Diponegoro Journal of Economics
e-ISSN 2963-1688, p-ISSN 2337-3814
Vol. 15, No. 2, 2026, 55-68

How Do FDI and Population Affect Carbon Emissions in Indonesia: An ARDL Approach

Dodi Tirtana[1, *], Galih Nugraha[1], Muhammad Nurhikmat[1], Tiara Pradani[2], Dwiyan Al Rasyid[2], and Nur Jannah Abdi Aziz[2]

[1]Development Economics Study Program, Faculty of Economics and Business, Universitas Siliwangi, Tasikmalaya, Indonesia

[2]Accounting Study Program, Faculty of Economics and Business, Universitas Siliwangi, Tasikmalaya, Indonesia

*Corresponding Email: dodi.ta@unsil.ac.id

Received: 21st April 2026; Last Revised: 4th September 2026; Accepted: 5th September 2026;
Available Online: 10th September 2026

Abstract

Indonesia is challenged to balance as income rises, population expands, and foreign direct investments grow, there is a tension between economic progress and reducing carbon emissions. This study examines both the immediate and extended connections between GDP per capita and carbon dioxide (CO_2) emissions, population, and foreign direct investments (FDI) in Indonesia using annual data spanning 1989 to 2023, resulting in 34 observations. The study uses the Autoregressive Distributed Lag (ARDL) approach in estimating the dynamic relationships between the variables. Augmented Dickey-Fuller with the bounds test confirming the establishment of long-run cointegration. The findings of the ARDL (1, 1, 0, 0) model revealed that GDP per capita and population exert substantial and beneficial effects on CO_2 emissions over both immediate and extended timeframes. On the other hand, foreign direct investment, after being transformed through inverse hyperbolic sine, has a negative and significant impact on CO_2 emissions both in the short- and long-run periods. An adjustment coefficient of -0.818 means that about 81.8 percent of the short-run imbalance is corrected in one period. Robustness analysis estimates retain the nature of the long-run coefficients.

Keywords: CO_2 emissions, GDP per Capita, Population, FDI, and ARDL

JEL Classification: *C32, F21, Q56*

How to Cite: Tirtana, D., Nugraha, G., Nurhikmat, M., Pradani, T., Rasyid, D. A., & Aziz, N. J. A. (2026). How do FDI and population affect carbon emissions in Indonesia: An ARDL approach. *Diponegoro Journal of Economics, 15*(1), 55-68. https://doi.org/10.14710/djoe.57027

Introduction

Carbon dioxide (CO_2) emissions are one of the biggest environmental problems, as production, economic activity, transport, and energy production still largely depend on fossil fuel use. Increases in income and production in developing and emerging markets may lead to rising energy demand and negative environmental effects if advances in technology and energy do not compensate for increasing levels of economic activity. Studies on developing and Asian markets continue to demonstrate that economic activity, energy consumption, demographic variables, and investments are important elements of emission dynamics, even if their weight and signs may differ from one country to another (Ahmed et al., 2023; Hoa et al., 2024; Oprea et al., 2025).

Indonesia is an essential location to study these interconnections. From one perspective, the economic growth and population growth in Indonesia have created additional demands for electricity generation,

https://doi.org/10.14710/djoe.57027

transport services, housing, infrastructure, and production activities, while fossil fuels, especially coal, still constitute a considerable part of the country's energy mix (IEA, 2023; Marwa et al., 2022). On the other hand, Indonesia has become more devoted to sustainable economic development and has kept its goal of becoming a net-zero carbon emitter no later than 2060. All these circumstances pose a crucial developmental dilemma for Indonesia – the country needs to maintain the current progress in welfare and productive capacity while avoiding additional emissions from meeting the increased demands.

The income level might be one of the factors influencing this connection. An increase in GDP per capita means a higher income level and leads to an increase in consumption, movement, demand for infrastructure, production, and energy consumption. If these processes depend on carbon-based energy sources, then income growth might relate to the growth of CO_2 emissions. The empirical studies concerning developing and Asian countries indicate a persistent relationship among income levels, economic activity, and environmental impacts, but it depends on energy structure, technology, and the level of economic growth (Ahmed et al., 2023; Hoa et al., 2024; Reza & Hasmarini, 2026). There is also the concept of the Environmental Kuznets Curve (EKC), which helps to understand how the income-environment connection changes depending on the level of economic development of the country. However, in the current research, the issue of EKC is not tested, as the income level enters the equation in linear form without any squared term. The EKC concept serves only as a background for this study.

Population is yet another critical aspect of environmental pressure. Population increase increases the scale of demand for electricity, transportation, housing, food, infrastructure, consumer goods, and public services. But the environmental implications of population increase depend on the way by which this increased demand will be satisfied. There are various ways through which urban development, energy efficiency, technological advancement, transport, and carbon intensity of electricity production affect the impact of population on carbon emissions. Empirical analysis of recent times has found that there is a significant relationship between population and carbon emissions in countries, despite differences in income levels and economic development (Ahmed et al., 2023; Oprea et al., 2025; Pickson et al., 2024). It is therefore critical to understand this demographic aspect when analysing Indonesia's emission dynamics in relation to economic prosperity and foreign investments.

Foreign direct investment (FDI), on the other hand, has a somewhat complicated association with environmental quality. According to the Pollution Haven Hypothesis, foreign investment may have a negative effect on environmental quality, as polluting production is likely to be induced by foreign investments in those countries that have weaker environmental standards, lower cost of compliance, or carbon-based production. Foreign investment in such countries is likely to expand production and increase energy consumption, leading to higher emissions of CO_2. According to the Pollution Halo approach, foreign direct investment (FDI) can improve environmental outcomes by facilitating the use of advanced technologies, increased efficiency of production, improved management practices, and technology spillover effects. Empirical evidence supports both hypotheses to some extent, with the environmental impact of FDI being sector-specific (Febriyanto et al., 2024; Nguyen, 2026; Pham et al., 2025).

The ambiguous nature of the role of FDI is also evident in the Indonesian-specific literature. According to Pujiati et al. (2023), using the ARDL method on Indonesian data from 1984 to 2020, it was discovered that FDI's impact on CO_2 emissions was not significant in the short term but had a negative effect in the long term, aligning with the Pollution Halo hypothesis. However, Leonardo et al. (2023), using time series data for Indonesia covering 1980 to 2021, identified a positive and statistically significant relationship between FDI and carbon-based environmental degradation in the long-run, and hence, their results were consistent with the Pollution Haven Hypothesis. An illustration of this heterogeneity is available in the literature, even based on an environmental indicator other than carbon dioxide emissions. Yilanci et al. (2023) found evidence consistent with the Pollution Halo hypothesis based on environmental degradation measured by the fishing footprint in Indonesia.

The mixed results of previous studies may partially be explained by variations between the indicators of the environment used, observation time periods, econometric models, and the nature of the foreign investments studied in these studies. Total foreign investments could vary widely in terms of their impact on the environment, depending on whether the investments are made in environmentally friendly production processes or environmentally damaging ones. The link between FDI and emissions is found to be heterogeneous rather than being universally positive or negative for ASEAN countries and other parts of the world (Adeleye et al., 2023; Febriyanto et al., 2024; Nguyen, 2026). Thus, it is a question of empirical investigation whether the relationship between Indonesia's FDI and CO_2 emissions conforms to the concept of Pollution Haven or Pollution Halo.

Another aspect to consider is the time horizon over which such relationships occur. The changes in GDP per capita, population, and foreign investments might take some time to materialize in the form of carbon dioxide emissions, as the process of production, consumption, energy requirements, and investment adjustments takes time. Therefore, the relationship in the short run could be different from that in the long run when the economy reaches long-run equilibrium. In fact, dynamic analysis conducted earlier has shown the significance of such an approach while investigating environmental issues (Ahmed et al., 2023; Pujiati et al., 2023). Thus, an empirical model that clearly differentiates between short-run and long-run relationships would be relevant to the present research question.

Based on the information provided, it can be inferred that the current research paper does not address a lack of studies concerning the effects of foreign investments on environmental degradation in Indonesia, but rather the absence of empirical conclusions concerning the nature of this relation and the necessity of assessment together with other factors, including demographic and income aspects. Previous studies conducted in Indonesia resulted in the achievement of results that are consistent with both Pollution Haven and Pollution Halo approaches, while studies performed worldwide revealed that population and economic prosperity are the crucial factors in carbon emissions dynamics (Leonardo et al., 2023; Oprea et al., 2025; Pickson et al., 2024; Pujiati et al., 2023).

This study aims to explore both the immediate and extended connections among per capita GDP, population size, foreign direct investment, and carbon emissions in Indonesia over the period from 1989 to 2023, using the Autoregressive Distributed Lag (ARDL) method. There are three main contributions of the current study to existing literature. First, the study analyses economic prosperity, population size, and FDI in a concise econometric model. Second, the study draws the distinction between short-run adjustments and long-run relationships, thus enabling the analysis of the consistency of the estimated associations over various time horizons. Third, the research evaluates the stability of the long-term estimates by employing methods such as Robustness analysis. Instead of presenting the first evidence on the issue of FDI and emissions in Indonesia, the present study offers an update to the empirical literature that is already there and evaluates the estimated association of FDI with the Pollution Haven and Pollution Halo theories.

Literature Review

Environmental degradation is likely to emerge as an externality from economic processes since the environment-related costs resulting from the processes of production and consumption may not have been fully internalized in private economic decision-making. Regarding carbon emissions, the rise in income levels may result in an expansion in terms of household consumption and movement, the use of infrastructure, production processes, and energy needs, especially when economic activities depend on fossil fuels for energy. Thus, GDP per capita is the affluence element in environmental pressures. Recent evidence indicates that income and economic activity remain important components of CO_2-emission dynamics, although their environmental implications vary according to energy structure, technology, and economic conditions (Ahmed et al., 2023; Hoa et al., 2024; Oprea et al., 2025). These findings suggest that the environmental consequences of rising affluence should be interpreted together with demographic, technological, and energy conditions rather than as an isolated income effect.

The Environmental Kuznets Curve (EKC) offers a wider context about the income and environment relationship. Nevertheless, for conducting an EKC test formally, there needs to be a non-linear specification of income, which would normally involve income and the square of income. In the current model, we have GDP per capita as a linear variable only, and therefore, this exercise does not conduct any formal test of the EKC hypothesis.

Population is yet another environmental pressure factor through the size of human activity. A growing population creates increased needs in electricity use, transportation, housing, infrastructure, food consumption, goods and services, but the impact on the environment depends on the way in which this increased need is satisfied. The factors of energy efficiency, urban form, transportation system, consumption patterns of households, technological factors, and carbon intensity of energy supply may affect the extent of emissions caused by the growth in population. Recent research confirms that the factors related to population still have a significant impact on CO_2 emissions, although they vary depending on the income level and economic structure of countries (Pickson et al., 2024; Zhong et al., 2025).

The nature of the environmental contribution of foreign investment has theoretical ambiguity and is usually justified using one of the two theories: the Pollution Haven Hypothesis and the Pollution Halo theory. The Pollution Haven Hypothesis assumes that foreign investments can cause increased environmental damage if pollution-intensive industries are attracted to an economy that is characterized by low environmental standards or an energy system based on carbon. Recent global empirical studies indicate that FDI contributes to higher CO_2 emissions in developing nations (Pham et al., 2025). Conversely, the Pollution Halo Theory posits that foreign investments might enhance environmental conditions due to advancements in technology and greater production efficiency, better environmental management, and technological spillover effects. Recent findings show that the environmental impacts of FDI are also affected by technology and energy conditions, and by the degree of renewables in the host economy (Nguyen, 2026). Thus, the positive correlation between FDI and CO_2 emissions is consistent with Pollution Haven theory, while a negative relationship corresponds to the Pollution Halo theory.

Further empirical evidence from recent studies within the ASEAN bloc supports the idea that the environmental effect of FDI varies not only across countries but also over time periods. Febriyanto et al. (2024), investigating Singapore, Indonesia, Malaysia, and Vietnam by employing the ARDL approach, found that the FDI–CO_2 effect varied across countries in both the short and long run, with Indonesia having a positive FDI effect in the short run.

The Indonesia case study serves as a good example of the theoretical confusion. According to Pujiati et al. (2023), who employed an ARDL approach in the period from 1984 to 2020, FDI is found to have no significance in the short run and to have a negative and significant association with CO_2 emissions in the long run; this finding is viewed as one confirming the Pollution Halo theory. On the other hand, Leonardo et al. (2023), analysing Indonesia's time-series data from 1980 to 2021, reveal a statistically significant positive linkage between foreign direct investment (FDI) and environmental degradation caused by carbon emissions.

Differences in findings from Indonesia could be due to variations in sampling periods, measures of independent variables, specification of models, the nature of control variables, and the nature of foreign investment. FDI as an aggregate measure might incorporate investment in different types of activities, where some may have very different effects on the environment compared to others. In other words, investment in extractive and carbon-heavy industries would contribute to increased emissions, while more efficient investment would create different results. The same is true for the rest of ASEAN countries and even globally (Jahanger, 2022; Nguyen, 2026; Pham et al., 2025).

Another reason for the need to distinguish short-run from long-run relationships is that GDP per capita, population, and FDI may create instantaneous effects, whereas infrastructure, production capacity, technology, and investment respond with some delay. The dynamic research shows that the environmental effects vary across different time periods under consideration, which proves the necessity of using the techniques of distinguishing temporary adjustment from equilibrium relationships (Leonardo et al., 2023; Oprea et al., 2025; Pujiati et al., 2023).

Collectively, the findings indicate positive correlations between CO_2 emissions and GDP per capita and population, considering that with affluence and larger populations, the level of carbon-based economic production will increase. In the case of FDI, there is no directional assumption made since the theories of Pollution Haven and Pollution Halo have conflicting assumptions regarding the effect of FDI on carbon dioxide emissions. An indication of a positive FDI coefficient would be consistent with the theory of Pollution Haven, while a negative FDI coefficient would conform to Pollution Halo theory.

Research Methods

The study employs quantitative time series techniques to examine the relationship among carbon dioxide (CO2) emissions, GDP per capita, population, and foreign direct investment (FDI) in Indonesia from 1989 to 2023. The dataset comprises 34 relevant observations derived from a consistent sample across all variables. Information for each variable was obtained from the World Development Indicators (WDI) database provided by the World Bank. CO2 emissions are quantified as emissions from fossil fuels and industry, measured in millions of tons. Per capita GDP is expressed in constant 2015 US dollars, population is represented in terms of the total population of Indonesia, while FDI is represented in terms of net inflows in current US dollars. CO2 emissions, GDP per capita, and population are converted into natural logarithms, which are represented as LnCO2, LnGDP, and LnPOP, respectively. Due to the possibility of having zero and negative observations for FDI, FDI is transformed using the inverse hyperbolic sine (IHS) transformation and represented as his FDI.

$$ihs\_FDI_t = \ln(FDI_t + \sqrt{FDI_t^2 + 1} \quad (1)$$

where FDI_t denote net inflows of foreign direct investment in period t.

Table 1. Variable Measurement

Variable	Symbols	Unit of measurement
Carbon dioxide emissions	LnCO2	Carbon dioxide (CO_2) emissions from fossil fuels and industry (millions of tonnes)
Per capita GDP	LnGDP	GDP Per Capita (constant 2015 US$)
Population	LnPOP	Total population of Indonesia (persons)
Foreign direct investment	ihs_FDI	Net inflows of foreign direct investment (BoP, current US$), adjusted with IHS

The empirical analysis utilizes the Autoregressive Distributed Lag (ARDL) model as its methodology. This model is appropriate because it can incorporate I(0), I(1), or a mix of these variables, though not I(2), in the estimation process. Additionally, the ARDL framework may incorporate lagged terms for each variable differently, and it may estimate short-run and long-run dynamics under one specification. This makes the ARDL method well suited for time-series samples which are relatively small. The recent applications of the ARDL model also highlight its suitability when it comes to mixed orders of integration and relatively small sample sizes (Sohail et al., 2025). Its suitability in small samples and mixed I(0)/I(1) variables has also been shown by Elfaki et al. (2021) in the Indonesian time series data. After the transformation of variables, the empirical long-run relationship may be written as:

$$LnCO_{2t} = \beta_0 + \beta_1 LnGDP_t + \beta_2 LnPOP_t + \beta_3 ihs\_FDI_t + \varepsilon_t \quad (2)$$

where $LnCO_{2t}$ represents carbon dioxide emissions, $LnGDP_t$ denotes GDP per capita, $LnPOP_t$ represents population, and ihs_FDI_t denotes foreign direct investment at time t.

The empirical specification in this study is made very concise considering the research goal of this paper. While other researchers have found other explanatory variables to be important for explaining CO_2 emissions, such as energy consumption, use of renewable energy, level of industrialization, and openness to international trade, the introduction of several regressors at one go will significantly reduce the number of degrees of freedom owing to the small sample size used annually in the analysis. The specification thus focuses on the variables that are relevant theoretically, and the absence of other structural variables and energy-related variables is a drawback of the study.

Prior to applying the ARDL method, the stationarity of the variables is evaluated using the Augmented Dickey-Fuller (ADF) unit root test. The ADF test identifies whether each variable is stationary at level I(0) or at first difference I(1) and confirms that none is stationary at second difference I(2). This procedure is essential because the bounds test is valid for variables integrated (Elfaki et al., 2021; Pesaran et al., 2001).

The ARDL bounds testing method is employed to determine whether a long-term cointegrating linkage exists among $LnCO_2$, LnGDP, LnPOP, and ihs_FDI. The test's null hypothesis posits that no level relationship exists among these variables in the long run. Cointegration is confirmed if the computed F-value surpasses the upper-bound critical value, I(1). Conversely, if the F-value is below the lower bound, I(0), the null hypothesis is not rejected. If the F-value falls between these bounds, the test outcome remains inconclusive (Pesaran et al., 2001). Bounds testing has been widely used in Indonesian time-series studies with different orders of integration (Elfaki et al., 2021).

After establishing cointegration, the ARDL model is employed to determine coefficient modifications. Based on the selected lag structure, the estimated specification in this study is ARDL (1,1,0,0). The corresponding error-correction representation can be expressed as:

$$\Delta LnCO_{2t} = \alpha_0 + \sum_{j=i}^{p} \alpha_j \, \Delta LnCO_{2t-j} + \sum_{j=i}^{q_1} \gamma_j \, \Delta LnGDP_{t-j} + \sum_{j=i}^{q_2} \delta_j \, \Delta LnPOP_{t-j} + \sum_{j=i}^{q_3} \theta_j \, \Delta ihs\_FDI_{t-j} + ECT_{t-1} + \mu_t \quad (2)$$

where Δ denotes the first-difference operator and serves as the lagged error correction term, indicating the rate at which adjustments are made toward long-term equilibrium. A negative and statistically significant coefficient for error correction suggests that short-term deviations are moving back toward the long-term equilibrium. Employing an error-correction framework to separate short-term dynamics from long-term relationships aligns with recent applications of ARDL (Sohail et al., 2025).

To assess the sensitivity of the long-run findings to the choice of estimator, the study additionally employs Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) as robustness checks. The emphasis will be put on the consistency of the main coefficient directions and levels of significance between different long-run estimation techniques. This approach is applied after Elfaki et al. (2021), who use the combination of ARDL, FMOLS, DOLS, and CCR in the Indonesian time series dataset. The latter technique is used for assessing the sensitivity of estimators and does not mean the exclusion of all potential specifications or omitted variable issues.

Lastly, model diagnostics and stability testing are carried out to evaluate model adequacy. The Breusch-Godfrey LM test is employed to assess serial correlation, the Breusch-Pagan/Cook-Weisberg test is applied to evaluate heteroscedasticity, and the Jarque-Bera test is used to examine the normality of residuals. Stability of parameters is evaluated through CUSUM and CUSUMQ statistics. Parameter stability is demonstrated where the recursive statistics stay within the 5% critical bounds. Use of diagnostics on residuals together with stability tests based on CUSUM is in line with past application of ARDL methodology in Indonesia (Elfaki et al., 2021). All econometric analyses are done using Stata 17.

Results and Discussion

Results

This empirical study starts with descriptive statistics and correlations among pairs to give a preliminary view of the variables before moving to the time series analysis. The descriptive statistics describe the distribution properties of the variables $LnCO_2$, LnGDP, LnPOP, and ihs_FDI, while the correlation shows the preliminary association among the pairs of variables. This analysis is considered descriptive evidence only, without considering any causal or dynamic relationships among them. The findings of the descriptive analysis are summarized in Table 2.

Table 2. Descriptive Statistics and Correlation Matrix

Variable	$LnCO_2$	LnGDP	LnPOP	ihs_FDI
Mean	19.73736	7.801917	19.2669	16.74562
Median	19.69117	7.740206	19.27723	23.12427
Maximum	20.45193	8.341082	19.45454	24.64011
Minimum	18.85888	7.293642	19.02773	-22.93162
Std. Dev.	0.4348064	0.317797	0.12993	16.23995
Skewness	-0.153816	0.2144019	-0.2396062	-1.974743
Kurtosis	2.042962	1.699753	1.846584	4.942808
Observations	34	34	34	34
$LnCO_2$	1			
LnGDP	0.4807	1		
LnPOP	0.1906	0.3571	1	
ihs_FDI	0.2938	0.3142	0.0387	1

As can be seen from the descriptive statistics above, there are clear disparities between the distribution features of the four variables. The smallest standard deviation can be observed in the case of LnPOP, which means that the distribution of the population in Indonesia had been homogeneous within the period of observations. At the same time, ihs_FDI has a much higher degree of dispersion, as foreign direct investments had been quite volatile in their movement over the sample period considered. $LnCO_2$ and LnPOP have slightly negative skewness, while LnGDP has slight positive skewness. However, the transformed variable ihs_FDI has significantly higher skewness in the negative direction and kurtosis larger than three. At the same time, the kurtosis of $LnCO_2$, LnGDP, and LnPOP is less than three.

The correlation matrix provides further preliminary information on the relationships among the variables. $LnCO_2$ is positively correlated with LnGDP, LnPOP, and ihs_FDI, with coefficients of 0.4807, 0.1906, and 0.2938. Among the explanatory variables, LnGDP is positively correlated with LnPOP and ihs_FDI, with coefficients of 0.3571 and 0.3142, while the correlation between LnPOP and ihs_FDI is relatively weak at 0.0387. Overall, the explanatory variables are modest, with none approaching a level that would immediately indicate an extremely strong linear association. Nevertheless, these coefficients represent only contemporaneous pairwise relationships and do not account for lagged adjustments, stationarity properties, or cointegration. Consequently, the substantive short- and long-run relationships among the variables are evaluated through the ARDL framework rather than inferred directly from the correlation matrix.

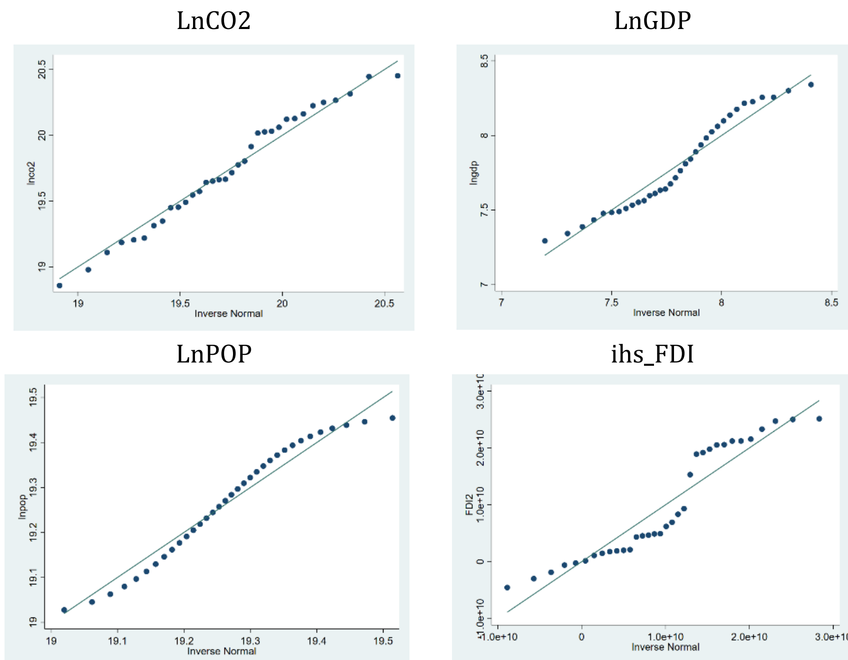

Figure 1. Q–Q Plots of the Transformed Variables

The quantile plots presented in Figure 1 help us get a graphical depiction of the features of the distributions of the variables after transformation. The observations of the variables $LnCO_2$ and LnPOP mostly align with the theoretical reference line, although there are some discrepancies in the tails of the distribution. The variable LnGDP is closer to the reference line than the others, but there are still some discrepancies. On the contrary, ihs_FDI deviates more from the reference line, especially in lower and medium quantiles, as one can see from the stronger skewness and kurtosis of this variable in Table 2. The graphs show that the non-normality of the FDI series is preserved after the transformation. However, quantile plots are used only for the descriptive analysis of each series, whereas the normality of the model is assessed through the Jarque-Bera residual diagnostic test presented below

Before estimating the ARDL model, the ADF test is conducted to evaluate the integration order of the variables. The outcomes of the ADF test at both the level and first difference are presented in Table 3. The data variables have different orders of integration in Table 3. The LnPOP is integrated of order zero, denoted I(0), with an ADF statistic of −19.811 and a probability value of 0.0000. $LnCO_2$ and LnGDP are integrated of order one, denoted l(1), since they are not stationary at level but stationary in first differences, with ADF statistic values of −1.463 and −2.417 and probabilities of 0.1575 and 0.0165, respectively. Additionally, ihs_FDI is not stationary at the 5% significance level (p=0.0567) but is stationary in first differences and is therefore considered as l(1).

Table 3. ADF Unit Root Test

Variables	ADF Statistic				Order of integration
	Level	Prob.	First different	Prob.	
LnCO2	-1.266	0.6444	-8.483	0.0000	l(0)
LnGDP	-0.093	0.9502	-8.483	0.0000	l(1)
LnPOP	-19.811	0.0000	-4.589	0.0001	l(0)
ihs_FDI	-2.811	0.0567	-9.132	0.0000	l(1)

Table 4. ARDL Bounds Test

Test statistic	Value	Sig. Level	L(0)	L(i)
F-statistic	7.921	10%	2.72	3.77
K	3	5%	3.23	4.35
		2.5%	3.69	4.89
		1%	4.29	5.61

Table 4 presents the results of the ARDL bounds test for cointegration. The calculated F-statistic of 7.921 exceeds the upper-bound I(1) critical values at the 10%, 5%, 2.5%, and 1% significance levels. The F-statistics remain above the upper-bound critical value even at the 1% level, leading to rejection of the null hypothesis of no long-run relationship. These findings provide robust evidence of cointegration among $LnCO_2$, LnGDP, LnPOP, and ihs_FDI, thereby justifying the estimation of both short- and long-run relationships within the ARDL framework.

Table 5. Assessment of Measurement Model Results

	$\Delta LnCO_2$	Coefficient	Std. Erorr	z	Prob.
ADJ	$LnCO_2$	-0.8181638	0.1676214	-4.88	0.000
Long-run	LnGDP	0.5170343	0.1645927	3.14	0.004
	LnPOP	2.113288	0.3854158	5.48	0.000
	ihs_FDI	-0.0023928	0.0010564	-2.27	0.032
Short-run	ΔLnGDP	0.6582944	0.2900171	2.27	0.031
	ΔLnPOP	1.729016	0.5540348	3.12	0.004
	Δihs_FDI	-0.0019577	0.0007767	-2.52	0.018
	Constant	-20.44161	7.675947	-2.66	0.013
ARDL	(1, 1, 0, 0)				
R^2	0.6299				

Table 5 presents the estimation outcomes for both long-term and short-term relationships, along with the adjustment coefficient for the ARDL model. In both the long and short term, per capita GDP and population exhibit a positive and statistically significant correlation with CO_2 emissions. Conversely, ihs_FDI shows a negative and statistically significant correlation with CO_2 emissions across both time frames. The ARDL model yields an R-squared value of 0.6299 and an Adjusted R-squared of 0.5614. In the long term, the coefficient for LnGDP is positive and statistically significant at 0.5170 (p-value = 0.004). Given that CO_2 emissions and per capita GDP are measured in natural logarithm form, this coefficient indicates that a 1% increase in per capita GDP results in a 0.517% increase in CO_2 emissions, assuming other variables remain unchanged.

LnPOP exhibits a positive and statistically significant long-run coefficient of 2.1133 ($p < 0.001$). The log–log specification indicates that a 1% increase in population corresponds to an estimated 2.113% increase in CO_2 emissions, controlling for other variables. This coefficient suggests a strong positive relationship between demographic scale and long-run carbon emissions. Conversely, ihs_FDI demonstrates a negative and statistically significant long-run coefficient of −0.00239 ($p = 0.032$). Since FDI is transformed using the inverse hyperbolic sine rather than the natural logarithm, this coefficient does not represent conventional elasticity. A one-unit increase in the IHS-transformed FDI measure is associated with an estimated 0.239% reduction in CO_2 emissions, controlling for other variables. The negative coefficient is more consistent with the Pollution Halo perspective than with the Pollution Haven Hypothesis, although the model does not specify the mechanisms by which FDI may affect emissions.

The short-run estimates demonstrate consistent coefficient directions. ΔLnGDP exhibits a positive and statistically significant coefficient of 0.6583 ($p = 0.031$), suggesting that a 1% increase in GDP per capita corresponds to an approximately 0.658% rise in CO_2 emissions in the short run. Similarly, ΔLnPOP is positive and statistically significant, with a coefficient of 1.7290 ($p = 0.004$), indicating that a 1% increase in population is associated with an approximately 1.729% increase in CO_2 emissions. These findings suggest that both economic growth and population expansion are positively correlated with short-run changes in emissions.

The coefficient for Δihs_FDI is estimated at −0.00196, showing statistical significance with a p-value of 0.018. Like the long-term coefficient, this estimate should be understood in relation to the IHS-transformed FDI measure rather than as an elasticity. A single unit alteration in the IHS-transformed FDI measure results in an approximate 0.196% decrease in CO_2 emissions in the short term. The negative short-term FDI coefficient aligns with the long-term findings and is further explored in the Discussion section, where it is analyzed considering the opposing Pollution Haven and Pollution Halo hypotheses regarding FDI's environmental impact. The adjustment coefficient is valued at −0.8182, with a high level of statistical significance at 1% ($p<0.001$).

Table 6. Robustness Checks of Long-Run Estimates

Variables	FMOLS		DOLS		CCR	
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
LnGDP	0.4504355	0.000	0.7418729	0.000	0.4506712	0.000
LnPOP	2.250797	0.000	1.774754	0.000	2.250266	0.000
ihs_FDI	-0.0012337	0.000	-0.0015443	0.000	-0.001236	0.000
Constant	-27.11888	0.000	-20.2583	0.000	-27.11034	0.000

Table 6 reports robustness check estimates of the long-run. Across all three estimators, LnGDP and LnPOP remain positive and statistically significant, whereas ihs_FDI remains negative and statistically significant. Although coefficient magnitudes vary across estimators, the directions of the estimated relationships are consistent with the ARDL long-run results.

The consistency of coefficient signs across FMOLS, DOLS, and CCR indicates that the principal long-run findings are not dependent on a single estimation procedure. These results therefore provide evidence of estimator robustness for the direction of the relationships. However, the alternative estimators do not eliminate potential specification concerns, including omitted-variable bias arising from variables not included in the parsimonious model.

Validity of the ARDL estimation outcomes is also dependent on the soundness of the estimated model in statistical terms. This is why several diagnostic tests are carried out after the estimation process to test for the presence of any serial correlation, heteroscedasticity, or deviation from normality among the residuals. Furthermore, the issue of parameter stability is checked through CUSUM and CUSUMQ tests. These diagnostic tests help determine the adequacy of certain underlying assumptions of the model apart from estimating coefficients.

Table 7. Diagnostic Test Results

Test	Statistic	Prob.	Decision
Breusch–Godfrey LM test	0.302	0.5823	No autocorrelation
Breusch–Pagan/Cook–Weisberg test	0.15	0.6993	No heteroskedasticity
Normality Jarque Bera	0.7854	0.6752	Normality

The diagnostic analysis indicates that there are no significant issues with residuals at a 5% significance level. Initially, the Breusch–Godfrey LM test does not reject the null hypothesis of no serial correlation ($p = 0.5823$). Similarly, the Breusch-Pagan/Cook-Weisberg test does not reject the null hypothesis of homoskedasticity ($p = 0.6993$). Furthermore, the data are normally distributed ($p = 0.6752$). Thus, the estimation results do not reveal any major concerns regarding serial correlation, heteroskedasticity, or residual normality according to these tests. Figure 2 illustrates the outcomes of the CUSUM and CUSUMQ stability tests, showing that both statistics remain within the 5% critical values throughout the evaluation period.

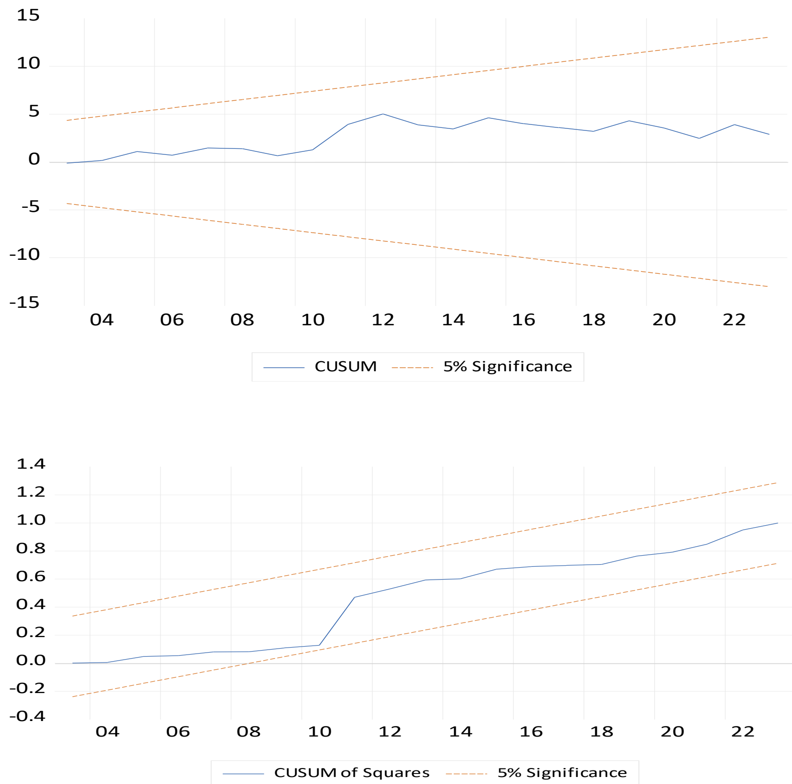

Figure 2. CUSUM and CUSUMQ Stability Tests

Discussion

The empirical results have established an empirical regularity in the dynamic process of carbon emissions in Indonesia. In both the short and long term, GDP per capita and population size have a positive correlation with CO_2 emissions, whereas FDI shows a negative correlation with CO_2 emissions over the same periods. This suggests that economic growth, demographic factors, and foreign investments each have distinct impacts on the environment. The most recent studies in the ASEAN region also confirm that economic growth and population growth continue to be significant factors in the formation of carbon emissions, and their environmental implications hinge on the energy mix, technology, and production conditions (Damayanti et al., 2025; Sugiharti et al., 2025).

The positive GDP per capita variable signifies that economic affluence is still positively correlated with the pressure of carbon emissions in Indonesia. Affluence can stimulate people's consumption, mobility, energy usage, industries, and even economic growth, which depend on fossil fuel energy. Somosi et al. (2024) highlight that increased energy consumption because of economic growth has been leading to higher levels of CO_2 emissions in Southeast Asian economies. Also, according to Damayanti et al. (2025), in ASEAN nations, one major contributor to rising emissions has been economic growth. The slightly elevated coefficient of per capita GDP in the short term suggests that economic prosperity could result in swift economic and energy activities during this period. Nevertheless, the positive coefficient in the long run means that adjustment cannot completely reduce the correlation between emissions and affluence. It would be incorrect to say anything about the Environmental Kuznets Curve since the current regression equation lacks a nonlinear income variable.

Population is another variable that is positively correlated with CO_2 emissions in both horizons, suggesting that demographic scale plays an important role in Indonesia's environmental pressure. A higher population causes increased total demand for energy, transport, infrastructure, commodities, and services, which in turn leads to higher emissions if these needs are met by systems that emit greenhouse gases. Population growth is highlighted by Damayanti et al. (2025) as a primary contributor to CO_2 emissions in

ASEAN countries, whereas Pickson et al. (2024) demonstrate that factors related to population affect CO_2 emissions in all income categories. The greater coefficient of long-term population could mean that the cumulative effects of infrastructure and energy system development necessary to satisfy increased demands have environmental implications. Similar results are provided by Sugiharti et al. (2025), who find that population, economic variables, and energy system features determine emissions in ASEAN countries. Population should be considered a demographic scale factor with environmental implications dependent on the system.

The negative FDI coefficient denotes the most significant theoretical conclusion drawn from the research findings. The association between FDI and CO_2 emissions is found to be negative and statistically significant for the short and long run. Therefore, the results obtained support the idea of the Pollution Halo effect more strongly than the Pollution Haven Hypothesis. The Pollution Halo effect may include cleaner technologies, increased efficiency of production, better management, and technology spillovers related to foreign investments. Zhao (2024) found out that green outward FDI in ASEAN helps reduce carbon emissions in the host country; however, it should be noted that the environmental effect is conditional and is dependent on the sector of investments, enterprise features, and environmental policy. Similarly, Xiang et al. (2024) found that FDI may have a pollution-reduction effect directly and through spillover, but it is determined by the concentration of foreign investments.

However, the fact that the negative coefficient of FDI in the model does not necessarily mean that technology transfer and cleaner production have been found to be the mechanisms that work in Indonesia. In this paper, aggregate FDI is used, and it is not known where the FDI is going to, what kind of technology is being used by those foreign firms, or how intense the environmental impact is. Therefore, it is safe to say that the results are in line with Pollution Halo theory, but not all foreign investments that come to Indonesia make the environment better for sure.

Studies specific to Indonesia provide further reasons for the significance of this result. Pujiati et al. (2023) demonstrate that FDI is only correlated with CO_2 emissions over the long term. This is interpreted as empirical support for Pollution Halo dynamics. The present study also confirms a negative and significant short-term relationship between the two. Meanwhile, Leonardo et al. (2023) identify a positive association between FDI and environmental pollution in Indonesia, thereby endorsing the Pollution Haven hypothesis. Also, Febriyanto et al. (2024) show a positive short-term FDI-CO_2 relationship for Indonesia. These conflicting results make it clear that the environmental implications of FDI in Indonesia haven't been explored empirically and remain ambiguous.

There is additional international literature supporting heterogeneity. For instance, Pham et al. (2025) have established that FDI is related to increased emissions of CO_2 internationally, although the relationship is even more adverse in developing and lower-income countries. In the same way, Liang (2025) has also found the Pollution Haven phenomenon for emerging markets and the Pollution Halo phenomenon for developed markets. Environmental regulation has been identified as a factor influencing the relationship between FDI and emissions. In addition, the findings of Nguyen (2026) show that consumption of renewable energy can moderate the adverse environmental effects of FDI in developing countries. Therefore, the factors of energy structures, environmental regulations, technology, and investment mixes will determine the relationship of FDI with either increased or decreased emissions.

The estimated coefficient of adjustment provides additional proof that the established relationship works in a stable dynamic system. With the adjustment coefficient of -0.818, it means that about 81.8% of the error will be corrected after one period. This quick adjustment suggests that the deviation caused by short-term disturbances will be offset by movements back to the long-run relationship estimated in this model. Pujiati et al. (2023) find an adjustment process statistically significant in their Indonesian ARDL model, even though their adjustment speed is different from what is estimated in this paper. Therefore, it is important to differentiate between the short-run reaction and long-run relationship.

The robustness analysis further supports the principal long-run coefficient directions. FMOLS, DOLS, and CCR consistently produce positive coefficients for GDP per capita and population and negative coefficients for ihs_FDI, indicating that the main long-run conclusions are not dependent on a single estimator. The use of these estimators alongside ARDL has methodological precedent in Indonesian time-series research (Elfaki et al., 2021). However, estimator robustness does not eliminate all forms of model uncertainty. The present specification does not include several potential determinants of CO_2 emissions, including energy consumption, renewable energy, industrialization, and trade openness, all of which may influence environmental outcomes (Shahbaz et al., 2015; Sugiharti et al., 2025). Accordingly, FMOLS, DOLS, and CCR should be interpreted as tests of estimator sensitivity rather than as solutions to potential omitted-variable bias. From a scientific perspective, the distinctive contribution of this study lies in providing updated dynamic confirmation for Indonesia over 1989–2023 rather than claiming to be the first study of FDI and CO_2 emissions in the country. The analysis jointly examines GDP per capita, population, and FDI, distinguishes short-run adjustments from long-run relationships, and evaluates the stability of the long-run coefficient directions using alternative cointegration estimators. The finding that FDI remains negatively associated with CO_2 emissions in both horizons adds evidence to an Indonesian literature that has produced competing Pollution Haven and Pollution Halo results (Jahanger, 2022; Pujiati et al., 2023). At the same time, the positive population and GDP-per-capita coefficients indicate that environmentally improving relationships associated with foreign investment can coexist with substantial carbon pressure from domestic economic and demographic expansion. This combined interpretation provides a more balanced explanation of Indonesia's emission dynamics than examining FDI in isolation.

The robustness analysis further supports the principal long-run coefficient directions. FMOLS, DOLS, and CCR consistently produce positive coefficients for GDP per capita and population and negative coefficients for ihs_FDI, indicating that the main long-run conclusions are not dependent on a single estimator. The use of these estimators alongside ARDL has methodological precedent in Indonesian time-series research (Elfaki et al., 2021). Nevertheless, robustness in estimators does not mean the absence of all forms of model uncertainty. The current model lacks several variables that can serve as possible drivers of CO_2 emissions in Indonesia, namely energy consumption, renewable energy production, industrialization, and openness to international trade. Consequently, FMOLS, DOLS, and CCR estimation should be regarded as sensitivity tests rather than as a solution to the problem of omitted variable bias. From a scientific point of view, the novelty of this study consists in providing dynamic evidence updated to 1989-2023 instead of being the first study about FDI and CO_2 emissions in Indonesia. It analyses GDP per capita, population, and FDI; separates short- and long-run dynamics; and performs a robustness test of long-run coefficient directions using different cointegration estimation techniques. The finding about the negative FDI and CO_2 contributes to the body of literature about FDI and CO_2 emissions that has produced two competing hypotheses in Indonesia – the Pollution Halo and Pollution Haven. At once, the positive population and GDP-per-capita coefficients indicate that environmentally improving relationships associated with foreign investment can coexist with substantial carbon pressure from domestic economic and demographic expansion. This combined interpretation provides a more balanced explanation of Indonesia's emission dynamics than examining FDI in isolation.

Overall, the study findings point to the fact that the Indonesian environmental problem goes beyond merely the extent of economic and demographic growth to include the carbon intensity and technological aspects of the systems behind it. The negative impact of FDI shows that foreign investment does not necessarily result in high levels of greenhouse gas emissions in all cases, but this will certainly be influenced by the quality of investment, sectors involved, technology used, and environmental regulations. On the other hand, the positive effects of GDP per capita and population imply that the issues of energy efficiency, clean electricity, low-carbon transportation, and sustainable infrastructure continue to matter as economic and demographic growth progresses. ASEAN literature confirms the significance of energy intensity, renewable energy, and investment quality in shaping environmental outcomes.

Conclusion

This paper explores the linkages between per capita GDP, population, foreign direct investment, and CO_2 emissions in Indonesia during 1989 to 2023 by applying the ARDL approach. The findings reveal that there exists a long-run cointegration linkage between the variables under investigation. Per capita GDP and population have been found to be positively and significantly related to CO_2 emissions in the short as well as in the long run, while FDI is negatively related to CO_2 emissions in the short as well as in the long run.

The findings imply that economic affluence and demographic expansion remain important sources of environmental pressure in Indonesia, while the negative FDI relationship is more consistent with the Pollution Halo perspective than with the Pollution Haven Hypothesis. However, this result cannot be regarded as direct evidence that all foreign direct investment (FDI) improves environmental sustainability, as the research does not specify the sectoral composition or technological characteristics of foreign investment. From a policy perspective, reducing emissions requires cleaner energy, more efficient infrastructure, low-carbon transportation, and greater attention to the technological content and environmental performance of foreign investment.

The study is limited by its parsimonious four-variable specification, relatively small annual sample, and the use of aggregate FDI. Other determinants of CO_2 emissions, including energy consumption, renewable energy, industrialization, and trade openness, are not included, and the robustness estimators do not eliminate potential omitted-variable bias. Future research should incorporate additional structural and energy variables, examine sectoral or green FDI, and consider structural breaks, nonlinearities, and interactions between FDI and renewable energy or environmental regulation.

CRediT Author Statement

Dodi Tirtana: Formal analysis and Writing-original draft. **Galih Nugraha**: Conceptualization and writing-original draft. **Muhammad Nurhikmat**: Methodology. **Tiara Pradani**: Data curation. **Dwiyan Al Rasyid**: Formal analysis and Data curation. **Nur Jannah Abdi Aziz**: Conceptualization, Writing-review and editing. All authors reviewed and approved the final version of the manuscript.

Funding Statement

This research received no external funding.

Generative AI Disclosure

During the preparation of this work, the authors used ChatGPT (OpenAI), Grammarly, and Paperpal to improve language paraphrase and readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the final content of the publication.

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