020). The Role of Tourism, Trade, Renewable Energy Use and Carbon Dioxide Emissions on Economic Growth: Evidence of Tourism-Led Growth Hypothesis in EU-28, *Environmental Science and Pollution Research*, Vol. 27, No. 36, 45883–45896. doi:10.1007/s11356-020-10375-1.

49. Amalina, F., and Silvia, V. (2023). The Effect of Economic Growth and Energy Consumption on Carbon Emissions in Indonesia, *International Journal of Advanced Research in Economics and Finance*, Vol. 4, No. 4, 97–106. doi:10.55057/ijaref.2022.4.4.10.

50. Solow, R. (1996). Growth Theory, in: *A Guide to Modern Economics*, 218–236, Routledge.

51. Schurr, S. H. (1985). Energy Conservation and Productivity Growth, *Energy Policy*, Vol. 13, No. 2, 126–132. doi:10.1016/0301-4215(85)90173-9.

52. Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., and Leitão, N. C. (2013). Economic Growth, Energy Consumption, Financial Development, International Trade and CO2 Emissions in Indonesia, *Renewable and Sustainable Energy Reviews*, Vol. 25, 109–121. doi:10.1016/j.rser.2013.04.009.

53. Shereen, S., and Laulita, N. B. (2023). Pengaruh Aktivitas Penggunaan Energi terhadap Emisi CO2 (Studi Kasus: Sembilan Negara dengan Kumulatif Emisi Terbesar), *Ecoplan*, Vol. 6, No. 2, 118–129. doi:10.20527/ecoplan.v6i2.667.

54. Wahyudi, H., and Palupi, W. A. (2023). What Is the Short-Term and Long-Term Relationship between Renewable Energy and Investment in Economic Growth?, *International Journal of Energy Economics and Policy*, Vol. 13, No. 3, 46–55. doi:10.32479/ijeep.14081.

55. Dwi Haryanto, R., Rahmawati, Y., Altamirano, O. G. R., Ahsani, S. F., Hudang, A. K., and Haryanto, T. (2022). An Empirical Investigation between FDI, Tourism, and Trade on CO2 Emission in Asia: Testing Environmental Kuznet Curve and Pollution Haven Hypothesis, *International Journal of Energy Economics and Policy*, Vol. 12, No. 4, 385–393. doi:10.32479/ijeep.13242.

56. Leal, P. H., Marques, A. C., and Fuinhas, J. A. (2018). How Economic Growth in Australia Reacts to CO2 Emissions, Fossil Fuels and Renewable Energy Consumption, *International Journal of Energy Sector Management*, Vol. 12, No. 4, 696–713. doi:10.1108/IJESM-01-2018-0020.

57. Aswadi, K., Jamal, A., Syahnur, S., and Nasir, M. (2023). Renewable and Non-renewable Energy Consumption in Indonesia: Does it Matter for Economic Growth?, *International Journal of Energy Economics and Policy*, Vol. 13, No. 2, 107–116. doi:10.32479/ijeep.13900.

58. Fatima, N., Xuhua, H., Alnafisah, H., and Akhtar, M. R. (2024). Synergy for Climate Actions in G7 Countries: Unraveling the Role of Environmental Policy Stringency between Technological Innovation and CO2 Emission Interplay with DOLS, FMOLS and MMQR Approaches, *Energy Reports*, Vol. 12, 1344–1359. doi:10.1016/j.egyr.2024.07.035.

59. Elfira, E., Silvia, V., and Nasir, M. (2022). The Effect of Farmer's Export, Import, and Exchange Rate on Value-Added of Agricultural Sector in Aceh Province, Indonesia, *International Journal of Finance, Economics and Business*, Vol. 1, No. 2, 91–102. doi:10.56225/ijfeb.v1i2.24.

60. Khan, Panigrahi, Almuniri, Soomro, Mirjat, and Alqaydi. (2019). Investigating the Dynamic Impact of CO2 Emissions and Economic Growth on Renewable Energy Production: Evidence from FMOLS and DOLS Tests, *Processes*, Vol. 7, No. 8, 496. doi:10.3390/pr7080496.

61. Jawad Sajid, M., Santibanez Gonzalez, E. D. R., and Danish. (2021). The Role of Labor and Capital in Sectoral CO2 Emissions and Linkages: The Case of China, India and the USA, *Ecological Indicators*, Vol. 131, 108241. doi:10.1016/j.ecolind.2021.108241.

62. Arsyah, R. P., and Yuwono, B. E. (2023). Identifikasi Jejak Karbon pada Pekerjaan Tiang Pancang (Studi Kasus: Proyek Konstruksi Indoor Multifunction Stadium GBK), *Jurnal Rekayasa Lingkungan Terbangun Berkelanjutan*, Vol. 1, No. 2, 133–138. doi:10.25105/jrltb.v1i2.16291.

63. Cui, Y., Wang, G., Irfan, M., Wu, D., and Cao, J. (2022). The Effect of Green Finance and Unemployment Rate on Carbon Emissions in China, *Frontiers in Environmental Science*, Vol. 10, 1–16. doi:10.3389/fenvs.2022.887341.

64. Mohommad, A. (2021). *Employment Effects of Environmental Policies – Evidence From Firm-Level Data*, International Monetary Fund.

65. Bai, S., Zhang, B., Ning, Y., and Wang, Y. (2021). Comprehensive Analysis of Carbon Emissions, Economic Growth, and Employment from the Perspective of Industrial Restructuring: A Case Study of China, *Environmental Science and Pollution Research*, Vol. 28, No. 36, 50767–50789. doi:10.1007/s11356-021-14040-z.

66. Zheng, D., Addas, A., Waseem, L. A., Asad Naqvi, S. A., Ahmad, M., and Sharif, K. (2024). The Hidden Costs of Inflation: A Critical Analysis of Industrial Development and Environmental Consequences, *PLOS ONE*, Vol. 19, No. 8, e0297413. doi:10.1371/journal.pone.0297413.

67. Musarat, M. A., Alaloul, W. S., Liew, M. S., Maqsoom, A., and Qureshi, A. H. (2021). The Effect of Inflation Rate on CO2 Emission: A Framework for Malaysian Construction Industry, *Sustainability*, Vol. 13, No. 3, 1562. doi:10.3390/su13031562.

68. Munir, K., and Ameer, A. (2020). Nonlinear Effect of FDI, Economic Growth, and Industrialization on Environmental Quality, *Management of Environmental Quality: An International Journal*, Vol. 31, No. 1, 223–234. doi:10.1108/MEQ-10-2018-0186.

69. Pazienza, P. (2019). The Impact of FDI in the OECD Manufacturing Sector on CO2 Emission: Evidence and Policy Issues, *Environmental Impact Assessment Review*, Vol. 77, 60–68. doi:10.1016/j.eiar.2019.04.002.

70. Trianto, M. F. S., and Pirwanti, E. Y. (2018). Pertumbuhan Penduduk, Inflasi dan Korupsi: Analisis Empiris Environmental Kuznets Curve (EKC) di Kawasan ASEAN Periode 2002-2016, *Jurnal Dinamika Ekonomi Pembangunan*, Vol. 1, No. 3, 71–81. doi:10.14710/jdep.1.3.71-81.

71. Candra, K. A. (2018). Analisis Pengaruh Pertumbuhan Ekonomi dan Penanaman Modal Asing terhadap Emisi Karbondioksida di Delapan Negara ASEAN Periode 2004-2013, *CALYPTRA*, Vol. 7, No. 1, 2646–2661.