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Does FDI Inflow Harm Environmental Quality in Indonesia? Evidence from ARDL Analysis

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Abstract

As sustainability becomes increasingly embedded in global normative frameworks, the persistent technological and informational asymmetries faced by developing countries remain salient. While previous studies have produced mixed evidence on the environmental effects of foreign direct investment (FDI), limited attention has been given to the combined influence of FDI, trade openness, and industrialization on CO_2 emissions in Indonesia. This study examined whether inward FDI facilitates the transmission of environmentally beneficial practices from foreign enterprises to host economies. The analysis employs an Autoregressive Distributed Lag (ARDL) approach using annual time series data covering the period 1970-2022. The results suggest that, in the long term, FDI can improve environmental quality in Indonesia through reductions in CO_2 emissions. This finding supports the pollution halo hypothesis. In the short term, however, FDI exhibits a negative but insignificant effect, suggesting a gradual transition toward more sustainable operations. Additionally, trade openness and industrialization lead to greater CO_2 emissions, implying that increased trade and industrial activity may elevate the demand for "dirty goods" and consequently diminish environmental quality. The policy implications of this study emphasize the need for long-term strategies that attract environmentally sustainable FDI, support the transition toward cleaner trade and industrial activities, and improve investment procedures to accelerate technology transfer and maximize the positive environmental effects of FDI.

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1. Introduction

In 2015, Indonesia outlined a national emission reduction agenda for the 2020-2030 decade, aiming for cuts of 29% and potentially 41% with overseas support (MoEF, 2021). This pledge positions Indonesia as an increasingly active participant in global climate initiatives and highlights the need to strengthen cooperative international efforts to confront environmental risks. Reducing greenhouse gas emissions requires more ambitious targets from all countries. To align with the 1.5°C global warming threshold, total emissions across all sectors must not exceed 850 million tons by 2030. Enhanced international cooperation and increased financial investments are critical to accelerating decarbonization efforts and ensuring the achievement of global climate objectives (Simanjuntak & Hasjanah, 2023).

In line with its broader development goals, Indonesia has also experienced substantial foreign direct investment (FDI), reaching $22 billion in 2023. This influx of investment is crucial for the country's industrial and economic growth. It can stimulate investment in innovative technologies, including those essential for the climate transition. However, the shift will be disruptive for certain businesses, particularly those in carbon-intensive industries, as it demands changes in both what they produce and how they operate. While fiscal, financial, investment, and trade support can aid this transformation, they alone are not enough. Companies also need access to knowledge, technology, financing, and skills to seize emerging opportunities and adapt to the new reality of carbon pricing and reduced demand for carbon-heavy products. Foreign firms and larger firms tend to score higher in assessments of green business practices (World Bank, 2023).

Attracting FDI may bring advantages by promoting environmentally friendly practices through the introduction of cleaner energy technologies (Abbas et al., 2021). These inflows contribute to enhancing environmental quality and fostering sustainability in the region. Additionally, technology transfers from foreign firms can boost income levels and stimulate economic growth. Higher income, in turn, can lead to improvements in health outcomes through access to nutritious food, better living conditions, and improved healthcare services (Immurana, 2020). As economies develop and grow, greater investment in clean technology and sustainable production methods can help mitigate pollution and improve environmental quality (Ren et al., 2024; Uddin et al., 2024).

However, foreign investors are often attracted to developing countries by abundant natural resources and low labor costs. Unfortunately, the relatively lax environmental regulations in these countries can result in foreign investors neglecting the environmental impact of their industrial activities (Deng et al., 2024; Wencong et al., 2023). While FDI can drive economic growth, it may also have negative consequences for environmental quality (Chi & Meng, 2023; Emmanuel et al., 2023; Sreenu, 2025). This adverse environmental impact may arise when foreign investors neglect environmental externalities and prioritize profit

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maximization, resulting in greater resilience to pollution-intensive production methods and fossil fuel consumption (Viglioni et al., 2024; Yu et al., 2024).

These divergent perspectives place policymakers in a dilemma between attracting FDI inflows at the cost of environmental degradation or prioritizing environmental quality at the expense of potential growth. The debate remains unresolved, given the conflicting empirical evidence and lack of consensus among environmental economists (Boateng et al., 2024; Khan et al., 2023; Siripi et al., 2024). Indonesia, as one of the largest economies in Southeast Asia, exemplifies this policy dilemma. The nation has witnessed significant inflows of FDI, greater trade openness, and rapid industrial expansion, all of which have been central to shaping its economic growth path. Nevertheless, these drivers also exert considerable pressure on environmental outcomes, particularly through rising carbon dioxide (CO_2) emissions. As a principal anthropogenic source of environmental degradation, rising CO_2 emissions pose a major risk and remain a pressing global concern. Most of these emissions stem from industrial activities and fossil fuel combustion, both of which are key engines of economic development.

Figure1. Indonesia's CO_2 Emissions, GDP, and FDI
Source: Our World in Data (2024)

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The trend of CO_2 emissions and FDI in Indonesia over the period 2000-2023 is shown in *(Fig. 1)*. The data reveal a general upward trend in CO_2 emissions, which have more than doubled over the past two decades, rising from an initial level of approximately 300 million tons. On the supply side, the majority of CO_2 emissions come from deforestation and fires, which account for 42% of Indonesia's total gas emissions. Activities such as agricultural and forestry practices have been the major drivers of land cover change, due to timber extraction for export and rapid expansion of pulp and paper plantations. In addition, the conversion of mangrove forests into agricultural land and aquaculture zones also contributed significantly to Indonesia's emissions (World Bank, 2023). Indonesia's abundant carbon-intensive resources, notably land and energy, are met with strong demand from key sectors such as industry, transportation, urban expansion, agriculture, and trade, all of which drive the country's economic growth. Moreover, rising global demand for key minerals including copper, nickel, and cobalt has increasingly attracted foreign investment to Indonesia, strengthening its role in global industrial supply chains (ASEAN Briefing, 2025).

The similar directional shifts of the green line (GDP) and the blue line (CO_2 emissions) over time imply a strong connection between economic growth and territorial emissions. As the economy expands, emissions also rise, underscoring the environmental consequences of economic development (Ritchie & Roser, 2024). A sharp increase can be observed after 2010 in both emissions and FDI inflows, reflecting Indonesia's deeper integration into global markets and the intensification of industrial activities. Evidence further indicates that per capita CO_2 emissions have been rising faster than GDP growth, suggesting that the current trajectory of economic expansion is increasingly reliant on emission-intensive sectors (OECD, 2010). The influx of FDI supplied essential capital for economic expansion, yet its effects are twofold: while it fostered growth and industrialization, it simultaneously intensified environmental pressures (Bekun et al., 2024).

Hanifah et al. (2023), using the ARDL approach, found that both FDI and trade openness increase CO_2 emissions in Indonesia. Meanwhile, Qian (2024) examined the impact of industrialization on environmental quality in China, India, and Indonesia and reported that industrialization significantly increases per capita emissions through greater reliance on fossil fuels. Despite these findings, limited evidence exists on the combined effects of FDI, trade openness, and industrialization on CO_2 emissions in Indonesia. Understanding these relationships is particularly important because Indonesia seeks to balance investment-led economic growth with its commitment to reducing greenhouse gas emissions. Therefore, a comprehensive assessment of these key economic drivers is needed to provide evidence that supports both sustainable development and climate policy.

This study makes several contributions to the literature on sustainable development in Indonesia. First, it provides a comprehensive assessment of the environmental effects of FDI, trade openness, and industrialization by examining these key economic drivers within unified empirical frameworks. Second, it employs an extensive annual time series dataset spanning

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more than five decades, enabling a more comprehensive evaluation of the evolving relationship between economic development and CO_2 emissions in Indonesia. Third, the ARDL approach is employed to distinguish between short-run adjustment and long-run equilibrium relationship, thereby providing a more nuanced understanding of the persistence of the environmental impacts associated with FDI, trade openness and industrialization. Finally, the findings contribute to the ongoing debate on the determinants of environmental quality and provide policy-relevant evidence to support Indonesia's efforts to achieve sustainable economic growth while advancing the Sustainable Development Goals (SDGs).

2. Literature Review

There are two contrasting hypotheses regarding the impact of FDI on environmental quality. On the negative side, it is argued that multinational firms from advanced economies relocate their operations to developing countries to continue using pollution-generating technologies. Because environmental regulations are less stringent, these firms can operate with outdated technologies. FDI may pose a risk to environmental quality as it often involves pollution-intensive activities. This situation is known as the Pollution Haven Hypothesis (Walter & Ugelow, 1979; Wang et al., 2020). Empirical evidence from Jordan confirms that insufficient regulations can exacerbate the environmental impact of FDI (Alnsour et al., 2024). Many firms, especially in the energy-intensive sector, relocate their operations to Jordan. While these firms contribute to export revenues and job creation, they also pose significant environmental risks. This situation becomes more serious as developing countries compete to attract more investment. In many cases, governments ease environmental requirements for international investors, enabling pollution-intensive industries to gain a comparative advantage through lower compliance costs (Achuo & Ojong, 2025; Arif et al., 2022).

The positive nexus of FDI and pollution can be explained through the scale effect and polluting industry transfer effect. Increased industrial activity often leads to greater fossil fuel consumption and higher pollution emissions (Boubacar et al., 2025; She & Mabrouk, 2023; Xiao et al., 2025). Resource-seeking FDI, especially in sectors such as coal and oil, can further increase environmental degradation through intensified natural resource extraction (Mahmood et al., 2023; Massimiliano et al., 2024; Xie & Zhang, 2024). Rising FDI inflows often stimulate infrastructure development in host countries, including transportation facilities such as roads, railways, and ports. The construction and operation of this infrastructure require significant energy and resource inputs, resulting in increased emissions (Dilanchiev et al., 2024). The environmental effects of FDI depend not only on the volume of investment but also on the sector in which it is concentrated. When FDI is concentrated in pollution-intensive sectors, such as mining and infrastructure, it is likely to exacerbate environmental degradation and increase pollution in host countries (Assamoi et al., 2020). Most FDI has been invested in pollution-intensive manufacturing rather than clean technologies, which may reinforce carbon-intensive development and challenge ASEAN's net zero target (Tran-Nam & Tran, 2026).

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On the other hand, FDI can provide substantial benefits through the transfer of managerial expertise, capital accumulation, and technology (Tanaya & Suyanto, 2024). The Pollution Halo Hypothesis (Birdsall & Wheeler, 1993) encapsulates the opportunity for developing countries to adopt new technologies that promote clean production and enhance environmental quality. Technology spillovers from FDI can strengthen research and development capabilities in host countries by improving core competencies, reducing energy consumption, and lowering production costs (Bello et al., 2024; Fang et al., 2024).

Emerging economies have experienced environmental improvements as FDI increasingly supports cleaner production and sustainable development. Rather than intensifying environmental degradation, FDI has been linked to lower carbon emissions and reduced ecological footprint, suggesting that its technology transfer and innovation benefits outweigh the environmental costs associated with expanded economic activity. Foreign investment has increasingly been allocated to sustainable activities, including green infrastructure, research and innovation, and other environmentally responsible industries, further supporting environmental improvements (Padhan & Bhat, 2026). Moreover, employees in foreign firms can gain advanced technological knowledge, management skills, and experience in a relatively short period, contributing to higher levels of human capital (Hao et al., 2020). FDI exposes emerging market firms to diverse institutional frameworks. Given that institutions provide stability and structure to social life while influencing resource formation, exposure to foreign institutional environments may improve firms' ability to acquire and utilize resources more effectively (Tang & Yang, 2024).

Table 1 summarizes previous empirical studies on the relationship between FDI and environmental quality in Indonesia. While several studies support the Pollution Haven Hypothesis, others provide evidence in favor of the Pollution Halo Hypothesis. These differences may stem from variations in the environmental indicators used, such as CO_2 emissions, ecological footprint, or environmental quality index, as well as differences in the national context. For example, Bello et al. (2024) found that FDI generally improves environmental quality across ASEAN countries but contributes to environmental degradation in Indonesia, suggesting that the environmental effects of FDI may vary across countries depending on their economic, institutional, and environmental conditions.

Chang et al. (2025) examined the environmental effects of FDI across the four most popular FDI destination countries (China, Japan, the United Kingdom, and the United States) and revealed substantial cross-country heterogeneity. While FDI is associated with economic growth accompanied by higher CO_2 emissions in the United States, it contributes to lower pollution levels in China. By contrast, neither the Pollution Halo nor the Pollution Haven Hypothesis is supported in the United Kingdom and Japan, indicating that the environmental impact of FDI depends on country-specific economic structures, regulatory frameworks, and absorptive capacities rather than following a uniform pattern. This evidence highlights that the FDI-environment nexus is context-dependent and cannot be generalized across countries.

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Table 1. Summary of FDI-Environment Nexus in Indonesia

Author(s)	Country	Time Period	Methodology	Variables	Main Results	Hypothesis
Hanifah et al. (2023)	Indonesia	1990-2018	ARDL	CO_2 emissions, FDI, trade	FDI has a positive effect on carbon dioxide emissions in the short run, whereas its impact is insignificant in the long run.	Haven
Pujiati et al. (2023)	Indonesia	1984-2020	ARDL	CO_2 emissions, FDI, energy use, corruption	FDI does not significantly influence environmental degradation in the short run but contributes to improving environmental quality in the long run.	Halo
Pamungkas et al. (2023)	Indonesia	2010-2020	OLS and random effect regression	Environment quality index, air quality index, FDI, domestic investment, regional GDP growth, total population, land size of agriculture, size of province, human development index	FDI contributes to increased environmental degradation	Haven
Nguyen et al. (2023)	ASEAN	2000-2019	Generalized Method of Moments (GMM)	CO_2 emissions, institutional quality, FDI, GDP per capita growth, urbanization, industrial, domestic	FDI increases environmental degradation, whereas strong institutional quality mitigates its	Haven

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Author(s)	Country	Time Period	Methodology	Variables	Main Results	Hypothesis
				investment, trade open, energy consumption, infrastructure	negative environmental impact in ASEAN countries	
Bello et al. (2024)	ASEAN	1981-2022	Driscoll-Kraay panel and cross-sectional autoregressive distributed lag model (CS-ARDL)	Ecological footprint, carbon footprint, CO_2 emissions, total energy consumption, renewable energy, non-renewable energy, real GDP, square of real GDP, FDI	FDI generally reduces environmental degradation across ASEAN countries, supporting the Pollution Halo Hypothesis, although opposite effects are found in Indonesia, the Philippines, and Thailand.	Haven in Indonesia
Tran-Nam & Tran (2026)	ASEAN	2005-2022	Pooled ordinary least squares, feasible generalized least squares (FGLS)	CO_2 emissions, FDI inflows, income, population, fossil fuel energy consumption	FDI is positively associated with sectoral CO_2 emissions	Haven
Padhan & Bhat (2026)	46 emerging countries	2010-2020	Two-step system GMM	Ecological footprint, consumption-based carbon emission, and production-based carbon emission, FDI, economic growth, import, renewable energy consumption, and industrialization.	FDI has a positive effect on environmental quality in the studied emerging countries.	Halo

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Trade activities often lead to increased resource utilization and energy consumption, which can consequently degrade environmental quality (Wang et al., 2022). The nature of products produced in a particular country may contribute to this phenomenon. In South Africa, export products focus on natural resource-intensive commodities such as tin, copper, coal, platinum, gold, and others. An increase in export demand for these commodities is likely to deteriorate the country's environmental quality further.

Additionally, the manufacturing processes and transportation associated with trade liberalization require significant energy consumption, which can amplify environmental harm (Udeagha & Ngepah, 2022). Trade policies designed to promote trade expansion may have detrimental effects on the environment (Van Tran, 2020). However, another study indicates that technological advancements driven by trade openness can foster economic growth while reducing negative externalities (Sohag et al., 2017).

High intensity of industrial activity is frequently correlated with elevated atmospheric pollutant concentrations (Wang et al., 2022). Heavy manufacturing activities can have detrimental effects, including species extinction and elevated CO_2 emissions (Udeagha & Ngepah, 2022). Countries dominated by carbon-intensive industries and with lower levels of development tend to consume more energy and produce higher CO_2 emissions (Yu et al., 2024). In developing countries, electricity generation is predominantly based on fossil fuels, which serve as major contributors to CO_2 emissions (Patel & Mehta, 2023).

3. Research Methods

Annual observations for Indonesia covering the period 1970-2022 are employed in the empirical analysis. Environmental quality is proxied by CO_2 emissions, which serve as the dependent variable. The main explanatory variables include FDI, trade, and industrialization, while population and economic growth are incorporated as control variables. *Table 2* provides definitions and measurements of the variables. All variables are transformed into their natural logarithmic forms for consistency and to reduce data variability. Before conducting the empirical analysis, the statistical properties of the variables are examined to determine whether the series display stochastic trends. This step is necessary because time series regressions may yield misleading outcomes when the underlying variables are not stable over time. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) are therefore implemented to identify the order of integration of each series. Employing both approaches provides additional confirmation regarding whether the variables stabilize in their original form or after differencing.

Following the assessment of integration properties, the ARDL framework is adopted to explore potential equilibrium relationships among the variables. This approach is particularly suitable in situations where the variables exhibit different integration orders but do not exceed first-order integration. Compared with conventional cointegration techniques, such as the

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Engle-Granger and Johansen methods, which generally require variables to be integrated of the same order, the ARDL approach is more appropriate for the present study. Moreover, ARDL simultaneously estimates both the short-run dynamics and the long-run equilibrium relationship within a single framework. The existence of a long-term association is evaluated using the bounds testing procedure. When evidence of cointegration is obtained, the specification incorporates an error correction representation to capture the adjustment of short-run deviations towards equilibrium. In the absence of such a relationship, the analysis focuses on the short-run dynamics of the model. The reliability of the estimated specification is subsequently evaluated through a series of post-estimation diagnostic checks.

Table 2. Description of The Data Set

Variables	Definition	Measurement	Source
CO_2	Annual per capita CO_2 emissions, excluding emissions from land use, land-use change, and forestry (LULUCF).	Metric tons of CO_2 equivalent per capita	World Development Indicators
FDI	Net inflows of foreign investment with a lasting management interest (10% or more of voting stock), expressed as a percentage of GDP	Net inflows (% GDP)	World Development Indicators
TO	The total value of exports and imports of goods and services.	Trade (% of GDP)	World Development Indicators
INDUS	Value added generated by the industrial sector, including mining, manufacturing, construction, electricity, water, and gas.	Industry value added (% of GDP)	World Development Indicators
POP	Total resident population, regardless of legal status or citizenship	Total population (persons)	World Development Indicators
EG	Total income generated from the production of goods and services, expressed on a per capita basis	GDP per capita (current US$)	World Development Indicators

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ADF test

The ADF test is conducted by adding the lag of the dependent variable ΔY_t into the regression equation (Dickey and Fuller, 1981). The ADF test equation is as follows:

$$\Delta Y_t = a_1 + a_2 t + bY_{t-1} + \sum_{t=1}^{m} c_1 \Delta Y_{t-1} + \varepsilon_t$$

Where ΔY_{t-1} is the first difference of the dependent variable, a_1 is intercept, a_2 is the coefficient of the time trend, b is the coefficient specifying unit root and ε_t is a pure white noise error term. According to conventional guidelines, the null hypothesis is accepted if the data pass the unit root test ($b = 0$). Therefore, if the hypothesis is rejected, the variable is said to be stationary.

Phillips-Perron test

Several alternatives to the Dickey–Fuller tests have been proposed, some aimed at improving finite sample properties, while others seek to accommodate more general modeling frameworks (Greene, 2018). Phillips-Perron test is computed as follows (Phillips & Perron, 1988):

$$y_t = \delta_t + \gamma y_{t-1} + \gamma_1 \Delta y_{t-1} + \cdots + \gamma_p \Delta y_{t-p} + \varepsilon_t$$

The modified dickey-fuller statistics are as follows:

$$Z_\tau = \sqrt{\frac{c_0}{a}} \left(\frac{\gamma - 1}{v} \right) - \frac{1}{2}(a - c_0) \frac{Tv}{\sqrt{as^2}},$$

$$Z_\gamma = \frac{T(\gamma - 1)}{1 - \gamma_1 - \cdots - \gamma_p} - \frac{1}{2} \left(\frac{T^2 v^2}{s^2} \right) (a - c_0)$$

Where

$$a = c_0 + 2 \sum_{j=1}^{L} \left(1 - \frac{j}{L+1} \right) c_j$$

$$c_j = \frac{1}{T} \sum_{s=j+1}^{T} e_t e_{t-s}$$

$$c_0 = \left[\frac{T - K}{T} \right] s^2$$

ARDL bounds testing

Pesaran introduced a new approach to cointegration testing known as the ARDL bounds testing method, which offers several advantages over conventional techniques (Pesaran et al., 2001). These advantages include: (1) Applicability to relatively small sample sizes; (2) The technique can be applied for different order variables as long as it is a mixture of I(0) and I(1); (3) Use of a single equation, which simplifies both implementation and interpretation; (4) The ability to apply different lag terms for different variables, allowing for the deduction

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of dynamic error correction models; (5) It generates unbiased estimates and effectively addresses econometric issues such as endogeneity, omitted variable bias, and autocorrelation. The equation below specifies the model employed to assess the presence of cointegration among the variables:

$$\begin{aligned}\Delta lnCO_{2t} = \alpha_0 &+ \sum_{i=1}^{m} \gamma_1 \Delta lnCO_{2t-i} + \sum_{i=0}^{m} \gamma_2\, \Delta lnFDI_{t-i} \\ &+ \sum_{i=0}^{m} \gamma_3 \Delta lnTO_{t-i} \\ &+ \sum_{i=0}^{m} \gamma_4 \Delta lnINDUS_{t-i} \\ &+ \sum_{i=0}^{m} \gamma_5 \Delta lnPOP_{t-i} + \sum_{i=0}^{m} \gamma_6 \Delta lnEG_{t-1} + \theta_1 lnCO_{2t-1} + \theta_2 lnFDI_{t-1} \\ &+ \theta_3 lnTO_{t-1} + \theta_4 lnINDUS_{t-1} + \theta_5 lnPOP_{t-1} + \theta_6 lnEG_{t-1} + \varepsilon_t\end{aligned}$$

Where ε_t is a serially uncorrected error term, Δ shows the first difference operator, the short-run coefficient γ captures the immediate effects of changes in the explanatory variables on CO_2 emissions. In contrast, the long-term coefficient θ represents the equilibrium relationship between the variables over time. The null hypothesis is that no cointegration exists against the alternative hypothesis that cointegration exists. The ARDL bounds testing approach employs a joint F-statistic and a non-standard asymptotic distribution. This method requires calculating two sets of critical values: the lower critical bounds and the upper critical bounds. The presence of a long-run relationship is confirmed when the F-statistic is greater than the upper critical value. In contrast, the absence of a long-run relationship is detected when the statistics are lower than the lower critical value. When the F-statistic lies between these two critical values, the test result is inconclusive.
For the short-run ARDL model, the error correction model is as follows:

$$\begin{aligned}\Delta lnCO_{2t} = \beta_0 &+ \sum_{i=1}^{q} \vartheta_1 \Delta lnCO_{2t-i} + \sum_{i=1}^{q} \vartheta_2 \Delta lnFDI_{t-i} + \sum_{i=1}^{q} \vartheta_3 \Delta lnTO_{t-i} \\ &+ \sum_{i=1}^{q} \vartheta_4 \Delta lnINDUS_{t-i} + \sum_{i=1}^{q} \vartheta_4 \Delta lnPOP_{t-i} + \sum_{i=1}^{q} \vartheta_5 \Delta lnEG_{t-i} + \varphi ECT_{t-i} \\ &+ \mu_t\end{aligned}$$

Where ϑ reflects the short-run variability and φ represents the error correction coefficient. After a temporary disturbance, the speed at which the system returns to its long-run equilibrium is captured by the coefficient φ, which should take a value between -1 and 0. Convergence toward equilibrium is supported when ECT carries a negative and significant impact.

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To ensure the reliability of the estimated model, several diagnostic procedures are performed. The presence of serial correlation and heteroscedasticity is evaluated using the Breusch-Godfrey LM test and the Breusch-Pagan-Godfrey test. The distribution of the residuals is further examined through the Jarque-Bera test to determine whether the normality assumption is satisfied. In addition, the Ramsey RESET test is conducted to assess potential model misspecification. The stability of the estimated parameters over time is also investigated by applying the CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (Cumulative Sum of Squares of Recursive Residuals) tests.

4. Results

Table 3 presents the descriptive statistics of the transformed variables. CO_2 has a mean of 5.2460 and a standard deviation of 0.9307, indicating relatively low variability. FDI, EG, and INDUS have mean values of about 21.3608, 25.6105, and 25.8690. The positive mean values over the sample period suggest an overall upward trend. For all variables except TO, the mean values exceed their respective standard deviations, indicating relatively stable variation over time. Finally, according to Jarque-Bera value results, all variables follow a normal distribution.

Table 3. Descriptive Statistics

Variables	Mean	Min	Max	SD	Jarque-Bera	P-value
CO_2	5.2460	3.4333	6.5399	0.9307	3.3988	0.1828
FDI	21.3608	18.7059	23.9470	1.8406	4.5268	0.1040
TO	-0.9616	-1.3565	-0.7011	0.1524	0.8438	0.6558
INDUS	25.6105	23.8916	26.7691	0.8548	3.2976	0.1922
POP	19.0764	18.5661	19.4461	0.2715	3.4814	0.1754
EG	25.8690	22.9371	27.9080	1.4131	1.8878	0.3891

The stationarity properties of the variables were evaluated using the ADF and Phillips–Perron methods (*Table 4)*. The findings indicate that POP is stationary in its level specification. Meanwhile, FDI, TO, and INDUS are stationary in level form but become stronger after first differencing. In contrast, CO_2 and EG do not satisfy the stationarity requirement in their initial form and only become stationary once the variables are expressed in first differences. The presence of variables integrated at different orders suggests that the ARDL approach is suitable for the subsequent empirical estimation.

Table 4. Unit Root Test Results

Variables	ADF test		Phillips - Perron		Conclusion
	At Level	First Difference	At Level	First Difference	

CO_2	-1.9028	-6.3202***	-1.8422	-6.2782***	Stationary at I(1)
FDI	-3.7110**	-10.9167***	-3.9258**	-11.1522***	Stationary at I(0)
TO	-3.3510**	-8.6961***	-3.2873**	-9.0082***	Stationary at I(0)
INDUS	-4.2229**	-4.8562***	-4.2229**	-4.7621***	Stationary at I(0)
POP	-3.6646**	-0.9059	-27.7411***	-0.7001	Stationary at I(0)
EG	-2.6723	-6.5026***	-2.7082	-6.4934***	Stationary at I(1)

$^{***}p < .01$, $^{**}p < .05$

Several criteria are available for selecting the appropriate lag length in time series analysis. Based on the evaluations using the Akaike Information Criterion (AIC) and the Hannan-Quinn Information Criterion (HQC), the optimal lag length is determined to be two *(Table 5)*.

Table 5. Lagged Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	124.7894	NA	1.61e-10	-5.5251	-5.2793	-5.4345
1	510.2283	645.3861	1.43e-17	-21.7781	-20.0578*	-21.1437
2	567.7825	80.3081*	5.79e-18*	-22.7806*	-19.5859	-21.6025*

$^{*}p < .1$

In *Table 6,* the outcomes of the ARDL model for the long-run relationship are detailed. The findings indicate that the lagged value of CO_2 emissions significantly affects current emission levels. The coefficient of -0.0248 shows that higher FDI is strongly associated with lower CO_2 emissions. Conversely, trade openness and industrial activity exhibit positive and significant effects on CO_2 emissions. Specifically, a 1% increase in trade openness leads to a 0.3629% rise in CO_2 emissions, while a 1% increase in industrial activity results in a 0.4990% increase in CO_2 emissions.

Table 6. Long-run ARDL Model

Variables	Coefficients	Std. Error	t-statistic
L_CO (-1)	0.6244	0.1264	4.9395***
L_CO (-2)	-0.3632	0.1221	-2.9745***
L_FDI	-0.0248	0.0096	-2.5710***
L_TO	0.3629	0.0883	4.1063***

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L_INDUS	0.4990	0.1329	3.7554***
L_POP	-25.2574	10.6711	-2.3669**
L_POP (-1)	25.5223	10.3799	2.4588**
L_EG	0.0304	0.0324	0.9372
Constant	-13.4307	8.3270	-1.6129
R-squared	0.9979		

***$p < .01$, **$p < .05$

Table 7 highlights the verification of cointegration using ARDL bounds test. The F-statistic (8.9411) and t-statistic (-6.2896) are both greater than the corresponding critical values at the 1%, 5%, and 10% significance levels. Thus, the test results indicate that cointegration is present, leading to the rejection of the null hypothesis.

Table 7. ARDL Bounds Test Results

Critical Bounds	F statistic: 8.9411		t statistic: -6.2896	
	I(0)	I(1)	I(0)	I(1)
1%	4.030	5.598	-3.430	-4.790
5%	2.922	4.268	-2.860	-4.190
10%	2.458	3.647	-2.570	-3.860

In the short-run results *(Table 8),* lagged CO_2 continues to play an important role, showing a significant positive effect on current emissions, reflected by a coefficient of 0.3593. FDI does not exhibit a significant impact in the short run. Additionally, trade openness and industrialization exert short-run pressures on environmental quality, with coefficients of 0.3414 ($p<.05$) and 0.5331 ($p<.1$) indicating their immediate contribution to rising emissions. The ECT value of 0.7059 ($p<.01$) indicates that about 70.59% of any short-term deviation is adjusted each period, pointing to rapid convergence toward long-run equilibrium, approximately within 1.42 years. This finding suggests that short-run deviations from the long-run equilibrium are temporary, as the relationship between CO_2 emissions, FDI inflows, trade openness, and industrialization adjusts relatively quickly to its equilibrium path. This confirms the stability of the long-run relationship among the variables and implies that long-run environmental policies addressing FDI, trade openness, and industrialization are likely to be more effective than measures focusing solely on short-run fluctuations.

Table 8. Short-run ARDL Model

Variables	**Coefficients**	**Std. Error**	**t-statistic**
D(L_CO (-1))	0.3593	0.1335	2.6906**
D(L_CO (-2))	0.0203	0.1481	0.1369
D(L_FDI)	-0.0179	0.0117	-1.5315
D(L_TO)	0.3414	0.1146	2.9791**

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D(L_INDUS)	0.5331	0.3123	1.7073*
D(L_POP)	18.8357	23.3046	0.8082
D(L_POP (-1))	-19.3499	22.9958	-0.8415
D(L_EG)	0.0120	0.0727	0.1654
Constant	0.0179	0.0243	0.7348
ECT (-1)	-0.7059	0.1870	-3.7743***
R-squared	0.6065		

***$p < .01$, **$p < .05$, *$p < .1$

Table 9 presents the results of the diagnostic tests, indicating that the estimated ARDL model satisfies all key model assumptions. The LM test yields a probability value of 0.9940, implying that the null hypothesis cannot be rejected and, therefore serial correlation is not a concern. The results of the Breusch-Pagan-Godfrey (p = 0.2520) suggest that the variance of the disturbance term remains constant across observations, while the Jarque-Bera statistic (p = 0.6695) indicates that the residual distribution does not deviate from normality. As the probability value of the Ramsey RESET test is 0.5115, it does not reveal any indication that the functional form of the equation is incorrectly specified.

Table 9. Diagnostic Test Results

Diagnostic test results	Breusch-Godfrey LM test		Breusch-Pagan-Godfrey		Jarque-Bera		Ramsey RESET test	
	F-stat	Sig.	F-stat	Sig.	Stat.	Sig.	F-stat	Sig.
	0.0060	0.9940	1.3465	0.2520	0.8025	0.6695	0.4396	0.5115

The CUSUM and CUSUMSQ procedures assess potential shifts in parameters over time (*Fig. 2*). The results show that the blue line consistently lies within the 5% critical range; the test reveals stable parameters throughout the observed timeframe. Because the lines do not cross the boundaries, the null hypothesis of parameter stability cannot be rejected. This confirms that the ARDL model is stable and that no systematic change in the parameters occurs over time. The findings from the diagnostic tests demonstrate that the estimated ARDL model is statistically adequate, thereby providing a reliable basis for subsequent interpretation of the estimation results.

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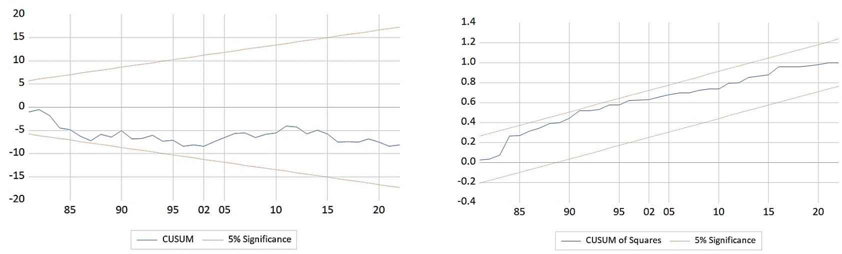

Figure 2. CUSUM and CUSUM of Squares

Discussion

FDI inflows in Indonesia appear to contribute to improved environmental quality by reducing CO_2 emissions. This indicates that FDI entering host countries is conducted in an eco-conscious manner and contributes to the "halo effect" (Eweade et al., 2024; Phung et al., 2023; Tripathy et al., 2022). Advanced production technologies introduced by foreign investors not only enhance resource efficiency but also significantly reduce environmental pollution. Furthermore, they facilitate the transformation of traditional industries into energy-efficient, low-carbon-emitting sectors, driving sustainable industrial growth (Bhujabal et al., 2021; Zhou et al., 2024). Recent economic advancement has increased awareness of environmental issues, which may influence the way FDI affects environmental quality. Consequently, foreign investment may facilitate the diffusion of cleaner technologies and environmentally friendly practices (Bergougui & Murshed, 2025; Yi et al., 2023).

Multinational investors commonly follow global environmental guidelines that exceed local regulatory requirements. The transfer of such standards can enhance environmental management practices in host economies (Georgescu & Kinnunen, 2024). Consistent with this mechanism, our finding supports the results of Pujiati et al. (2023), who reported that FDI improves environmental quality in Indonesia over the long run, providing evidence for the Pollution Halo Hypothesis. Similar evidence has also been documented in emerging economies, where technology transfer and improved production efficiency associated with FDI contribute to lower environmental degradation (Padhan & Bhat, 2026).

On the other hand, trade openness and industrial activities may deteriorate environmental quality. Indonesia's export structure is dominated by the industrial sector, which accounts for approximately 73% of total exports, followed by the mining sector at 19.43%. The country's main export commodities consist of mineral fuels, animal fats and oils, as well as iron and steel. Within the mining sector, coal remains the leading export commodity, representing more than 70% of total mining exports in 2022 (Indonesian Central Board of Statistics, 2023). The growth of international trade can increase the exchange of energy-intensive products and technologies, commonly referred to as "dirty goods," which contribute significantly to environmental pollution due to their high energy consumption and harmful production processes (Bhujabal et al., 2021).

This result is consistent with Hanifah et al. (2023), who also found that trade openness contributes to environmental degradation in Indonesia. One possible explanation is that the environmental costs associated with expanding trade are not fully internalized due to weaknesses in environmental regulation and enforcement. Consequently, firms may continue to engage in pollution-intensive production practices, resulting in higher CO_2 emissions. Although trade expansion supports economic development, it is often accompanied by higher non-renewable energy consumption. Consequently, the continued growth of international trade may pose greater environmental risks by increasing dependence on fossil-based energy sources (Dingru et al., 2023; Xuan, 2025).

Industrial activity itself is a major contributor to CO_2 emissions. Industries heavily rely on fossil fuels, a primary source of atmospheric CO_2 (Muhammad et al., 2022; Patel & Mehta, 2023). To mitigate the environmental impacts of industrialization, many emerging economies have adopted more advanced technologies and gradually transitioned from pollution-intensive industries to cleaner manufacturing and service sectors. Nevertheless, these efforts have not been sufficient to reduce environmental degradation significantly (Padhan & Bhat, 2026).

In contrast to the long-run findings, FDI does not exert a statistically significant influence in the short run. This outcome is reasonable, as the transfer of knowledge, management practices, and sustainable production methods from foreign investors to domestic companies requires time to take effect fully. These learning processes gradually improve productivity and environmental outcomes, making their impact more evident over the long term rather than immediately (Kim & Seok, 2023; Li et al., 2025). Furthermore, the investment realization process in Indonesia is relatively slower than neighboring countries such as Vietnam. While investment projects in Vietnam typically require around two years to become operational, the realization process in Indonesia generally takes four to five years. During the initial one to two years, investors primarily focus on obtaining permits and completing administrative procedures. As a result, the transfer of technology, managerial expertise, and production knowledge is unlikely to occur immediately, which may explain the insignificant short-run effect of FDI on environmental quality (IDNFinancials, 2025).

5. Conclusion and Suggestion

The investigation explores the consequences of FDI, trade openness, and industrialization on CO_2 emissions in Indonesia throughout 1970-2022. Results from the ARDL estimation suggest that FDI inflows in Indonesia support environmental sustainability in both the short and long run. Greater FDI intensity corresponds with reduced CO_2 output, suggesting that foreign investments in Indonesia are increasingly eco-conscious and contribute to the transformation of traditional industries toward more energy-efficient practices. In the near term, the FDI coefficient does not attain statistical relevance. This could reflect the diffusion of superior technology and skills from foreign enterprises typically unfolding gradually rather than immediately. Trade and industrialization are found to negatively affect the environment, primarily due to their reliance on fossil fuels.

This study offers several important policy implications. First, FDI plays a crucial role in improving environmental quality in Indonesia. To attract high-quality and environmentally sustainable FDI, the government should provide incentives such as tax reductions for firms adopting renewable energy and cleaner production technologies, as well as other measures that encourage green investment. Second, given that trade openness and industrialization contribute to higher CO_2 emissions, the government should reform existing trade and industrial policies to promote cleaner production and green innovation. In addition, environmental regulations should be more effectively enforced to ensure that firms internalize the environmental costs of their activities through the implementation of the polluter pays principle.

Third, our findings highlight the importance of adopting a long-term policy perspective. Since the environmental benefits of FDI materialize gradually, the government should improve the investment climate by streamlining business procedures and reducing the time required for investment realization. A more efficient investment process can facilitate earlier technology transfer, managerial learning, and the adoption of cleaner production practices, allowing the environmental benefits of FDI to emerge more quickly.

This study is not without limitations. First, environmental quality is proxied solely by CO_2 emissions, as it represents the most dominant contributor to the greenhouse effect. However, future studies may employ broader indicators such as green growth to provide a more comprehensive assessment of the environmental impact of FDI. Second, this study does not account for other potentially important determinants, such as financial development, green innovation, and education level, which may influence the nexus of FDI and CO_2 emissions. Incorporating these variables may provide deeper insight into the mechanisms linking FDI and environmental outcomes.

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Commented [m1]: There must be 50 references, 60% of which must come from WOS articles, Scopus, and reputable international journals.

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