



# “Foreign direct investment and carbon emissions in developing economies: The moderator of renewable energy consumption”

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# FOREIGN DIRECT INVESTMENT AND CARBON EMISSIONS IN DEVELOPING ECONOMIES: THE MODERATOR OF RENEWABLE ENERGY CONSUMPTION

## Abstract

This study delves into the combined impact of foreign direct investment (FDI) and renewable energy consumption (REC) on carbon emissions (CO<sub>2</sub>) in developing countries. The primary objective is to assess the moderating role of renewable energy consumption in the impact of FDI on CO<sub>2</sub> emissions in 50 developing countries from 2013 to 2021. To ensure rigorous accuracy in addressing potential endogenous issues in the proposed model, this study employs a two-step systematic generalization estimation (S-GMM) method. The results show that the individual impact of FDI on CO<sub>2</sub> emissions is positive and statistically significant, further verifying the Pollution Haven Hypothesis. Meanwhile, the combined impact of FDI and REC is inversely related to CO<sub>2</sub> emissions. This is considered a significant finding because renewable energy consumption can mitigate the negative impact of FDI on CO<sub>2</sub> emissions, supporting the Pollution Halo Hypothesis. Furthermore, REC and innovation are important supporting factors in emission reduction, implying that if developing countries prioritize clean energy use and clean technology transfer, it will significantly reduce environmental pressure. On the other hand, trade openness, natural resource rents, and economic growth have statistically significant positive effects on CO<sub>2</sub> emissions; increases in these variables lead to higher CO<sub>2</sub> emissions. Overall, the importance of REC shows that policies promoting clean energy transition are necessary for FDI to play a positive role in reducing carbon emissions instead of becoming an increasing source of environmental pollution.

## Keywords

carbon emissions, foreign direct investment, renewable energy consumption, developing countries, S-GMM

## JEL Classification

Q53, F35, O13, Q56

## INTRODUCTION

Global climate change is now considered one of the most serious environmental challenges of the 21<sup>st</sup> century due to its association with fossil fuel consumption (Raihan & Tuspekova, 2022). Since carbon dioxide (CO<sub>2</sub>) emissions are considered the main cause of global warming (Shahbaz et al., 2019) and environmental pollution (Tiba & Omri, 2017), environmental degradation is increasingly attracting the attention of both policymakers and non-governmental organizations (Gyimah et al., 2023). Despite increasing international efforts to control and mitigate CO<sub>2</sub> for natural ecosystems and economic growth (Adedoyin et al., 2020; Dauda et al., 2021), economies are facing unpredictable fluctuations in the global climate system due to climate change (Nguyen et al., 2021b).

In the context of economic development and global integration, foreign direct investment (FDI) is a crucial and effective channel for attracting capital. FDI assists host countries in improving their production capacity, accessing advanced technology, enhancing labor skills,

and promoting knowledge transfer (Samuelson, 1948). Several studies also affirm that attracting FDI is a crucial issue for each country (Farooq et al., 2025; Pham et al., 2025). However, FDI inflows can weaken the competitiveness of domestic businesses, encourage overexploitation of natural resources, and contribute to environmental degradation (Ayamba et al., 2020). This is because in pursuing rapid economic growth, developing economies tend to downplay or ignore issues related to environmental protection and sustainable development (Nguyen et al., 2020). Furthermore, Sebri (2015) argues that energy production and consumption play a key role in achieving and maintaining sustainable long-term economic growth. In developing countries, industrialization is proceeding at a high rate, while the continued use of non-renewable energy sources such as fossil fuels in production exacerbates emissions (Jie & Rabnawaz, 2024). Based on this view, Fu et al. (2021) affirmed the irreplaceable role of renewable energy.

The scientific issue revolves around the findings that FDI and renewable energy consumption (REC) have individual impacts on CO<sub>2</sub> emissions, but the interaction effects remain unclear. While reducing CO<sub>2</sub> emissions and improving environmental conditions are global concerns to ensure long-term growth and mitigate the adverse consequences of climate change (Raihan & Tuspekova, 2022; Wang & Wang, 2023), the lack of real validation may overlook the inherent impact on environmental pollution. This underscores the need for thorough scientific investigation into the role of REC in the environmental impact of FDI on CO<sub>2</sub> emissions. Understanding the interactive relationship enhances approaches for attracting FDI while ensuring environmental sustainability.

## 1. LITERATURE REVIEW

The impact of foreign direct investment (FDI) on CO<sub>2</sub> emissions is attracting much scientific discussion on environmental issues. The initial premise emphasized that the Environmental Kuznets Curve (EKC) links economic development with environmental degradation (Tripathy et al., 2025). According to EKC, three channels describe the impact of FDI on CO<sub>2</sub> emissions, including scale effects, component effects, and engineering effects (Grossman & Krueger, 1995). From these three impact channels, the EKC theory has been expanded by suggesting that if most existing studies show that scale effects negatively impact environmental quality (Liu et al., 2018), and if scale effects and component effects outweigh engineering effects, this creates a Pollution Haven Hypothesis (PHH) (Tripathy et al., 2025). Meanwhile, in cases where engineering and component effects outweigh scale effects, the Pollution Halo Hypothesis (PHL) is generated (Pazienza, 2019; Shahbaz et al., 2018). Some studies suggest that FDI flows are linked to increased CO<sub>2</sub>, while others emphasize the potential for improving environmental quality through technology transfer and efficiency enhancement. Prior studies also examine the role of REC in mitigating pollution (Andrei et al., 2025; Madaleno & Nogueira, 2023).

In the ASEAN region, several empirical studies have shown the impact of FDI on CO<sub>2</sub> emissions. Febriyanto et al. (2024) investigate the short-term and long-term impacts of FDI on CO<sub>2</sub> emissions in countries with high FDI levels, including Singapore, Indonesia, Malaysia, and Vietnam, between 1990 and 2020 using Autoregressive Distributed Lag (ARDL) analysis. The study confirms that the positive short-term impact of FDI on CO<sub>2</sub> was observed in Singapore and Indonesia, while a negative impact was observed in Vietnam. Regarding the long-term relationship, positive impacts were found in Vietnam and Singapore. Nasir et al. (2019) examine a sample of the five largest economies in ASEAN (Singapore, Thailand, Malaysia, the Philippines, and Indonesia) between 1982 and 2014 using the Dynamic Ordinary Least Squares and the Fully Modified Ordinary Least Squares methods. The results show that FDI has a statistically significant long-term cointegration relationship with environmental degradation (CO<sub>2</sub> emissions), meaning that increased FDI leads to increased environmental degradation.

Tripathy et al. (2025) show a long-term relationship between FDI and CO<sub>2</sub> emissions in India by employing the Johansen cointegration and Granger causality tests. Notably, the results indicate that the impact of FDI on CO<sub>2</sub> emissions is

primarily transmitted through indirect channels, including changes in energy structure, industrial structure, and increased use of high-carbon technologies. These findings imply that FDI can exacerbate environmental pollution problems if allocated to carbon-intensive industries. It also highlights the role of policy orientation in redirecting FDI toward cleaner and lower-emission technologies to promote sustainable growth. Similarly, Rana and Sharma (2020), using a dynamic multivariate Toda-Yamamoto and modified Wald test, also affirm the existence of the PHH in India. Solarin et al. (2017) confirm the PHH in Ghana during the period 1980–2012 by using the ARDL method. Specifically, the empirical results indicate that increased FDI is associated with higher CO<sub>2</sub> emissions. The existence of PHH has also been verified in Asian countries (Abbasi et al., 2023), China (Ozkan et al., 2023), Romania (Chiriluş & Costea, 2023), and BRICMT countries (Ozcelik et al., 2024).

On the other hand, several prior experimental works support the PHL. From this perspective, FDI promotes the transfer of clean technologies through spillover effects, modernizes production, enhances innovation, and improves environmental quality (Aust et al., 2020; Wang et al., 2021; Yilanci et al., 2019; Zhu et al., 2016). Leitão et al. (2023) further noted that FDI flowing into countries with stricter environmental regulations leads to environmental improvements, which is consistent with the PHL. Furthermore, some studies also suggest that the isolated impact of FDI on CO<sub>2</sub> emissions is inverse. Specifically, Zhou et al. (2013) used a dynamic panel data model to assess the environmental impact of industrial structural transformation. Additionally, Mert and Bölük (2016) used unbalanced panel data between 2002 and 2010, from 21 countries participating in the Kyoto Protocol, and applied the ARDL approach. The results support PHL and affirm that FDI brings clean technology and improves environmental standards. In China, using panel data from 112 cities during the period 2002–2015, Liu et al. (2017) used the first-difference GMM method and found that FDI had a negative impact on pollution factor, measured by per capita SO<sub>2</sub> emissions and soot. Therefore, policies need to be designed to enhance the positive impact of FDI on the environment. Similarly, Huang et al. (2019) used panel da-

ta from Chinese provinces between 1997 and 2014 and applied quantile regression. The study finds that the impact of FDI on CO<sub>2</sub> emissions was negative and statistically significant, except at the 5<sup>th</sup> and 10<sup>th</sup> percentiles.

Since economic growth is closely linked to energy consumption demand (Fu et al., 2021), the shift from fossil fuels to clean energy sources has become a central goal of sustainable energy development (Nguyen et al., 2021a). Renewable energy is widely recognized for its ability to reduce CO<sub>2</sub> emissions and improve the quality of the ecological environment (Charfeddine & Kahia, 2019). Deng and Du (2020) and Saidi and Omri (2020) both indicated that renewable energy can reduce global CO<sub>2</sub> levels. In the same vein, the impact of REC on CO<sub>2</sub> emissions has been extensively analyzed in prior empirical studies, reflecting the growing academic interest in identifying sustainable growth pathways in the context of increasingly severe global climate change. Hu et al. (2018) examine the sample of 25 developing countries and find that CO<sub>2</sub> emissions decreased significantly due to the direct role of REC. Specifically, increasing the proportion of REC reduces CO<sub>2</sub> emissions, and developing countries consider promoting trade in services and the proportion of REC to achieve low-carbon economic growth. Furthermore, by applying FMOLS and DOLS methods, the role of REC was confirmed by Chen et al. (2019) as contributing to CO<sub>2</sub> emission reduction and environmental quality improvement in China through renewable energy consumption. Similarly, Dauda et al. (2021) showed that renewable energy also reduced CO<sub>2</sub> in middle-income African countries, including 9 countries, namely Tunisia, Algeria, Mozambique, Egypt, Kenya, Morocco, Mauritius, Zambia, and South Africa, from 1990–2016, using a fixed-effect model and generalized method of moments (GMM) for the panel and ordinary least squares (OLS) for individual countries.

By applying advanced econometric methods such as the method of moments quantile regression (MMQR), Sun et al. (2025) found that CO<sub>2</sub> emissions can be mitigated, leading to more sustainable environmental improvements in BRICS economies through renewable energy. Similarly, in the BRICS economies, Chen and Lubabu (2026) used data from BRICS-MA countries – Brazil,

India, Russia, China, South Africa, Mexico, and Argentina – over 22 years, corresponding to the research period from 1999 to 2021, and used panel vector autoregression (VAR)/generalized method of moments (GMM), and Granger causality analysis. The results showed a complex and dynamic interdependence between these variables, in which REC showed a negative impact on CO<sub>2</sub> emissions.

On the other hand, by selectively inheriting the ideas of Makki and Somwaru (2004), Huang et al. (2019) found that the indirect positive impact of FDI and international trade on CO<sub>2</sub> emissions is greater than the direct negative impact in China; therefore, the overall effects are positive and more harmful to the environment. Furthermore, Limazie and Woni (2024) found that the combined impact of FDI and governance quality on CO<sub>2</sub> emissions is negative in ECOWAS, implying that stronger institutional quality helps reduce the negative effect of the FDI environment on environmental degradation.

In addition to the key factors mentioned above, namely FDI and REC, other relevant variables affecting CO<sub>2</sub> emissions include innovation, trade openness, natural resources rents, and economic growth. First, Dauda et al. (2021) define innovation as the use of new or significantly improved organizational products, processes, tactics, or techniques, including the formation of international strategic partnerships. Furthermore, the innovation variable is increasingly recognized as a key factor in attracting FDI to developing countries (Nguyen, 2024), as well as an effective way to reduce CO<sub>2</sub> emissions in modern environmentally friendly growth models (Dauda et al., 2021; Nguyen et al., 2020). Secondly, the relationship between economic growth and environmental degradation can be explained through the classic Kuznets Environmental Curve hypothesis (Wang et al., 2024). Grossman and Krueger (1995) argued that environmental quality initially deteriorates as economic activity expands; however, once a certain income level is reached, further economic growth will lead to environmental improvement, creating an inverted U-shaped relationship between economic growth and pollution. For instance, Hu et al. (2018) found that economic growth had a significant impact on carbon emissions in 25 major developing countries during the period 1996–2012 through FMOLS and DOLS methods.

Third, as demonstrated in Ghana (Kwakwa et al., 2020), OECD economies (Farooq et al., 2025), and developing countries (Khan & Hassan, 2024), a variety of empirical studies demonstrate a positive impact on natural resource rents and carbon emissions, meaning that environmental degradation can worsen with increased reliance on natural resource extraction. Fourth, trade openness is thought to exacerbate environmental pollution as high-carbon emission industries tend to relocate to countries or regions with less stringent environmental standards and regulations, consistent with the PHH argument (Dauda et al., 2021). Conversely, trade liberalization also facilitates the diffusion of technology, knowledge, and green production practices, thereby contributing to improved environmental efficiency and quality, supporting the PHL (Dauda et al., 2021). Furthermore, empirical evidence from Kasman and Duman (2015) shows that trade expansion in developing countries often faces the additional challenge of importing relatively high-emission industries from developed countries, thus increasing pressure on environmental degradation in these recipient countries. Essandoh et al. (2020) note that increased trade tends to transfer high-emission production units from developed countries to developing countries, forcing developed nations to reduce emissions at the expense of developing countries.

The literature review highlights three key observations. First, foreign direct investment plays a significant role in shaping environmental outcomes in developing economies; however, its impact on CO<sub>2</sub> emissions remains ambiguous, reflecting the coexistence of polluting investments and technology spillover effects. Second, renewable energy consumption is widely recognized as an effective mechanism for mitigating carbon emissions by replacing fossil fuels and promoting cleaner production processes. Third, while more research examines the environmental impacts of FDI and renewable energy separately, empirical evidence on their combined effects remains limited, particularly regarding the moderating role of renewable energy in the link between FDI and emissions. This summary highlights a notable gap in the literature regarding the interaction between FDI and REC in developing countries, where the goals of economic expansion and environmental sustainability often coexist in tension.

Based on the above arguments, developing countries face the dual requirement of both continuing to attract foreign direct investment and promoting the transition to a low-carbon development model through the expansion and increase of renewable energy use. In this context, the current study aims to empirically verify the moderating role of renewable energy consumption in the relationship between FDI and CO<sub>2</sub> emissions in 50 developing countries.

By simultaneously analyzing the direct impact of renewable energy consumption and its indirect impact through its interaction with FDI, the study aims to bridge the gap in existing literature and provide more comprehensive empirical evidence on the environmental consequences of FDI under different energy structures. Based on the research objectives, theoretical arguments, and relevant empirical evidence, the following research hypotheses are proposed:

- H<sub>1</sub>: The impact of foreign direct investment on CO<sub>2</sub> emissions is positive in developing countries.*
- H<sub>2</sub>: The impact of renewable energy consumption on CO<sub>2</sub> emissions is negative in developing countries.*
- H<sub>3</sub>: The combined impact of foreign direct investment and renewable energy consumption on CO<sub>2</sub> emissions is negative in developing countries.*

## 2. METHODS

Based on the empirical models of Kwakwa et al. (2020) and Febriyanto et al. (2024), this study proposes a model to examine the impact of foreign direct investment (FDI) on CO<sub>2</sub> emissions. The general econometric framework can first be expressed as a functional relationship for 50 developing countries over the period 2013–2021:

$$CO_{2it} = \beta_0 + \beta_1 FDI_{it} + \beta_2 REC_{it} + \beta_3 FDI_{it} \cdot REC_{it} + \sum_{i=4}^7 \beta_i C_{it} + \varepsilon, \quad (1)$$

where CO<sub>2</sub> is the dependent variable. The independent variables include FDI, REC, and the moderating effect of FDI·REC. Other control variables include innovation (INN), trade openness (TRA), natural resources rents (NRR), and economic growth (GDP). In Equation (1), the indices *i* and *t* represent the developing countries in the study sample (50 countries) and the observation years in the period 2013–2021 (nine years). Furthermore, unobservable factors that could influence the dependent variable are reflected in the error component  $\varepsilon$ .

In Equation (1), the control variable INN was collected from the Global Innovation Index (Dutta et al., 2017; Nguyen, 2024), while other variables CO<sub>2</sub>, FDI, REC, TRA, NRR, and GDP were taken from the World Development Index (WDI) database. The interaction between the foreign direct investment and renewable energy consumption (FDI·REC) variable was also established based on FDI and REC data sources, which originate from WDI. The dataset includes 50 developing countries for the period 2013–2021, with 450 observations. Measurement and source of variables are presented in Table 1. Empirical analysis was performed using STATA 17.0 software. Research data are publicly available on Mendeley to ensure transparency and reproducibility (Nguyen, 2025).

This study estimates Equation (1) using the Generalized Method of Moments (GMM) to effectively handle potential endogeneity issues. The GMM method, proposed by Hansen (1982), is considered superior to traditional instrumental variable techniques such as 2SLS, especially in the context of heterogeneity among observed units (Baum et al., 2003). In addition, traditional estimation methods such as OLS and fixed effects model (FEM) have many limitations in ensuring the stability of covariance estimates when applied to panel data with a large number of observed units but short time dimensions (N = 50, T = 9) (Allison & Waterman, 2002). The flexible GMM framework can handle unbalanced data sets and multiple endogenous variables (Roodman, 2009). Moreover, GMM techniques are considered superior to conventional OLS estimation methods because they can produce reliable estimates even when the model exhibits heterogeneity, autocorrelation, and endogeneity (Jagannathan et al., 2002). Therefore,

**Table 1.** Measurement and source of variables

Variable	Measurement	Source
$CO_2$	Carbon dioxide emission levels (metric tons per capita)	Pham et al. (2023), Febriyanto et al. (2024) and Andrei et al. (2025)
$FDI$	Foreign direct investment inflows % of GDP	Nguyen et al. (2020), Pham et al. (2023) and Febriyanto et al. (2024)
$REC$	% of total final energy consumption	Dauda et al. (2021), Febriyanto et al. (2024) and Sun et al. (2025)
$INN$	Innovation index (score)	Nguyen et al. (2020) and Nguyen (2024)
$TRA$	Export plus Import ratio of GDP (%)	Nguyen et al. (2020), Febriyanto et al. (2024) and Alvi et al. (2025)
$NRR$	Total natural resources rents (% of GDP)	Kwakwa et al. (2020) and Khan and Hassan (2024)
$GDP$	GDP per capita (current USD)	Nguyen et al. (2020) and Dauda et al. (2021)
$FDI-REC$	The product of net FDI inflows and renewable energy consumption (%)	Proposed variable

this study excludes OLS and 2SLS methods and selects the GMM estimation method because GMM is suitable for short datasets (Góes, 2016; Nguyen, 2024).

GMM estimation can be implemented in two forms, namely Difference GMM (D-GMM), developed by Arellano and Bond (1991), and System GMM (S-GMM), developed by Blundell and Bond (1998). S-GMM offers advantages over D-GMM (Singhania & Saini, 2021), as the latter may suffer from weak instruments due to information loss across cross-sectional units, resulting in greater variance (Blundell & Bond, 1998). Furthermore, Arellano and Bover (1995) note that insufficient information on parameters in level variables, that is, omitted variable bias when key exogenous or endogenous variables are excluded in D-GMM, can lead to a substantial loss of efficiency in the estimated models.

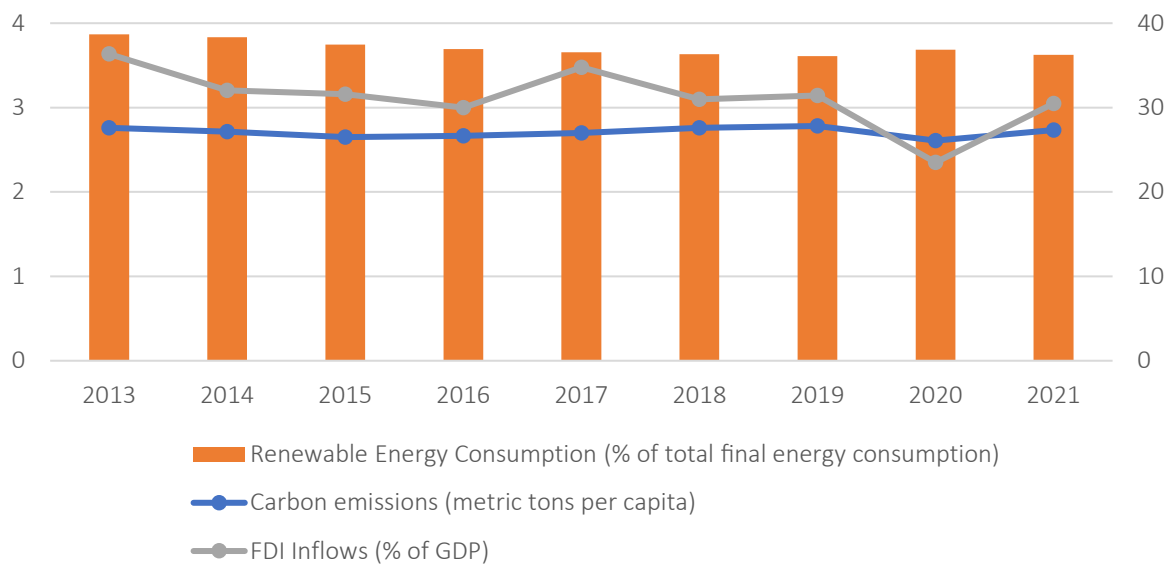
In practice, system GMM is typically implemented in one-step and two-step variants (Roodman, 2009). When a large number of instruments is used, the one-step system GMM is less efficient than the two-step estimator, as the one-step method may result in the loss of observations (Roodman, 2009). Moreover, Xiao et al. (2007) and Roodman (2009) argue that the two-step system GMM is generally more efficient than its one-step system GMM counterpart. Accordingly, this study applies a two-step S-GMM to estimate the parameters of Equation (1).

Furthermore, the study evaluates the validity of the S-GMM estimation by considering three criteria. First, model residuals are examined for sec-

ond-order serial correlation using the Arellano-Bond (AR(2)) test, with  $H_0$ : There is no second-order serial correlation in Equation (1) and  $H_1$ : There is second-order serial correlation in Equation (1). Second, the overall validity of the instrumental variables is assessed using the Hansen (1982) test of over-identifying restrictions, with  $H_0$ : The instruments are exogenous in Equation (1) and  $H_1$ : The instruments are not exogenous in Equation (1). Third, the number of instruments in Equation (1) is controlled to be lower than the number of groups to limit the phenomenon of instrumental explosion and effectively handle endogeneity issues (Roodman, 2009). To ensure scientific rigor in the evaluation of  $p$ -values, the study applied a 1% significance level to all the tests mentioned above.

### 3. RESULTS

The study presents descriptive statistics for the variables in Equation (1), including the number of observations, mean, standard deviation, and minimum and maximum values. According to Table 2 and public research panel data of Nguyen (2025), during the period 2013–2021, the highest  $CO_2$  emissions were recorded in Kazakhstan in 2013 and the lowest in Rwanda in 2014. FDI had an average value of 3.20% with a standard deviation of 3.39%, reflecting the large degree of differentiation among the 50 countries; the highest value was 18.83% in Guinea, and the lowest was  $-37.17\%$  in Mongolia in 2016. REC averaged 37.06% with a standard deviation of 29.20%, showing significant variability between observations; specifically, the



**Figure 1.** Trends in FDI inflows, renewable energy consumption, and CO<sub>2</sub> emissions in 50 developing countries (2013–2021)

**Table 2.** Descriptive statistics of the variables

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
CO <sub>2</sub>	450	2.7078	2.9899	0.0842	16.3016
FDI	450	3.2009	3.3901	-37.1727	18.8280
REC	450	37.0562	29.2046	1.2000	93.1000
FDI-REC	450	113.0169	146.2785	-197.4678	1,417.7490
INN	450	30.4000	6.7617	16.7000	54.8000
TRA	450	69.5603	31.9672	16.3522	186.4682
NRR	450	4.9859	5.4562	0.0011	35.2642
GDP	450	4.405	3.312	484	15,941

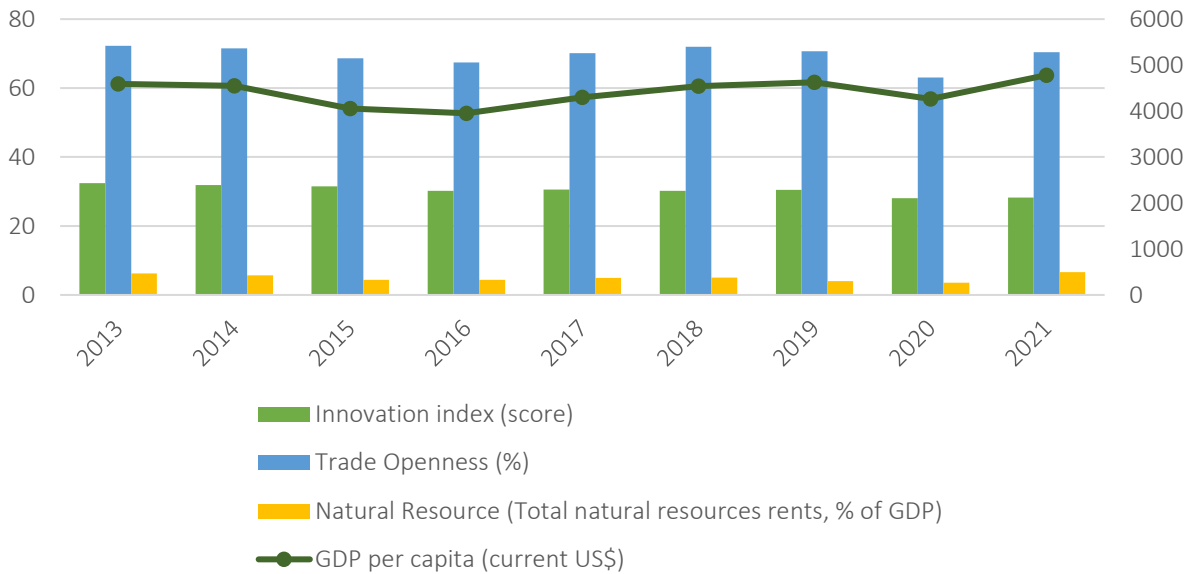
REC value mainly fluctuates between 7.86% and 66.26%. Figure 1 shows the average trends of CO<sub>2</sub>, REC, and FDI throughout the study period.

The average innovation level of the 50 developing countries tended to decrease throughout the study period, suggesting that improvements in innovation capacity in some individual countries were insufficient to raise the overall innova-

tion level of the entire sample. This implies that technological progress and innovation capacity in general remain limited in most developing economies, as shown in Figure 2. Furthermore, Figure 2 also shows significant average fluctuations over time for trade openness, natural resources rents, and GDP, indicating the important role these factors play in explaining changes in CO<sub>2</sub> emissions.

**Table 3.** Correlation matrix

Variable	CO <sub>2</sub>	FDI	REC	FDI-REC	INN	TRA	NRR	GDP	VIF
CO <sub>2</sub>	1.0000	-	-	-	-	-	-	-	N/A
FDI	0.0118	1.0000	-	-	-	-	-	-	1.80
REC	-0.1159	-0.0567	1.0000	-	-	-	-	-	2.95
FDI-REC	-0.3937	0.5251	0.5250	1.0000	-	-	-	-	2.45
INN	0.6400	0.0448	-0.6494	-0.3173	1.0000	-	-	-	2.43
TRA	0.2393	0.2715	-0.3155	0.0552	0.2745	1.0000	-	-	1.28
NRR	0.1958	0.1048	0.1057	0.1038	-0.1912	-0.0175	1.0000	-	1.07
GDP	0.7197	0.0440	-0.6302	-0.3257	0.6947	0.1084	-0.0539	1.0000	2.29



**Figure 2.** Fluctuation in the innovation, trade openness, natural resources, and GDP per capita, 2013–2021

Gujarati and Porter (2009) suggested that any explanatory variable with a correlation coefficient ( $r$ ) greater than 0.8 or a variance amplification factor (VIF) exceeding 10 should be removed from the empirical model to minimize the risk of multicollinearity. Based on the results illustrated in Table 3, we found that no explanatory variable (independent variable) had a VIF above 10 or a pairwise correlation coefficient ( $r$ ) exceeding 0.8. Therefore, Equation (1) does not exhibit multicollinearity, allowing the analysis to continue with the next estimation steps.

To mitigate the risk of bias in estimation results due to endogeneity, this study applies the two-step S-GMM estimation method, which is considered an effective tool for handling common endogeneity issues in dynamic panel data models. As Wooldridge (2002), and Doytch and Uctum (2011) stressed, the Durbin-Wu-Hausman test is an effective tool for detecting endogeneity issues in empirical models. Based on that, an auxiliary test to assess the endogeneity of the independents is the two-stage least squares (2SLS) method. In particular, the Hausman test for Equation (1) was performed with the null hypothesis ( $H_{0a}$ ): The independent variable  $m$  is exogenous and the alternative hypothesis ( $H_{1a}$ ): The independent variable  $m$  is endogenous, where  $m$  represents FDI, INN, REC, TRA, NRR, GDP, and FDI·REC, respectively. Accordingly, the endogenous test was per-

formed seven times for each variable mentioned above, with a 10% significance level applied uniformly for the Hausman test.

**Table 4.** Endogeneity test

Explanatory variable	Wu-Hausman test
<i>FDI</i>	$P_{Wu-Hausman} = 0.0866$
<i>INN</i>	$P_{Wu-Hausman} = 0.3151$
<i>REC</i>	$P_{Wu-Hausman} = 0.2445$
<i>TRA</i>	$P_{Wu-Hausman} = 0.4722$
<i>NRR</i>	$P_{Wu-Hausman} = 0.0254$
<i>GDP</i>	$P_{Wu-Hausman} = 0.0433$
<i>FDI·REC</i>	$P_{Wu-Hausman} = 0.0001$

Based on Table 4, hypothesis H1a is supported because the Wu-Hausman test yields a p-value less than 10%, implying that variables, namely FDI, NRR, GDP, and FDI·REC, can be considered exogenous in the Equation (1), while H0a is accepted for the remaining variables because their p-values all exceed 10%, indicating exogenous variables. The clear classification of endogenous and exogenous variables in Table 4 provides a solid foundation for applying the two-step S-GMM method to Equation (1), ensuring higher reliability for the results of subsequent analyses of the study.

The study conducted several diagnostic tests to assess the suitability of the proposed model to ensure the accuracy of the estimates obtained from the two-step S-GMM method in Equation (1).

**Table 5.** Estimated coefficients using two-step system GMM

Variables	Expected signs	Empirical results	Estimated coefficients
$CO_2(-1)$	(+)	(+)	0.8365***
FDI	(+)	(+)	0.0428***
REC	(-)	(-)	-0.0018**
FDI*REC	(-)	(-)	-0.0003*
INN	(-)	(-)	-0.0073***
TRA	(+)	(+)	0.0006***
NRR	(+)	(+)	0.0238***
GDP	(+)	(+)	0.0001***
Constant	(-)	(-)	-0.1262***
Validity tests for S-GMM estimation			
Specification tests and P-values			$P_{AR(2)} = 0.953$
		$P_{Hansen} = 0.625$	
Number of instruments			49
Number of groups			50

Note: \* $p < 0.1$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ .

First, the Hansen test results presented in Table 5 show a  $p$ -value of 0.625, higher than the 1% significance level, thus not rejecting the null hypothesis of exogeneity of the instrumental variables. This implies that the model is well-defined and the instruments used are not correlated with the error. Second, the Arellano-Bond AR(2) test for Equation (1) gives a  $p$ -value of 0.953, exceeding the 1% significance level, thereby confirming the absence of quadratic series autocorrelation in the residuals. In addition, the number of instruments used is 49, smaller than the number of observation groups (50), indicating that the Hansen test results are reliable and the model has effectively handled potential endogenous issues.

Based on Table 5, foreign direct investment (FDI) has a positive impact with an FDI coefficient of 0.0428 and is statistically significant at the 1% level on  $CO_2$  emissions, thus supporting hypothesis  $H_1$ . Conversely, renewable energy consumption (REC) shows a negative impact and is statistically significant at the 5% level, accepting hypothesis  $H_2$ . More notably, hypothesis  $H_3$  is also accepted because the coefficient of the interaction variable, FDI-REC, has a negative value and is statistically significant at the 10% level.

## 4. DISCUSSION

The two-step S-GMM estimation results show significant and statistically significant impacts from the variables, including foreign direct investment (FDI), renewable energy consumption (REC), the

combined foreign direct investment and renewable energy consumption (FDI-REC), innovation (INN), trade openness (TRA), natural resources rents (NRR), and economic growth (GDP) on  $CO_2$  emissions.

The estimates in Table 5 show that FDI has a positive and statistically significant effect on  $CO_2$  emissions at the 1% level. This result is consistent with many previous empirical studies, notably the study by Nguyen et al. (2020) on G-20 countries, Pham et al. (2023) in the context of Vietnam, as well as the study by Febriyanto et al. (2024) on ASEAN economies. FDI coefficient of 0.0428 shows that a one-unit increase in FDI leads to a 0.0428-unit increase in  $CO_2$  emissions, ceteris paribus. This finding suggests that the influx of FDI into developing nations often brings with it higher  $CO_2$  emissions. A common explanation is that these economies, with their advantages of low labor costs and relatively lax environmental regulations, easily become destinations for polluting production activities from MNCs, which take advantage of the lack of strict environmental oversight (Eskeland & Harrison, 2003). In addition, this research result also provides empirical evidence supporting the Pollution Haven Hypothesis, which was introduced by Pethig (1976).

REC contributes to a reduction in  $CO_2$  emissions in developing economies, with an estimated coefficient of  $-0.0018$  that is statistically significant at the 5% level. This finding further confirms the potential of REC; its benefits have previously been

found in Africa (Dauda et al., 2021), in the ASEAN countries (Febriyanto et al., 2024), and in the BRICS nations (Sun et al., 2025). Although the role of renewable energy consumption in reducing CO<sub>2</sub> emissions was confirmed in the study by Hu et al. (2018) in 25 developing countries, we significantly expanded the sample size to 50 developing countries, which allows the empirical results obtained to be more generalizable. The trend of the favorable environmental impact of REC is also illustrated in Figure 1, where the level of renewable energy consumption shows stability over time. These results imply that developing countries are progressively promoting the implementation of more sustainable energy policies, with a focus on green transition, increased investment in clean technologies, and expanded renewable energy use to mitigate negative environmental impacts in the context of economic growth.

An important finding of this study is that the impact of the moderator of the REC on the FDI and carbon emissions nexus has a statistically significant negative effect at the 10% level. However, the FDI-REC interaction coefficient, which is only  $-0.0003$ , is relatively small, indicating that the moderation of REC on the impact of FDI on CO<sub>2</sub> emissions is limited. In other words, although renewable energy has been incorporated into the national energy mix of developing countries, where the level of renewable energy use during the 2013–2021 period was relatively stable (Figure 1), the scale and effectiveness of REC deployment are generally limited. Furthermore, the moderating role of REC on the impact of carbon emission on FDI may diminish, become disposable, or even develop an “immunity effect” when REC policies are not implemented rigorously. This situation is of considerable concern in the context of developing countries, where Onifade et al. (2025) emphasize that these countries remain largely dependent on fossil fuels, thus posing a risk that the regulatory capacity of REC may no longer be apparent. Overall, our empirical results show that REC plays a significant role in weakening and even reversing the impact of FDI on CO<sub>2</sub> emissions, from increasing to decreasing emissions. This finding is consistent with Pollution Halo Hypothesis, implying that when developing countries effectively combine with expanding renewable energy consumption, FDI can promote clean technology transfer, reduce CO<sub>2</sub> emissions, and enhance environmental governance.

Innovation has a statistically significant negative impact on CO<sub>2</sub> emissions at the 1% level, with a regression coefficient of  $-0.0073$ , indicating that developing countries with higher innovation capacity are better able to create and deploy green technologies, thereby effectively reducing carbon emissions and improving environmental outcomes. This result is consistent with the empirical findings of Nguyen et al. (2020) in selected G-20 countries. However, there are differences compared to the article of Dauda et al. (2021). This suggests that when using data from 50 developing countries, a crowding-out effect can be observed where developing countries have better innovation capacity than the others. Meanwhile, Dauda et al. (2021) only used data from nine countries in Africa (Algeria, Egypt, Kenya, Morocco, Mozambique, Mauritius, Tunisia, South Africa, and Zambia), most of which are also developing countries and may be biased due to weak innovation capacity.

Furthermore, Table 5 shows that the variables trade openness, natural resource rents, and GDP all have a positive impact on CO<sub>2</sub> emissions and are statistically significant at the 1% level. The positive impact of trade openness is consistent with the results of Nguyen et al. (2020) in selected G-20 countries, Febriyanto et al. (2024) in the ASEAN countries, and Alvi et al. (2025) in the OECD. The result that the expansion of international trade will exacerbate environmental degradation (increase CO<sub>2</sub> emissions) is also consistent with Pollution Halo Hypothesis (Dauda et al., 2021). The impact of natural resource rents is consistent with previous empirical evidence from Kwakwa et al. (2020) in Ghana as well as Khan and Hassan (2024) in developing economies, implying that natural resource exploitation, when not accompanied by environmentally friendly management and technology measures, can exacerbate environmental degradation in developing countries. Furthermore, the results for GDP are consistent with EKC, similar to previous empirical evidence from Nguyen et al. (2020) in G-20 countries, and Dauda et al. (2021) in nine African nations, reinforcing the argument of Lieb (2004) and Tanveer et al. (2025), namely, rapidly increasing energy demand and production inputs during the early stages of economic development often lead to a significant increase in carbon emissions.

## CONCLUSION

This study aims to explore the impact of renewable energy consumption in the context of foreign direct investment (FDI) on carbon emissions. The process was analyzed across 50 developing countries from 2013 to 2021 to determine whether the interaction between FDI and renewable energy consumption (REC) on CO<sub>2</sub> emissions exists.

Overall, the environmental impact of FDI is highly dependent on the energy structure of the host country. Indeed, the study's striking finding implies that higher renewable energy proportions can effectively mitigate the emission-boosting impact of FDI through the individual effects and regulatory role of REC. Furthermore, innovation is a driving force in reducing CO<sub>2</sub> emissions, while trade liberalization, reliance on natural resources, and economic growth, if not accompanied by appropriate controls, can still increase emission pressures in developing countries.

From the above results, several important implications can be drawn. First, FDI only truly becomes a driver of green growth when placed within a consistent environmental policy framework (strict environmental standards and clear emission reduction targets) and when prioritizing the attraction of FDI associated with clean technologies among domestic and foreign-invested enterprises. In this context, institutional capacity in designing and implementing technology support policies, including investment incentives, financial support, and a transparent legal framework, plays a crucial role in the success of the energy transition. Finally, increasing the share of renewable energy in the national energy supply structure is considered a decisive factor in leveraging the economic benefits of FDI to achieve long-term sustainable development goals by developing a transition roadmap appropriate to their level of development and national priorities at each stage.

This study finds the moderator of REC; however, it cannot distinguish the difference in income level. Since income level could affect the scale of REC, future research could extend the analysis of income diversification for the investment scale of renewable energy. Moreover, further studies may explore the effects of nonlinear factors on CO<sub>2</sub> emissions.

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## APPENDIX A

**Table A1.** List of countries included in the empirical analysis (50 countries)

1. Albani	11. Colombia	21. India	31. Mongolia	41. South Africa
2. Armenia	12. Costa Rica	22. Indonesia	32. Morocco	42. Sri Lanka
3. Azerbaijan	13. Dominican Republic	23. Jamaica	33. Nepal	43. Thailand
4. Bangladesh	14. Egypt	24. Jordan	34. Niger	44. Togo
5. Belarus	15. Ethiopia	25. Kazakhstan	35. Nigeria	45. Tunisia
6. Benin	16. Georgia	26. Kenya	36. Peru	46. Uganda
7. Brazil	17. Ghana	27. Lebanon	37. Philippines	47. Ukraine
8. Bulgaria	18. Guatemala	28. Malaysia	38. Russian Federation	48. Viet Nam
9. Cambodia	19. Guinea	29. Mali	39. Rwanda	49. Zambia
10. China	20. Honduras	30. Mexico	40. Senegal	50. Zimbabwe