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The Moderating Role of Foreign Direct Investment in the Electricity Consumption and Carbon Emissions Nexus: Evidence from Developing Countries

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***Abstract* – This paper examines the dynamic relationship between electricity consumption (ELE), foreign direct investment (FDI), and carbon dioxide (CO_2) emissions in 88 developing countries from 1985 to 2024. While electricity demand is widely recognized as a primary driver of CO_2 emissions, the moderating role of FDI remains contested, oscillating between the "Pollution Haven" and "Pollution Halo" hypotheses. Employing the Difference Generalized Method of Moments estimation and Granger causality tests, this study provides empirical evidence of three critical patterns. First, electricity consumption exerts a significantly positive effect on CO_2 emissions, reflecting the persistent reliance on fossil fuels in the energy mix. Second, FDI mitigates CO_2 emissions, consistent with the "Pollution Halo" hypothesis. Third, the positive moderating effect of FDI in the ELE-CO_2 nexus shows an interesting inference. The FDI targets energy-intensive sectors, creates scale effects to offset efficiency gains (mitigating CO_2 emissions), and leads to expanding CO_2 emissions. These results highlight integrated policy design. Decarbonizing electricity systems and strategically regulating FDI toward low-carbon sectors offer developing countries a coherent pathway to establish economic sustainability.**

***Keywords* – CO_2 emissions; developing countries; D-GMM; electricity consumption; foreign direct investment.**

1. INTRODUCTION

The demand for electricity for production and consumption in developing countries is increasing rapidly with population growth, urbanization, industrialization, and economic growth. Indeed, urbanization velocity creates densely populated centers with large electricity needs (for public transport, urban lighting). Moreover, large industrial zones with heavy industries consume a significant amount of electricity to operate machinery and industrial automation lines [1]. For instance, over 73 million kilometers of power lines must be constructed or modernized in developing nations, surpassing the total length of power lines installed worldwide in the last century [2]. Hence, electricity supports products and services, increases labor productivity through automated processes, and stimulates economic growth [3], indicating that electricity consumption plays an essential role in economic development.

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However, electricity production and consumption are also major sources of CO_2 emissions. Electricity production is responsible for about 42 % of total global CO_2 emissions [4]. In developing countries, the situation is exacerbated by the heavy reliance on fossil fuels such as coal and oil for electricity generation. Those economies suffer a sharp increase in emissions, with an increase of 1.8 % or 261 Mt, reaching an all-time high of 14.6 Gt [5].

The fossil fuels thirsty phenomenon and the lack of clean technology have forced developing countries to attract foreign direct investment (FDI) to reduce CO_2 emissions. The "Pollution Halo" hypothesis argues that FDI improves environmental quality through the transfer of clean technology [6]–[8]. Since renewable energies initially require high capital investment, FDI overcomes financial barriers and accelerates the energy transition. In other words, FDI plays a key role in filling the clean energy investment gap in emerging economies [9].

On the other hand, the "Pollution Haven" hypothesis argues that countries with lax environmental regulations attract FDI from polluting industries [10]. Consequently, FDI from developed countries moves their polluting industries to countries with lax environmental regulations [11]. In addition, FDI increases CO_2 by the scale effect. FDI stimulates industrial growth and input consumption, leading to an increase in energy demand (usually fossil fuels) as well as CO_2 emissions. The effect is observed in regions such as Sub-Saharan Africa and BRICS, where FDI inflows significantly increase CO_2 emissions [12]. Similarly, early economic integration in China entails highly polluting flow in via FDI, leading to a surge in electricity consumption and emissions [13]. In India, MNCs tend to invest in heavy industries, mining, or fossil fuel-intensive manufacturing because of high short-term profits, escalating CO_2 emissions [14].

Fig. 1 illustrates the long-run evolution of CO_2 emissions, electricity consumption, and FDI inflows in developing countries from 1985 to 2024. While electricity consumption exhibits a persistent upward trend, CO_2 emissions do not increase proportionally over time, suggesting a potentially nonlinear relationship between electricity use and environmental outcomes. On the other hand, the trajectory of FDI inflows appears to fluctuate across periods, indicating that FDI may adjust the electricity-emissions linkage rather than expending a uniform effect. This visual evidence motivates the empirical investigation of whether FDI moderates the impact of electricity consumption on CO_2 emissions in developing economies.

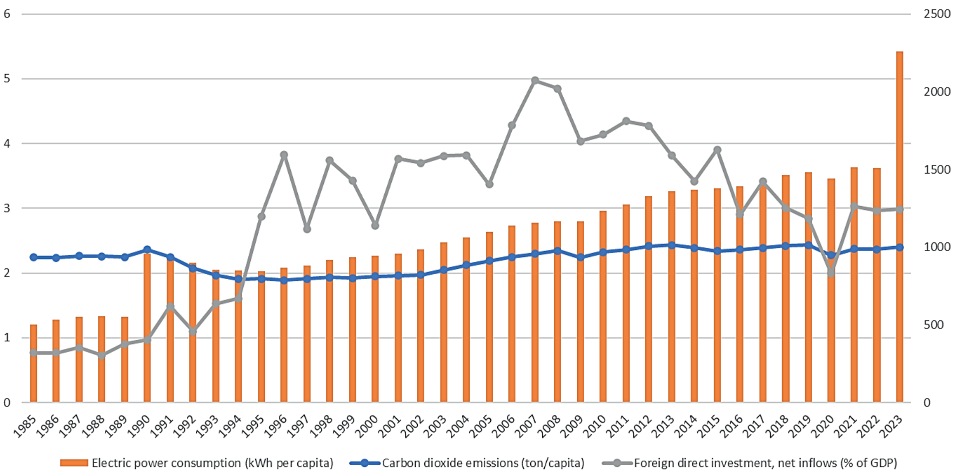

Fig. 1. Evolution of 2021 CO_2 emissions, Electricity consumption, and FDI in developing countries, 1985–2024.

Hence, electricity consumption and CO_2 emissions are associated. Meanwhile, the role of FDI in this nexus is not consistent in both theory and practice and needs further investigation, especially in developing countries. The rest of this paper is organized as follows. Section II presents a related review on the FDI, electricity, and CO_2 emissions. Section III describes the dataset and the econometric methodology. Section IV reports and discusses the empirical findings, while Section V provides the conclusion.

2. RELATED LITERATURE

2.1. Electricity and CO_2 Emissions

In recent decades, the global demand for electricity production and consumption has increased dramatically, leading to a significant increase in CO_2 emissions from electricity consumption. Al Mamun, *et al*. [15] utilize a Panel VECM method on data from 106 middle-income countries for the period 1980–2023 to find that energy consumption, mostly electricity, is the most substantial factor driving long-term CO_2 emissions. At the regional level, Esso and Keho [16] examine the long-run causality between energy consumption, CO_2 emissions, and economic growth for 12 selected sub-Saharan African countries. The results show that in the long run, energy consumption and economic growth are associated with increased atmospheric pollution in most countries. Extending the sample to 45 sub-Saharan African countries over the period 1960–2017, Acheampong *et al*. [17] find that electricity consumption accounts for approximately 0.14 % of one-way carbon emissions. In Southeast Asia, Voumik *et al*. [18] provide empirical evidence showing that coal-based electricity generation exerts a greater impact on emissions compared to other energy sources. Their findings suggest that reducing fossil fuel consumption could lower CO_2 emissions without causing major disruptions to electricity production. Similarly, Phrakhruopatnontakitti *et al*. [19] in a study of four countries, including Malaysia, Myanmar, Thailand, and Vietnam, also find that energy consumption and CO_2 emissions have Granger causality in both the long- and short-run. Vietnam is the highest correlation index (1.55), indicating a dependence on fossil fuels in energy production. Therefore, increasing clean energy investment and regulatory policies to curb emissions without harming growth are suggested. At the national level, Rehman *et al.* [20] find a short-run unidirectional Granger causality relationship between energy consumption and CO_2 emissions in the sample of Pakistan. The study also suggests that the government takes steps to increase the use of renewable energy sources to address the domestic energy crisis and introduce new policies to reduce CO_2 emissions. Similarly, Rehman *et al*. [21] find that energy use has a significant positive impact both in the short- and long-run in China. The results imply a need for potentially conservative policies to reduce CO_2 emissions and tackle the problem without affecting economic development. Based on the analysis, the study develops the hypothesis H1 as follows:

H1: Electricity consumption increases CO_2 in developing countries.

2.2. Foreign Direct Investment and Emissions

FDI is commonly known as a crucial capital to support developing economies in economic growth, financial development, logistics, and environment [22]–[25]. FDI affects CO_2 emissions via three main effects: scale, structural, and technology effects [26]. According to the scale effect, FDI supports industrial output and expands emissions [27]. The structural effect is related to the origin and sector of investment, implying that FDI in heavy industries will emit more emissions than other sectors [28]. The technology effect suggests that FDI transfers advanced technology and reduces emission intensity by using more energy-efficient technology as well as cleaner sources of energy [29].

Empirical studies on the relationship between FDI and CO_2 emissions show mixed results. Pao and Tsai [30] used panel cointegration techniques to examine the BRIC sample for 1980–2007. The study finds the bidirectional causality between emissions and FDI, while CO_2 emissions and FDI are inelastic in the long-run equilibrium. The results support "Pollution Haven" and "Pollution Halo" in the same sample due to national characteristics difference. The study suggests that BRIC strictly regulates conditions to attract FDI. Specifically, promoting environmental protection via coordinated technology and know-how transfer with foreign companies to avoid environmental damage. Similarly, Apergis *et al.* [11] find relatively mixed evidence in the BRICS sample. FDI inflows from Denmark and the UK are found to increase CO_2 emissions, providing support for the "Pollution Haven" hypothesis. In contrast, FDI originating from France, Germany, and Italy is associated with reductions in CO_2 emissions, indicating the "Pollution Halo" hypothesis. Also, BRICS considers promoting clean FDI and ranking FDI according to its environmental impact in host countries.

Regarding studies that support the "Pollution Haven" hypothesis, Hoffmann *et al.* [31] examine a sample of 112 low-income, middle-income, and high-income countries with unbalanced data from 15 to 28 years. The Granger Cause between FDI and CO_2 exists in the low- and middle-income countries. This situation reflects the lack of infrastructure and high-skilled labor, so that low-income countries have low environmental regulations. Meanwhile, in middle-income countries, FDI increases industrial output, leading to higher emissions. These findings are aligned with the study of Perkins and Neumayer [32], which shows no evidence between environmental initiatives for FDI bolster and CO_2 emissions reduction. Similarly, Shahbaz *et al.* [33] find the bidirectional causality between CO_2 emissions and FDI and FDI increases environmental degradation in long-run. In the ASEAN region, Febriyanto *et al.* [34] confirm the structural effect. In other words, since FDI inflows to energy-intensive manufacturing and processing industries, there will be a positive effect of FDI and CO_2 emissions. Moreover, industries that are highly polluting are also caused by weak environmental standards [35].

In contrast, studies supporting "Pollution Halo" hypothesis also have notable findings. Zhang and Zhou [36] utilize provincial-level panel data of China between 1995–2010 to find that FDI reduces CO_2 emissions from the western region to the eastern and central regions. The finding implies that MNCs transfer greener technologies to developing countries and operate in ways that are more environmentally sustainable. In particular, in countries with strict environmental regulations, this transfer is more evident as FDI often promotes environmentally friendly activities [29]. In addition, several other issues related to the FDI-CO_2 nexus including income, institutional quality, and renewable energy, have also been studied in literature. First, since average income is higher than the threshold, FDI has a negative impact on CO_2 emissions. This argument implies that countries need to increase their income to be able to overcome the threshold and thus take advantage of the emission reduction effect provided by FDI [37]. Institutional quality is positively linked to higher emissions across income groups, suggesting that stronger institutions are needed to more effectively regulate the activities of foreign investors [38]. This argument confirms the status quo with low-income countries, where institutional deficiencies are often associated with a "technology trap" that causes FDI to low value-added segments, increases emissions intensity [12]. In addition, suitable renewable energy policies and infrastructure are likely to attract green FDI, thereby reducing emissions when institutional quality and absorptive capacity are strong enough [39], [40].

Since FDI promotes the reduction of fossil energy use through technology transfer, thereby supporting "Pollution Halo". The study develops hypotheses as follows:

H2: FDI mitigates CO_2 emissions in developing countries

H3: The moderated effect of FDI and Electricity reduces CO_2 emissions in developing countries.

3. MODEL AND DATA SOURCE

3.1. Model Specification

Refer to models in past studies [12], [33], [34], [38], this study proposes a model to investigate the impact of electricity usage and CO_2 emissions under the moderating effect of FDI. The model is represented by the following equation:

$$CO2_{it} = \beta_0 + \beta_1 ELE_{it} + \beta_2 FDI_{it} + \beta_3 \left(ELE \cdot FDI \right)_{it} + \sum_{k=4}^{6} \beta_k C_{it} + e_{it}, \quad (1)$$

where CO_2 represents carbon emissions, *ELE* is the electricity consumption, *FDI* denotes foreign direct investment inflows, and *ELE·FDI* is the interactive variable to measure the moderating impact of *FDI* on CO_2. The set of control variables (C_{it}) comprises trade openness (TRA), industrial activities (IND), and the ratio of urban population able to access electricity (URB). In Eq. (1), *i* denotes the countries ($i = 1, 2..., N$), while *t* refers to time periods ($t = 1, 2, ..., T$). The model incorporates the error term e_{it} to capture unobserved influences.

To examine the formed hypotheses, two steps are undertaken: (a) testing for stationarity; and (b) estimating coefficients using the Generalized Method of Moments (GMM).

First, given the time-series dimension of panel data, stationarity tests are necessary to prevent spurious inferences arising from non-stationary processes [41], [42]. Three unit root tests are employed: the Im-Pesara-Shin test [43], the ADF-Fisher test, and the PP-Fisher test [44].

Second, the GMM estimator is applied to mitigate potential endogeneity among macroeconomic variables [45], [46]. The approach introduced by Hansen [47] also provides robustness against heteroskedasticity [48]. Given the short-panel structure with 88 countries over 39 years ($N > \mathrm{T}$), this study adopts the Difference GMM (D-GMM) proposed by Arellano and Bond [49]. The estimation of D-GMM is as follows:

$$\Delta Y_{it} = \sum_{m}^{t-1} \alpha_m \Delta Y_{im} + \gamma_1 \Delta X_{it} + \Delta \mu_{it} \quad (2)$$

where α_k represents the coefficient of the lagged dependent variable, *m*, and μ_{it} denotes the error term varying across countries (*i*) and time periods (*t*).

It should be noted that when the autoregressive process persists, ΔY_{it} may remain correlated with $\Delta\mu_{it}$, which may induce a downward bias in the D-GMM estimates, particularly when the time dimension *T* is small. Let θ_{POLS}, $\theta_{D\ GMM}$), and θ_{FEM} denote the coefficients of the lagged dependent variable Y_{it-1} estimated using pooled OLS, D-GMM, and fixed effects, respectively. If $\delta_{POLS} > \delta_{D\ GMM} > \delta_{FEM}$, the D-GMM estimator is considered appropriate. Conversely, if $\delta_{D\_GMM} < \delta_{FEM}$, reflecting a stronger downward bias, the System GMM (S-GMM) estimator is preferred [50]. To validate the reliability of the GMM estimator, robustness checks are conducted using two standard diagnostic tests: the J Sargan-Hansen test and the Arellano-Bond test [51]. The J Sargan-Hansen test [47], [52] evaluates instrument validity under the null that they are strictly exogenous. In parallel, the Arellano and Bond

[49] test examines whether first- and second-order serial correlation exists in the residuals, with the null hypothesis indicating no autocorrelation [53].

3.2. Variables and Data Sources

Table 1 presents the measured explanatory variables and their expected signs in relation to the dependent variable.

TABLE 1. VARIABLES DESCRIPTION

Variable	Acronym	Measurement	Refer to	Sign
Carbon emissions	CO_2	CO_2 per capita	Boateng *et al.* [38]	
Electricity consumption	ELE	kWh per capita	Nguyen *et al.* [54]	Positive
Foreign direct investment	FDI	FDI net inflows (% of GDP)	Pham *et al.* [12]	Mixed
Trade openness	TRA	Total imports and exports to GDP (%)	Carvalho *et al.* [55]	Positive
Industrial activities	IND	Industry value added (% of GDP)	Lan *et al.* [56]	Positive
Electricity for urban	URB	Access to electricity, urban (% of urban population)	Chen *et al.* [57]	Positive

The dataset draws on World Development Indicators for 88 developing countries (classified as low-income, lower-middle-income, and upper-middle-income countries) between 1985 and 2024. The tests were conducted using EViews 10 software. In total, there were 3490 observations in unbalanced panel data available for the analysis. The data supporting this study are available in the Mendeley Data repository at the link below: https://data.mendeley.com/datasets/sf5v7jhc5n/1.

4. EMPIRICAL FINDINGS

4.1. Description

Table 2 reports the descriptive statistics of the variables used in the analysis. CO_2 emissions display substantial cross-country heterogeneity, with a mean of 2.28 t/pc and a wide range spanning from 0.02 to 16.30 t/pc. This diffusion reflects differences in economic structure, energy intensity, and stages of development across the sample.

Electricity consumption is also considerable variation, ranging from 5.44 to 6.112 kWh per capita. Generally, higher electricity consumption is observed in more urbanized and industrialized economies, as indicated by the relatively high mean values of urban electricity access (URB mean ~86.24 %) and industrial activity (IND mean ~29.42 %). However, it is notable that while electricity consumption has increased and is large in countries (mean ~1.206 kWh/capita), CO_2 emissions have not increased correspondingly in all cases. Probably, the evolution of the fuel mix - shifting from coal to natural gas and renewables – has reduced the amount of CO_2 emitted and thus weakened the impact of electricity transmission on CO_2. Second, improvements in conversion and end-use efficiency (e.g., more efficient power plants, industrial equipment, and processes) have allowed electricity consumption to increase without a proportional increase in emissions. Third, structural shifts towards decarbonization (expansion of services and high-tech manufacturing) have meant that the growing demand for electricity can be met without a 1:1 increase in emissions. As a result, in some economies, increased electricity use is accompanied by changes in technology and fuel mix, which mitigate the environmental costs of additional electricity consumption.

FDI inflows show pronounced volatility, with a mean value of 3.29 % of GDP and a large standard deviation, suggesting substantial heterogeneity in both the scale and stability of FDI across countries. This variation underscores the potential for FDI to exert heterogeneous effects on environmental outcomes rather than a uniform influence.

TABLE 2. VARIABLES DESCRIPTION

	CO_2	ELE	FDI	INT	IND	TRA	URB
Mean	2.28	1206	3.29	4455	29.42	70.75	86.24
Median	1.36	865	2.29	1642	26.63	64.86	97.10
Maximum	16.30	6112	55.07	124 058	86.67	220	100
Minimum	0.02	5.44	–37.17	–75 336	2.39	2.70	7.74
Std. Dev.	2.53	1.161	4.64	8379	11.36	32.70	20.38
Observations	2199	2199	2199	2199	2199	2199	2199

4.2. Correlation

Table 3 reports the correlation test results for the examined variables, indicating that they are significantly correlated with one another at the 1 % level (except FDI-URB). It is notable that ELE and CO_2 are strongly correlated $R(CO_2, \text{INT}) = 0.837$, while $R(CO_2, \text{FDI}) = 0.07$. As a result, INT is moderately correlated with CO_2 (0.426), implying that INT partially captures ELE-CO_2, but FDI's variability weakens ELE-CO_2. From an economic perspective, INT can be viewed as a proxy for projects funded by FDI that consume electricity. Hence, the $R(CO_2, \text{INT}) = 0.426$ suggests that FDI and electricity consumption are both moderately related to emissions, but not as strongly as when electricity alone is. In other words, along with increased electricity consumption, FDI may boost emissions, but this effect is not similar across the sample, as FDI inflows are not accompanied by high electricity intensity (for instance, FDI in services), or the electricity intensity is provided from low-carbon sources. All pairs of explanatory variables show low correlation coefficient, which is lower than 0.8, suggesting no multicollinearity in the model [41].

TABLE 3. CORRELATION MATRIX

Correlation	CO_2	ELE	FDI	INT	IND	TRA	URB
CO_2	1						
ELE	0.8372[a]	1					
FDI	0.0774[a]	0.0629[a]	1				
INT	0.4258[a]	0.5088[a]	0.5340[a]	1			
IND	0.4087[a]	0.1944[a]	0.0776[a]	0.0946[a]	1		
TRA	0.2760[a]	0.3149[a]	0.3122[a]	0.3199[a]	0.3138[a]	1	
URB	0.4490[a]	0.5009[a]	0.0369[a]	0.2690[a]	0.1599[a]	0.2775[a]	1

Note: [a] $p < 0.01$

4.3. Panel Unit Root Tests

Table 4 presents the results of the stationarity tests for the variables incorporated in the model. The results indicate that most variables are stationary either at levels or at first differences, as confirmed by both the ADF-Fisher and PP-Fisher tests. Since the D-GMM framework is designed to capture dynamic relationships, stationarity in either form is sufficient for analyzing the variables specified in Eq. (1). Accordingly, the variables satisfy the fundamental conditions for subsequent econometric estimation.

TABLE 4. PANEL UNIT ROOT TESTS

	Im-Pesaran-Shin W-stat		**ADF-Fisher Chi square**		**PP-Fisher Chi square**	
	Intercept	**Intercept & trend**	**Intercept**	**Intercept & trend**	**Intercept**	**Intercept & trend**
CO_2	2.67	1.49	163	152	157	159
$\triangle CO_2$	-29.77^a	-27.09^a	1185^a	1003^a	1975^a	2691^a
ELE	12.72	3.93	103	187	88	312^a
△ELE	-23.84^a	-24.13^a	908^a	926^a	1574^a	2170^a
FDI	-9.00^a	-6.00^a	385^a	311^a	602^a	546^a
△FDI	-39.04^a	-34.56^a	1599^a	1326^a	2540^a	9371^a
INT	-4.46^a	-5.42^a	280^a	297^a	460^a	604^a
△INT	-35.41^a	-30.64^a	1411^a	1149^a	2200^a	8862^a
IND	-3.62^a	-1.45^c	242^a	204^c	279^a	218^c
△IND	-30.77^a	-26.79^a	1230^a	1002^a	2039^a	3689^a
TRA	-4.51^a	-5.03^a	269^a	305^a	311^a	322^a
△TRA	-34.96^a	-29.96^a	1433^a	1176^a	2189^a	3770^a
URB	0.44	-5.31^a	193	324^a	340^a	1542^a
△URB	-35.42^a	-31.79^a	1389^a	1191^a	2833^a	1027^a

Note: $^a p < 0.01$, and $^c p < 0.1$

4.4. Results and Discussion

The first three rows of Table 5 present the estimated coefficients of $CO_2(-1)$ using alternative estimators. The Pooled OLS, D-GMM, and fixed-effects methods yield values of 0.90, 0.74, and 0.68, respectively. Notably, the coefficient derived from D-GMM lies above the lower bound, confirming the appropriateness of the D-GMM estimator for the sample analyzed. The robustness tests also confirm the reliability of D-GMM estimation. Specifically, The AR(1) test rejects the null hypothesis of no first-order autocorrelation in the first-differenced residuals, while the AR(2) test fails to reject the null, indicating no second-order serial correlation in the differenced residuals. To avoid instrument proliferation, the lag depth of the GMM instruments was restricted to a maximum lag depth of two, resulting in an instrument count (68) that remains below the number of cross-sectional units (88), indicating the reliability of the Hansen J-test.

Table 5 presents the results of dynamic regression estimates of CO_2 emissions on the explanatory variables in Eq. (1). All estimated coefficients are highly statistically significant ($p < 0.01$), indicating a reasonably selected model. The coefficient of $CO_2(-1)$ is about 0.7446, reflecting the cyclical nature and lag of CO_2 pollution between years. The coefficient of electricity consumption is positive and statistically significant (+0.0002), indicating that the higher the electricity consumption, the higher the CO_2 emissions, confirming hypothesis H1. This finding reflects two substantial economic facts: (i) the majority of electricity in developing countries is still produced from fossil fuels with high carbon intensity, so boosting electricity consumption often leads to an expansion in direct emissions [5], [15]; and (ii) increases in electricity reflect an expanding energy-intensity (scale effect), thereby amplifying CO_2, leading to emissions over time in the absence of technological innovation [58], [59]. It is worth noting that CO_2 also has a negative impact and causes an increase in electricity consumption in the sample. This finding can be explained by the phenomenon of CO_2 emissions mainly coming from the heavy industries, which consume a lot of electricity. Hence, CO_2 emissions act as a leading indicator for electricity demand [60].

TABLE 5. THE ESTIMATED RESULTS

D-GMM selection check		
δ_{POLS}	$\delta_{D\text{-}GMM}$	δ_{FEM}
0.90	0.74	0.68
Coefficients estimated for Equation (1) following D-GMM		
Variable	**Coefficient**	**Granger causality test**
$CO_2(-1)$	0.7446^a	N/A
ELE	0.0002^a	^{a} ELE $\Leftrightarrow$ CO_2 ^{a}
FDI	–0.0151^a	^{b} FDI $\Leftrightarrow$ CO_2 ^{a}
INT	0.0013^a	^{a} INT $\Leftrightarrow$ CO_2 ^{b}
IND	0.0115^a	No
TRA	0.0011^a	^{a} TRA $\Leftrightarrow$ CO_2 ^{a}
URB	0.0032^a	URB $\Rightarrow$ CO_2 ^{a}
Robustness tests		
J-statistic	32.24	
Prob(J-statistic)	0.1711	
Prob [AR(1)]	0.0023	
Prob [AR(2)]	0.6725	
Number of instruments	68	
Number of countries	88	

Note: ^{a} $p < 0.01$, and ^{b} $p < 0.05$

Regarding the impact of FDI, the results show that increased FDI mitigates CO_2 emissions, confirming hypothesis H2. This finding is consistent with the “Pollution Halo” hypothesis that FDI probably brings clean technology to improve the environment [61], [62] and is consistent with previous findings in a sample of developing countries [36], [63]. The result can be explained by: (i) MNCs often have cleaner technology than domestic enterprises because MNCs comply with environmental standards from their headquarters [29]; or (ii) strict environmental regulations force MNCs to invest in less environmentally damaging ways to avoid rejection from host countries [64]. Our findings show a bidirectional causality between FDI and CO_2, reinforcing past findings in developing economies [65], [66]. Specifically, the bidirectional Granger causality between ELE and CO_2 emissions can also be interpreted through investment and technological responses. In developing economies, increased CO_2 emission levels often trigger adjustments in investment decisions, including increased adoption of energy-efficient technologies, shifts toward cleaner production processes, and the inflow of environmentally oriented FDI. These responses can affect future ELE patterns by reducing energy intensity or changing the composition of electricity demand. As a result, CO_2 emission levels may affect electricity use, giving rise to a bidirectional predictive relationship.

The moderated term (INT) is statistically significant and positive (contrary to hypothesis H3), implying that the effect of FDI on CO_2 depends on the level of electricity consumption. Specifically, the alone effect of FDI (when ELE = 0) is negative at –0.0151, but each unit increases in ELE enlarges this effect by 0.0013. At the average level of electricity consumption (~1.206 kWh/capita), the net marginal effect of FDI is about +1.55. In other words, in most economies with high electricity consumption, an increased FDI boosts CO_2 by about 1.55 units. This phenomenon implies that when the economy is more electricity-intensive (usually related to high-energy industries), FDI escalates the CO_2 emission intensity. In contrast, FDI contributes to CO_2 reduction in low-energy-consuming economies (at ~5.44 kWh/capita). Generally, the interaction term indicates that the marginal effect of electricity consumption on CO_2 emissions decreases with higher levels of FDI. Particularly, when FDI is relatively low, increases in ELE are associated with a stronger rise in CO_2 emissions, whereas this effect becomes weaker as FDI increases. In addition, Granger causality tests also confirm the bidirectional causality between CO_2 and INT. As the control variables, industrial activities, trade openness, and urbanization boost the CO_2 emissions, which are aligned with past studies [55]–[57]. The interaction term indicates that the marginal effect of electricity consumption on CO_2 emissions decreases with higher levels of FDI. Specifically, when FDI is relatively low, increases in electricity consumption are associated with a stronger rise in emissions, whereas this effect becomes weaker as FDI increases.

From an energy policy perspective, the results highlight the importance of improving the carbon efficiency of electricity consumption in developing economies. Given the positive impact of electricity use on CO_2 emissions, policies promoting cleaner power generation, energy efficiency, and technological upgrading in the electricity sector remain central to mitigating environmental pressures. In line with clean energy, the moderating role of FDI suggests that policymakers consider complementing energy policies with targeted FDI screening and regulatory frameworks that encourage environmentally friendly and technology-intensive investments, while discouraging pollution-intensive activities. Such an approach allows FDI to function as a channel for cleaner technologies and improved production practices rather than as a source of additional environmental pressure.

5. CONCLUDING REMARKS

Adopting the D-GMM approach to analyze data of 88 developing countries between 1985 and 2024, this study investigates the relation between electricity consumption, FDI, and CO_2 emissions. The empirical findings show that electricity consumption has a significantly positive impact on emissions, reflecting the highly carbon-intensive nature of existing electricity systems in the sample. In contrast, FDI has a significant negative impact on emissions, confirming the "Pollution Halo" hypothesis. However, the significant positive moderated coefficient (FDI × ELE) shows an interesting fact that when FDI is probably directed to electricity-intensive sectors, scale effects may outweigh technological effects and push emissions up. Consequently, economies that utilize a lot of electricity still experience an increase of CO_2 emissions. The energy policies ought to be designed for decarbonization

[12]; otherwise, rising electricity demand continues to expand emissions and reduces the environmental benefits of FDI. Similarly, FDI attraction policies need to be carefully designed to prioritize sectors where technology transfer has clear environmental benefits, such as renewable energy [40]. Overall, by viewing energy policy and FDI policy as mutually reinforcing, this study suggests that developing countries can simultaneously advance their growth goals and climate commitments, moving towards low-carbon development.

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