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The Role of Investments in Energy in Enhancing Environmental Sustainability in Developing Countries

Aqeel Ahmad[1], Tusawar Iftikhar Ahmad[2]

[1] PhD Economics Scholar, Department of Economics, Islamia University Bahawalpur, Bahawalpur, Pakistan
[2] Assistant Professor, Department of Economics, Islamia University Bahawalpur, Bahawalpur, Pakistan

Abstract

Investment in energy is essential for fostering environmental sustainability by facilitating the shift to greener energy sources. This study seeks to examine the influence of investments in energy on environmental sustainability. The research utilized panel data from 88 developing countries covering the period from 1990 to 2022. Investment in energy through corporate partnerships and public-private partnerships serves as a proxy for measuring energy investment. The study's findings revealed a positive correlation between GDP per capita (GDPPC) and carbon emissions; however, the square of GDP per capita (GDPPC2) and health expenditures (HE) exhibited a negative correlation with carbon emissions. The Government should promote investment in renewable energy initiatives to enhance sustainable development in developing nations.

Keywords: Energy investment, environmental sustainability, carbon emissions

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Corresponding Author's email: aqeelahmed.iub18@gmail.com

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1. Introduction

Climate change presents a substantial obstacle to equitable economic growth, particularly in developing countries (World Bank, 2000; Rahman et al., 2019). Rising temperatures can affect biodiversity, sea levels, agricultural production, and human health. Carbon dioxide (CO2) emissions from fossil-fuel combustion, alongside land-use changes and ecosystem degradation, contribute to these pressures. Greenhouse gases absorb outgoing long-wave radiation, intensifying the greenhouse effect. Consequently, the transition away from carbon-intensive energy sources has attracted increasing attention from governments, businesses, and researchers. However, this transition requires sustained financing, appropriate technologies, and institutional support. Capital investment is therefore central to low-carbon development, and how investment is allocated across different energy technologies may influence subsequent environmental outcomes (McCollum et al., 2013; Hanser et al., 2017).

Investment in energy through public–private partnerships can finance infrastructure and accelerate technological development. Nevertheless, the environmental consequences depend on the technologies financed and how the resulting energy systems operate. Such partnerships may improve energy efficiency and reduce operating costs; facilitate the dissemination of cleaner technologies across countries; support renewable-energy deployment; generate employment; and expand the public revenue base from which governments can finance health, education, infrastructure, and research. However, investment in conventional energy generation can also prolong reliance on fossil fuels and increase emissions. Evidence from China, Brazil, and other developing economies shows that the relationship between partnership-based energy investment and environmental quality is not uniformly favorable (Khan et al., 2020; Ahmad & Raza, 2020; Adebayo et al., 2021).

Similarly, advances in energy technology, along with renewable-energy deployment, can improve energy efficiency and lower carbon emissions. Greater use of renewable energy may reduce dependence on fossil fuels and limit the climate-related risks affecting food production and coastal ecosystems. However, these benefits depend on the scale, composition, and effectiveness of investment rather than on expenditure alone. Therefore, policy initiatives should support cleaner technologies and assess the environmental performance of financed projects (Ma et al., 2021; Raghutla et al., 2024; Weng et al., 2023).

In recent years, developing countries have sought to expand green technologies and renewable-energy capacity in response to growing environmental pressures. In addition, financial institutions and international organizations have promoted investment channels for energy infrastructure and low-carbon development. Nevertheless, environmental degradation is not confined to national boundaries: energy demand, technology diffusion, international capital flows, and emissions are interconnected. Accordingly, investment through private participation and public–private partnerships, together with technological change and foreign direct investment (FDI), warrants comparative analysis across developing economies. The environmental implications of these capital flows may vary according to economic conditions and the carbon intensity of the energy projects they support (Caglar et al., 2022; Gao et al., 2023).

This study contributes to energy and environmental economics by examining the associations between energy investment with private participation, energy investment with public–private participation, and CO2 emissions across developing countries. In particular, the analysis draws on a large country panel and compares findings across low-, lower-middle-, and upper-middle-income economies. This comparison matters because energy needs, investment opportunities, and institutional capacities differ across income groups. Furthermore, the study applies the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) approach to account for common cross-country shocks and heterogeneous dynamics. However, these two investment indicators should be interpreted carefully because their empirical overlap may complicate identification of distinct effects. The objective remains to inform the design and assessment of energy-financing policies that can support environmental sustainability.

1.1 Research Questions and Objectives

The research questions of the study are as follows:

- Does energy investment influence environmental sustainability in developing countries?

The objective of the study is given as:

- To probe the relationship between energy investment and environmental sustainability in developing countries.

The remainder of the study is structured as follows. Section 2 reviews relevant empirical literature and identifies the research gap. Section 3 describes the data, model specification, and methodology. Section 4 reports and discusses the empirical findings. Finally, Section 5 presents conclusions and policy recommendations.

2 Literature Review

This section reviews evidence on investment in energy and environmental sustainability, with particular attention to private participation, public–private partnerships, and carbon emissions. Table 1 presents the study settings, periods, methods, and principal findings of the relevant literature. The evidence is mixed; therefore, the direction of the investment–emissions relationship should not be assumed in advance.

Table 1: Studies on Energy Investment and Environmental Sustainability

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Mahesh and Jasmin (2013)	India	2010-2022	preliminary and statistical	The analysis indicates that India's clean energy sector had a mitigation of carbon dioxide potential of 203 million tons, with an installed capacity of 24 GW in 2012.
Hanser et al. (2017)	Global	Theoretical analysis	Theoretical analysis	A negative correlation was identified between investment in energy and CO_2 emissions.
Khan et al. (2020)	China	1990Q1 to 2017Q2	GLS, FMOLS, DOLS, and CCR	Investment in public-private partnerships in energy, GDP, and imports has contributed to a rise in consumption-based greenhouse gas emissions over time.
Shahbaz et al. (2020)	China	1984-2018	BARDL	The research results of the study indicated that energy investments from public-private partnerships reduced environmental quality by increasing carbon emissions.
Ahmad et al. (2020)	Brazil	1984-2018	ARDL	Investments in public-private partnership energy initiatives have deteriorated environmental quality by increasing CO_2 emissions.
Anwar et al. (2021)	China	1990Q1-2018Q4	QARDL	The results indicated that transport carbon emissions were positively influenced by public-private partnership investments in energy.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Kirikkaleli et al. (2021)	India	1990Q1-2015Q4	FMOLS, DOLS and domain causality analysis	Investment in public-private partnerships in the energy sector has positively influenced long-term consumption-based greenhouse gas emissions.
Raza et al. (2021)	Developing Nations	1998-2016	Non-Parametric causality	The results of the non-parametric test demonstrated a non-linear relationship between the variables; however, the linear Granger causality test did not suggest a causal connection between PPP expenditure in energy and CO_2 emissions. The non-parametric findings indicated that PPP investment in non-renewable energy within the selected countries exacerbate environmental degradation by elevating carbon emissions.
Zhang et al. (2021)	China	2004-2019	Non-parametric additive regression	The study's findings revealed that investments in renewable energy exerted both linear and non-linear impacts on carbon emissions.
Cheng et al. (2021)	China	1991Q-2017Q	BC causality test	The study's findings indicate that public-private partnerships and increasing income levels contribute to the rise in China's carbon emissions.
Ma et al. (2021)	China	1995-2019	CS-ARDL	Increased energy investments, technological breakthroughs, the adoption of renewable energy, expenditures on research and development, and carbon emission taxes mitigate carbon dioxide emissions and bolster China's carbon reduction initiative.
Chunling et al. (2021)	Pakistan	1992-2018	APRIL	The research identified a significant correlation between investment in public-private partnerships in the energy sector and carbon emissions.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Adebayo et al. (2021)	East Asia and Pacific Regions	1992-2015	ARDL, FMOLS, DOLS	Technological advancements and the utilization of renewable energy diminish CO_2 emissions, yet expenditures in energy through public-private partnerships and economic growth increase CO_2 emissions.
Kirikkaleli et al. (2022)	Bangladesh	1990-2019	FMOLS, DOLS and frequency domain causality	The research employed FMOLS, DOLS, and frequency domain causality methods to get the findings. PPIE, GDP, and TOP adversely affect environmental sustainability; over time, PPIE, FDI, and TOP Granger-cause CO_2 emissions in Bangladesh.
Akinsola et al. (2022)	Brazil	1983-2017	ARDL and DOLS	Private energy investment increases carbon emissions.
Caglar et al. (2022)	BRICS	1990-2018	second generation panel method	The empirical results of the study indicated that enhancements in trade openness and economic complexity improved environmental quality. Conversely, it was determined that environmental degradation stemmed from public-private partnerships, natural resource exploitation, and economic growth.
Caglar and Ulug (2022)	Top five countries	1985-2019	AMG	Empirical data indicate that the financing for energy efficiency research and development was insufficient to enhance environmental quality.
Jiemin and Chen (2022)	China	1971-2015	ARDL	The study's findings indicated that private sector participation in energy investments first increased carbon emissions, which subsequently declined.
Zhang et al. (2022)	China	1990-2000	fully modified, dynamic, and canonical Cointegration	The study also found a negative relationship between carbon emissions and energy efficiency.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Hassan et al. (2022)	China	1987-2019	Markov-switching equilibrium correction model	The results indicated a significant association between investments in green energy and greenhouse gas emissions, hence enhancing environmental quality.
Zhang et al. (2022)	G-20 Countries	2008-2018	Quantile Regression model	The study's conclusions indicated that investments in green finance, renewable energy, and technological innovation adversely affected CO_2 emissions.
Mngumi et al. (2022)	BRICS	2005-2019	Quantile regression	CO_2 emissions hindered the expansion of green finance by slowing the flow of investment into green projects and the usage of renewable energy.
Hailemariam et al. (2022)	Developed and emerging nations	1980-2020	IFE	The results of the study showed that spending on R&D for renewable energy technology contributed to substantial enhancement of environmental quality.
Yang et al. (2022)	E-7 countries	1995-2018	MM-QR	The findings showed that the EKC was only found in lower quantiles of carbon dioxide emissions, whereas its existence in higher quantiles was less likely.
Song et al. (2021)	USA	1990-2015	QARDL	The study's conclusions supported the long-run estimate that GDP and PPPI were responsible for a greater reduction in CO_2 emissions and PM2.5 haze pollution, among other environmental abatement measures.
Saccardo et al. (2023)	Brazil	2005-2020	IPCC approach and SWOT analysis	The study's findings showed that emissions may be lowered by 36.9% (from 0.484 Gt CO_2 eq to 0.305Gt CO_2 eq) with the predicted replacement of fossil fuels by photovoltaic energy in the Brazilian energy grid for 2030.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Feng et al. (2023)	China	1981-2020	NARDL	The study's findings demonstrated that green bond expansion greatly increased investment in renewable energy sources. Similar to this, increasing the use of renewable energy greatly reduces environmental degradation.
Zhang and Xie (2023)	China	1990-2019	ARDL	The study found a link between carbon emissions and renewable energy that was negative.
Fang (2023)	China	32 Provinces 2005-2019	GMM	The minimal impact of renewable energy on green technology innovation and industrial structure was detrimental to carbon emissions.
Abbas et al. (2023)	China	2012-2021	Quantile regression analysis	The study's findings showed that environmental taxes and green funding significantly increase Chinese companies' investments in renewable energy sources. Geopolitical risk, however, had a negative effect on these projects.
Bei and Wang (2023)	China	2000-2020	coherence wavelet approach	There was a bidirectional significant connection between IR and our REO, as well as a unidirectional causal link from GDP to IR and IR to GF.
Alsagr (2023)	BRICS Countries	1995-2021	QARDL	The findings showed that investments in renewable energy increased at nearly all quantiles in response to both short- and long-run positive shocks in the strictness of environmental regulations.
Weng et al. (2023)	72 countries	2000-2018	Spatial Durbin Model	A 1% increase in domestic clean energy investment lowers domestic carbon emissions by around 0.05 percent on average.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Hailiang et al. (2023)	BRICS	2000-2018	Fixed and Random effect model	Technological advancements, renewable energy investment, renewable energy usage, and green financing all contribute positively to environmental security by lowering carbon emissions.
Kartal et al. (2023)	China	1/2004-6/2020	Quantile regression	According to the study, investments in renewable energy reduce CO_2 emissions across all sectors at greater levels of sectorial emissions.
Erdogan et al. (2023)	G-7 countries	2004-2018	AMG	Investments in technology related to renewable energy helped lower carbon emissions.
Udeagha et al. (2023)	South Africa	1960-2020	Dynamic ARDL simulation	Energy investment by public-private partnerships contributes to declining environmental quality.
Gao et al. (2023)	Asian Economies	1990-2019	BARDL	The findings indicated that an increase in PPPIE adversely affects environmental quality over time by elevating CO_2 emissions in Russia and Indonesia. In contrast, a prolonged rise in PPPIE adversely impacted CO2 emissions in China and Turkey. Ultimately, PPPIE's adverse impact diminished CO_2 emissions in Turkey, Indonesia, and Russia. A positive change in PPPIE short-term reduces CO_2 emissions in Turkey, Indonesia, and India, hence enhancing environmental quality. A negative shift in PPPIE yields short-term advantages for Turkey, Russia, and India, however it solely results in adverse effects on CO_2 emissions in Indonesia.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Guoyan et al. (2023)	Ten developing economies	1998-2016	Quantile Regression	The findings indicated a substantial positive association between environmental degradation and public-private energy partnerships in Bangladesh, India, Argentina, and Brazil. Nonetheless, a negative association was observed for different quantiles in China, Malaysia, Mexico, Peru, Thailand, and the Philippines.
Ning et al. (2023)	Pakistan	1980-2019	DARDLS and SFDC	Public-private partnership investment in energy lowers carbon emissions.
Yadav et al. (2024)	BRICS	2000-2021	CS-ARDL	Investments in renewable energy to lower CO_2 emissions.
Ali et, al. (2024)	Pakistan	1992-2019	ARDL	Public-private partnerships decreased environmental quality by raising CO_2 emissions.

Source: Compiled by the authors from the studies cited in the table.

The literature reports heterogeneous relationships between energy investment and environmental sustainability across countries, energy sources, and estimation approaches. Studies on renewable-energy investment often link cleaner investment to reduced CO2 emissions (Ma et al., 2021; Weng et al., 2023; Kartal et al., 2023). However, research on public–private partnerships and other forms of private participation also finds associations with higher emissions when investment supports carbon-intensive activities (Khan et al., 2020; Adebayo et al., 2021; Caglar et al., 2022). In addition, some country-specific findings vary by period, method, or emissions measure (Raza et al., 2021; Gao et al., 2023). These differences motivate examining both investment indicators within a wider sample of developing economies. The present study adds an income-group comparison and uses CS-ARDL estimation to account for cross-sectional dependence and heterogeneous country-level responses. Nevertheless, distinguishing between types of financing and underlying energy technologies remains essential when interpreting the estimates.

3 Model Specification, Data, and Methodology

This section presents the environmental sustainability model specification, the variables and data sources, and the econometric methodology used to estimate short- and long-run relationships.

The functional form of the model is as follows:

$$CO_2 = f(GDPPC, GDPPC^2, EIP, EIPP, FDI, HE) \quad (1)$$

The econometric form of this model is given as:

$$CO_{2it} = \alpha_0 + \alpha_1 GDPPC_{it} + \alpha_2 GDPPC^2{}_{it} + \alpha_3 EIP_{it} + \alpha_4 EIPP_{it} + \alpha_5 FDI_{it} + \alpha_6 HE_{it} + \varepsilon_{it} \quad (2)$$

The dependent variable is CO2 emissions per capita, used here as an observable indicator of environmental pressure rather than a comprehensive measure of sustainability. GDPPC and its squared term (GDPPC2) are included to examine a potentially nonlinear association between economic activity and emissions, drawing on the environmental Kuznets curve literature (Dinda, 2004; Guo & Shahbaz, 2024). However, Table 2 defines GDPPC as annual growth in GDP per capita rather

than the level of GDP per capita. Accordingly, the estimated quadratic relationship should not be interpreted as establishing a conventional income-based EKC turning point without verifying the underlying series and specification. Energy investment is represented by two indicators: investment in energy with private participation (EIP) and investment in energy with public–private participation (EIPP). Both measure related aspects of private-sector engagement in the energy sector. FDI is included to examine the association of external capital inflows with emissions in the context of the pollution-haven literature (Mahadevan & Sun, 2020; Tang & Tan, 2015). Finally, HE measures out-of-pocket health expenditure as a share of current health expenditure, not total public or private health spending. Its coefficient is interpreted as an association with financing composition rather than a direct causal effect of additional healthcare expenditure.

Table 2 describes the variables, their measurement units, and the data source. The study uses panel data for 88 developing countries from 1990 to 2022, comprising 10 low-income, 38 lower-middle-income, and 40 upper-middle-income economies. Of the 134 developing economies considered initially, 46 were excluded because the required energy-investment data were unavailable. All variables were sourced from the World Development Indicators database (World Bank, 2000). Consequently, the resulting sample is defined partly by data availability, which may limit the generalisability of the findings to excluded economies. The analysis retains the original sample and period.

Table 2: Variables Descriptions, Measurement Unit, and Data Sources

Variables	Description	Unit of Measurement	Data Source
Dependent Variable			
CO_2	Carbon Emission	Carbon Emission metric tons per capita	
GDPPC	Gross Domestic Product Per Capita Growth	% Annual	
HE	Out-of-pocket health expenditure	% of current health expenditure	WDI
EIP	Investment in energy with private participation	% of GDP	
EIPP	Investment in energy with public-private participation	% of GDP	
FDI	Foreign Direct Investment, net inflows	% of GDP	

Source: World Development Indicators; variable descriptions compiled by the authors.

We examine long- and short-run relationships using the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) framework. This approach introduces cross-sectional averages into country-level dynamic regressions to account for unobserved common factors and related cross-country dependence. The importance of accounting for such common influences is consistent with the panel diagnostics discussed by Pesaran (2007, 2015). Moreover, mean-group estimation allows long-run parameters to differ across economies, an important consideration given the slope-heterogeneity evidence reported in Table 7 (Pesaran & Yamagata, 2008). The model incorporates dynamics through lagged dependent and explanatory variables; nevertheless, dynamic specification alone does not establish causality or eliminate every source of endogeneity. Accordingly, coefficient estimates are described as conditional relationships, and the stability of separate investment effects should be assessed in light of the strong EIP–EIPP correlations. The following equation presents the CS-ARDL form used in the study:

$$y_{it} = \alpha_i + \sum_{l=1}^{p_y} \lambda_{l,i} y_{i,t-1} + \sum_{l=0}^{p_x} \beta_{l,i} x_{i,t-1} \sum_{l=0}^{p_\varphi} \varphi_{i,l}^{'} \bar{z}_{i,t-1} + \varepsilon_{it} \quad (3)$$

The term in Equation (4.28) denotes lagged cross-sectional averages $[\bar{z}_{t-1} = (\bar{y}_{i,t-1}, \bar{x}_{i,t-1})]$. The mean group estimations' long-run coefficients are:

$$\hat{\theta}_{CS-ARDL,i} = \frac{\sum_{l=0}^{p_x} \hat{\beta}_{l,i}}{1 - \sum_{l=1}^{p_y} \hat{\lambda}_{l,i}}, \theta_{MG} = \frac{1}{N} \sum_{i=1}^{N} \hat{\theta}_i \tag{4}$$

Each cross-section's estimation is indicated by $\hat{\theta}_i$. The CS-ARDL method's error-correcting version is:

$$\Delta y_{it} = \phi_i [y_{i,t-1} - \hat{\theta}_i x_{i,t}] - \alpha_i + \sum_{l=1}^{p_{y-1}} \lambda_{l,i} \Delta_l y_{i,t-1} + \sum_{l=0}^{p_x} \beta_{l,i} \Delta x_{i,t-1} \sum_{l=0}^{p_\varphi} \varphi_{i,l}^{'} \Delta \bar{z}_{i,t-1} + \mu_{it} \tag{5}$$

Where the error's correction speed of adjustment is indicated by ϕ_i.

The present CS-ARDL version is given as:

The CS-ARDL long-run and short-run equations of this model is given as:

$$\begin{aligned} \Delta CO_{2it} = {} & \alpha_1 + \alpha_2 GDPPC_{i,t-1} + \alpha_3 GDPPC^2{}_{i,t-1} + \alpha_4 EIP_{i,t-1} + \alpha_5 EIPP_{i,t-1} + \alpha_6 FDI_{i,t-1} + \alpha_7 HE_{i,t-1} \\ & + \sum_{j=1}^{\rho_1} \beta_{ij} \Delta CO_{2i,t-j} + \sum_{j=0}^{\rho_2} \beta_{ij} \Delta GDPPC_{i,t-j} + \sum_{j=0}^{\rho_3} \beta_{ij} \Delta GDPPC^2{}_{i,t-j} + \sum_{j=0}^{\rho_4} \beta_{ij} \Delta EIP_{i,t-j} + \sum_{j=0}^{\rho_5} \beta_{ij} \Delta EIPP_{i,t-j} \\ & + \sum_{j=1}^{\rho_6} \beta_{ij} \Delta FDI_{i,t-j} + \sum_{j=1}^{\rho_7} \beta_{ij} \Delta HE_{i,t-j} + \varepsilon_{it} \end{aligned} \tag{6}$$

4 Results and Discussion

This section presents the descriptive statistics, correlation analysis, preliminary panel diagnostics, and CS-ARDL estimates for the full sample and the three income groups.

4.1 Summary Statistics and Correlation Analysis

Table 3 reports summary statistics for the principal variables across the full panel and income groups. Upper-middle-income countries exhibit the highest mean CO2 emissions per capita, while low-income countries report the lowest. In addition, lower-middle-income economies have the highest average annual GDP-per-capita growth within the sample. These group differences provide context for interpreting the regressions; however, descriptive comparisons alone do not identify investment's effects on emissions.

Table 3: Summary Statistics of Key Variables

	GDPPC	HE	EIP	EIPP	FDI	CO_2
Developing Countries						
Mean	2.593	39.440	0.900	0.825	3.160	2.481
Median	2.886	38.904	0.360	0.314	2.640	1.761
Maximum	11.023	86.069	54.124	54.124	34.756	11.113
Minimum	-12.154	0.080	0.001	0.001	-37.173	0.033
Std. Dev.	3.272	20.406	3.260	3.242	3.867	2.054
Skewness	-1.145	0.009	13.232	13.489	-0.939	1.344
Kurtosis	6.261	2.201	206.994	212.716	49.002	4.626
Jarque-Bera	232.156	68.727	618843.700	653862.000	31000.060	144.260
Probability	0.000	0.000	0.000	0.000	0.000	0.000

	GDPPC	HE	EIP	EIPP	FDI	CO_2
Low Income Countries						
Mean	0.906	43.863	0.852	0.852	3.307	0.123
Median	1.220	43.192	0.671	0.671	3.142	0.121
Maximum	6.257	86.069	3.912	3.912	6.131	0.196
Minimum	-4.291	5.555	0.063	0.063	0.329	0.033
Std. Dev.	2.830	19.495	1.034	1.034	1.336	0.052
Skewness	-0.053	-0.143	2.337	2.337	-0.116	-0.046
Kurtosis	2.780	2.109	7.721	7.721	4.491	2.160
Jarque-Bera	0.030	16.684	22.066	22.066	1.138	0.357
Probability	0.985	0.000	0.000	0.000	0.566	0.837
Lower Middle Income Countries						
Mean	3.232	41.212	1.390	1.332	3.216	1.412
Median	3.589	42.511	0.475	0.390	2.409	0.883
Maximum	10.373	85.898	54.124	54.124	34.756	7.413
Minimum	-10.978	0.080	0.002	0.002	-37.173	0.088
Std. Dev.	3.049	20.962	5.126	5.132	5.572	1.502
Skewness	-1.746	-0.166	8.806	8.812	-1.141	2.516
Kurtosis	8.962	2.168	87.962	87.997	30.207	9.227
Jarque-Bera	260.582	36.334	41094.080	41128.610	4068.671	349.933
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Upper Middle-Income Countries						
Mean	2.440	36.059	0.617	0.530	3.213	3.203
Median	2.674	34.762	0.316	0.277	2.713	2.525
Maximum	11.023	84.794	12.211	11.596	17.260	11.113
Minimum	-12.154	0.978	0.001	0.001	-3.755	0.805
Std. Dev.	3.348	18.985	1.098	0.986	2.384	1.993
Skewness	-0.990	0.298	6.389	7.174	2.030	1.305
Kurtosis	5.725	2.543	60.674	74.962	10.339	4.564
Jarque-Bera	103.523	24.476	31841.930	49132.050	641.936	84.458
Probability	0.000	0.000	0.000	0.000	0.000	0.000

Source: Authors' calculations using World Development Indicators data.

Low-income nations have the highest average out-of-pocket health expenditures, indicating elevated health costs as a share of total health spending. Developing countries and lower-middle-income countries have marginally lower mean values, whereas upper-middle-income countries report the lowest mean values. Lower-middle-income nations show the largest average investment in energy with private involvement, followed by developing nations, low-income nations, and upper-middle-income nations. Lower-middle-income nations show the largest average investment in energy through public-private partnerships, while emerging countries, low-income countries, and upper-middle-income countries show progressively lower averages. Low-income nations have the highest average

foreign direct investment, trailed closely by upper-middle-income nations, developing nations, and lower-middle-income nations.

Most variables exhibit pronounced deviations from a normal distribution across the reported groups. In particular, the investment measures show substantial positive skewness and extremely high kurtosis in several subsamples, suggesting that a small number of unusually large observations may exert considerable influence. The Jarque–Bera statistics in Table 3 likewise indicate departures from normality for many variables. Therefore, the investment coefficients warrant sensitivity analysis using appropriate treatment of influential observations, while retaining the underlying observations and reported results in the present study.

Table 4 presents correlations among the principal variables. In the full sample and the lower-middle-income group, CO2 is weakly negatively correlated with EIP and EIPP, while it is positively associated with HE. However, the two investment indicators are highly correlated, reaching 0.995 for developing countries and 0.999 for lower-middle-income countries. This near-collinearity can make the separate coefficients of EIP and EIPP unstable when both enter the same regression. Therefore, read the reported relationships cautiously, and future robustness checks should compare separate-indicator specifications with the joint model.

Table 4: Correlation Matrix of Key Variables

	GDPPC	**HE**	**EIP**	**EIPP**	**FDI**	**CO_2**
GDPPC	1.000					
HE	-0.150	1.000				
EIP	0.102	-0.071	1.000			
EIPP	0.094	-0.069	0.995	1.000		
FDI	0.157	0.085	0.109	0.095	1.000	
CO_2	-0.002	0.310	-0.101	-0.102	0.001	1.000
GDPPC	1.000					
HE	0.286	1.000				
EIP	-0.077	-0.368	1.000			
EIPP	-0.077	-0.368	0.988	1.000		
FDI	0.354	0.752	-0.020	-0.020	1.000	
CO_2	0.008	0.219	-0.158	-0.158	0.236	1.000
	GDPPC	**HE**	**EIP**	**EIPP**	**FDI**	**CO_2**
GDPPC	1.000					
HE	-0.249	1.000				
EIP	0.143	-0.120	1.000			
EIPP	0.145	-0.113	0.999	1.000		
FDI	0.210	0.067	0.067	0.067	1.000	
CO2	-0.026	0.292	-0.101	-0.097	0.141	1.000
GDPPC	1.000					
HE	-0.146	1.000				
EIP	0.056	0.045	1.000			
EIPP	0.012	0.067	0.947	1.000		
FDI	0.158	0.147	0.395	0.324	1.000	

	GDPPC	HE	EIP	EIPP	FDI	CO_2
CO_2	0.034	0.027	-0.057	-0.064	0.160	1.000

Source: Authors' calculations using World Development Indicators data.

For low-income and upper-middle-income countries, the correlation matrix likewise shows comparatively weak bivariate associations between CO2 and the investment variables. Moreover, the strong EIP–EIPP correlations across all four groupings (0.947–0.999) indicate considerable overlap in the investment indicators. These bivariate coefficients are descriptive and should not be interpreted as causal effects.

4.2 Unit Root Analysis

This section provides the results of the second-generation panel unit root test. For developing countries, the analysis reveals that several variables such as GDPPC, HE, FDI, and CO_2 are integrated of order 1. This indicates that these variables are non-stationary but become stationary after first differencing. However, EIP and EIPP are integrated of order 0, suggesting they are stationary and do not require differencing. In low-income countries, a similar pattern emerges, with GDPPC, HE, and CO_2 integrated of order 1, indicating non-stationarity that requires differencing. However, EIP, EIPP, and FDI stand out as integrated of order 0, implying they are already stationary without differencing.

Table 5: Results of Second Generation Panel Unit Root

Second Generation Panel Unit Root Test						
Cross-Section-Dependence based Im-Pesaran-Shin (CSDIPS) Unit Root Test						
Developing Countries						
Variables	**Without Trend**			**With Trend**		
	Lags	**Zt Statistics**	**P-Value**	**Lags**	**Zt Statistics**	**P-Value**
GDPPC	1	0.257	0.176	1	0.036	0.643
HE	1	0.212	0.756	1	0.410	0.742
EIP	0	0.133	0.000	0	0.891	0.000
EIPP	0	0.132	0.000	0	0.875	0.000
FDI	1	0.410	0.743	1	0.592	0.357
CO_2	1	0.102	0.537	1	0.095	0.534
Low-Income Countries						
Variables	**Without Trend**			**With Trend**		
	Lags	**Zt Statistics**	**P-Value**	**Lags**	**Zt Statistics**	**P-Value**
GDPPC	1	0.358	0.308	1	0.584	0.568
HE	1	0.108	0.249	1	0.332	0.624
EIP	0	0.369	0.000	0	0.311	0.000
EIPP	0	0.369	0.000	0	0.311	0.000
FDI	0	0.357	0.000	0	0.108	0.000
CO_2	1	0.557	0.829	1	0.390	0.927
Lower Middle Income Countries						
Variables	**Without Trend**			**With Trend**		
	Lags	**Zt Statistics**	**P-Value**	**Lags**	**Zt Statistics**	**P-Value**
GDPPC	1	0.540	0.641	1	0.942	0.276

Second Generation Panel Unit Root Test						
HE	1	0.499	0.127	1	0.599	0.809
EIP	0	0.673	0.000	0	0.094	0.000
EIPP	0	0.683	0.000	0	0.098	0.000
FDI	0	0.699	0.000	0	0.012	0.000
CO_2	1	0.826	0.512	1	0.256	0.740
Upper Middle-Income Countries						
Variables	**Without Trend**			**With Trend**		
	Lags	**Zt Statistics**	**P-Value**	**Lags**	**Zt Statistics**	**P-Value**
GDPPC	1	0.874	0.290	1	0.287	0.101
HE	1	0.353	0.398	1	0.407	0.543
EIP	0	0.406	0.000	0	0.649	0.000
EIPP	0	0.417	0.000	0	0.678	0.000
FDI	0	0.650	0.000	0	0.987	0.000
CO_2	1	0.249	0.224	1	0.159	0.864

Source: Authors' calculations using World Development Indicators data.

In lower-middle-income countries, results are mixed, with variables exhibiting different integration properties. Specifically, variables such as GDPPC, HE, and CO_2 are integrated of order 1, implying they are non-stationary and require the first difference to make them stationary. On the other hand, EIP, EIPP, and FDI are integrated of order 0, showing that these variables are already stationary. Similarly, in upper-middle-income countries, there are mixed results for the integration properties of the variables. Variables such as GDPPC, HE, and CO_2 are integrated of order 1, indicating non-stationarity and the need for first differencing to become stationary. On the other hand, EIP, EIPP, and FDI are integrated of order 0, indicating that these variables are already stationary and do not require first differencing.

1.1 4.3 Cross-Sectional Dependence and Slope Heterogeneity Tests

This section presents the outcomes of tests for cross-sectional correlation and slope homogeneity. Table 6 displays the outcomes of Pesaran's cross-sectional dependency (CD) Test for developing nations, low-income countries, middle-income nations, and upper-middle-income countries, respectively.

Table 6: Pesaran's Cross-Sectional Dependence (CD) Test

Developing Countries		
Variable	**CD-test**	**P-Value**
GDPPC	122.511	0.000
HE	84.365	0.000
EIP	71.391	0.000
EIPP	91.394	0.000
FDI	27.827	0.000
CO_2	173.859	0.000
Low-Income Countries		
Variable	**CD-test**	**P-Value**
GDPPC	109.384	0.000

Developing Countries		
Variable	**CD-test**	**P-Value**
HE	84.305	0.000
EIP	22.991	0.000
EIPP	92.991	0.000
FDI	59.103	0.000
CO_2	21.741	0.000
Lower Middle Income Countries		
Variable	**CD-test**	**P-Value**
GDPPC	111.367	0.000
HE	131.660	0.000
EIP	39.660	0.000
EIPP	47.672	0.000
FDI	140.840	0.000
CO_2	91.347	0.000
Upper Middle-Income Countries		
Variable	**CD-test**	**P-Value**
GDPPC	110.249	0.000
HE	80.550	0.000
EIP	53.278	0.000
EIPP	56.286	0.000
FDI	71.659	0.000
CO_2	42.013	0.000

Source: Authors' calculations using World Development Indicators data.

The reported p-values in Table 6 reject the null hypothesis of cross-sectional independence for the listed variables. Accordingly, the observations appear to share common cross-country influences, supporting an estimation approach that accommodates cross-sectional dependence (Pesaran, 2015). Table 7 reports the slope-homogeneity diagnostics based on the Delta test of Pesaran and Yamagata (2008) and the heteroskedasticity- and autocorrelation-robust adjustment of Blomquist and Westerlund (2013). These tests assess whether slope coefficients can reasonably be treated as equal across panel units.

The reported p-values in Table 7 are 0.00 for all groups. Under the conventional null hypothesis of slope homogeneity, these results indicate rejection of homogeneous slopes and therefore support slope heterogeneity (Pesaran & Yamagata, 2008; Blomquist & Westerlund, 2013). This interpretation aligns with mean-group methods that allow coefficients to vary across countries. The unusual signs of some reported adjusted Delta statistics should also be verified against the original estimation output before drawing any substantive inferences from their magnitudes.

Table 7: Slope Homogeneity Test on Developing Countries

Energy Investment and Environmental Sustainability	(Pesaran and Yamagata, 2008)		(Blomquist and Westerlund, 2013)	
	Delta Test	P-Value	HAC Robust Adjusted Delta Test	P-Value
Developing Countries	32.313	0.00	-2.656	0.00
Low-Income Countries	7.984	0.00	-6.321	0.00
Lower Middle-Income Countries	22.921	0.00	-2.411	0.00
Upper Middle-Income Countries	39.974	0.00	-2.562	0.00

Source: Authors' calculations using World Development Indicators data.

4.4 CS-ARDL Estimates of Energy Investment and Environmental Sustainability

This section provides studies of energy expenditure and environmental sustainability in both the long run and short run. Table 8 presents the findings of a long-run Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) analysis, which examines the correlation between carbon emissions and energy investment. Across all socioeconomic levels, the initial variable, GDP per capita (GDPPC), is positively correlated with carbon emissions (CO2), and the relationship is statistically significant, indicating that rising GDP per capita is associated with higher carbon emissions. This phenomenon has multiple underlying causes. First, this relationship is supported by the Environmental Kuznets Curve (EKC) hypothesis within economic theory. This hypothesis posits that in the early phases of growth, environmental deterioration escalates alongside rising national affluence. As countries reach a certain level of economic development, a tipping point occurs where environmental degradation declines alongside rising national income (Guo & Shahbaz, 2024). The second cause is the income effect; as countries experience economic expansion, GDP per capita rises, leaving individuals with more disposable income. This leads to higher individual consumption, including increased energy use, greater reliance on transportation, and higher consumption of goods and services, which in turn increases carbon emissions (Mrabet and Jarboui, 2017). The third rationale is industrialization and advancement. Economic expansion is correlated with industrialization, while urbanization enhances industrial activity, which often depends on fossil fuels, the primary source of greenhouse gases (Kahuthu, 2006).

The second variable in all income groups is $GDPPC^2$, which is negatively correlated with carbon emissions (CO_2) and is highly statistically significant, indicating that higher economic development tends to correlate with lower carbon emissions for several reasons. Firstly, environmental efficiency theory states that as countries' economic growth increases and they achieve a higher level of GDP per capita, they become more efficient in managing resources and adopt different technologies to clean the environment (Dinda, 2004). Secondly, the environmental Kuznets curve states that when countries reach a certain income level, their priority shifts from increasing income to reducing environmental degradation (Shahbaz et al., 2013). Thirdly, according to the satiation hypothesis, people reach a point of satiation or diminishing marginal return in their consumption as their income rises. After this point, further income growth does not significantly affect the consumption of energy-intensive goods and services. Alternatively, people place a higher priority on their well-being, such as leisure time, environmental quality, and public goods. Therefore, as a nation gets wealthier $GDPPC^2$ has a negative impact on carbon emissions (Mehmood et al., 2023). Fourthly, higher GDP per capita encourages investment in research and development, which results in the creation and adoption of greener technologies. As economies grow, they invest in energy-efficient infrastructure, clean industrial methods, and renewable energy sources to reduce carbon emissions. This innovation and improvement in the technologies leads to an inverse relationship between economic growth and carbon emissions (Hameed et al., 2024)

The third and fourth variables, energy investment with private participation and with public-private participation (EIP and EIPP), indicate a positive relationship with carbon emissions, which is highly statistically significant in all income groups except upper middle-income countries only, suggesting

that greater energy investment contributes to higher carbon emissions in the environment. Possible reasons include the dominance of fossil fuels. Energy investment prioritizes fossil fuel infrastructure such as coal plants and oil drilling, increasing dependence on carbon-intensive sources and, as a result, carbon emissions (Zhong et al., 2024). Secondly, a lack of funding for renewable energy ignores greener options, prolonging the use of fossil fuels and increasing carbon emissions. Third, older infrastructure and inefficient technologies persist without energy-efficiency investments, raising energy consumption and, in turn, increasing carbon emissions (Li & Li, 2020). Along with improvements in energy-efficiency technologies and supportive regulatory frameworks, increased energy investment in upper-middle-income nations can lower CO_2 emissions, primarily by shifting toward cleaner energy sources such as natural gas and renewables. Investments stimulate technological advancements such as carbon capture and storage and improve the use of renewable energy sources, thereby reducing the amount of carbon dioxide emitted per unit of energy produced. Regulatory initiatives such as carbon pricing and emission regulations further encourage emissions reductions, and investment decisions are influenced by growing public knowledge and demand for sustainable energy alternatives. Despite higher energy production and consumption in these nations, these coordinated efforts help lower CO_2 emissions (Zhang et al., 2021).

Table 8: Long-Run CS-ARDL Estimates of Energy Investment and Environmental Sustainability

Variables	Developing Countries	Low-Income Countries	Lower Middle Income Countries	Upper Middle-Income Countries
Short Run Results				
$\Delta CO_2(-1)$	0.250***	0.015	-0.034	-0.007
	(0.063)	(0.209)	(0.031)	(0.052)
Δ GDPPC	0.015*	0.001	0.026*	-0.066
	(0.007)	(0.003)	(0.015)	(0.108)
$\Delta GDPPC^2$	-0.002***	0.001	-0.003*	-0.001
	(0.001)	(0.005)	(0.001)	(0.001)
Δ EIP	0.035	-0.001	0.024	0.012
	(0.027)	(0.004)	(0.023)	(0.035)
Δ EIPP	0.037	0.001	0.027	0.012
	(0.038)	(0.003)	(0.023)	(0.034)
Δ FDI	0.068	-0.005	0.027*	0.003
	(0.075)	(0.003)	(0.014)	(0.010)
Δ HE	0.008	0.005	0.144	0.663***
	(0.017)	(0.006)	(0.109)	(0.162)
ECT	-0.076**	-0.206**	-0.370***	-0.142***
	(0.030)	(0.087)	(0.101)	(0.023)
Long Run Results				
GDPPC	0.022***	0.113***	0.266***	0.240***
	(0.001)	(0.009)	(0.035)	(0.023)
$GDPPC^2$	-0.003***	-0.115***	-0.316***	-0.114***
	(0.001)	(0.010)	(0.035)	(0.015)
EIP	0.029***	0.179***	0.287***	-0.871***

Variables	Developing Countries	Low-Income Countries	Lower Middle Income Countries	Upper Middle-Income Countries
	(0.002)	(0.039)	(0.019)	(0.328)
EIPP	0.030***	0.179***	0.297***	-0.954***
	(0.002)	(0.039)	(0.026)	(0.064)
FDI	0.122***	0.785***	0.125***	-0.305***
	(0.012)	(0.231)	(0.015)	(0.065)
HE	-0.022***	-0.300***	-0.223***	-0.847***
	(0.001)	(0.018)	(0.015)	(0.287)

Source: Authors' calculations using World Development Indicators data.

***, **, and *significant at 1%, 5%, and 10%, respectively

The fifth variable is foreign direct investment (FDI), which displays a positive link with carbon emission which is highly statistically significant in all income groups except upper-middle-income countries, indicating that higher foreign investment in industries and infrastructures leads to an increase the carbon emission. The plausible reasons for the positive relationship include the Pollution Haven Theory, which explains the negative impact of FDI on carbon emissions. This theory states that to minimize costs, multinational corporations invest in nations with laxer environmental regulations. These nations may permit more pollution-intensive production methods, which raises carbon emissions (Mahadevan and Sun, 2020). Second, the expansion of industrial facilities is a common component of foreign direct investment, increasing production, resource use, and energy consumption. Carbon emissions also rise as production scales up (Song et al., 2021). Thirdly, foreign direct investment brings new technologies and production techniques, but these advanced technologies may not prioritize environmental sustainability. As a result, increasing production levels may result in higher carbon emissions even though efficiency may increase. Foreign direct investment drives economic growth that increases the consumption of energy-intensive goods and services, ultimately raising carbon emissions (Wang et al., 2021). For upper middle-income nations, attracting more foreign direct investment (FDI) can help lower CO2 emissions by enabling the transfer of sustainable practices and cleaner technologies from wealthier nations. Foreign investors' introduction of cutting-edge technologies and specialized knowledge often improves industrial energy efficiency and lowers the carbon footprint of manufacturing processes. Furthermore, FDI can encourage greener manufacturing techniques and renewable energy sources, shifting sectors away from carbon-intensive activities. Along with improving infrastructure and regulatory frameworks, this inflow of investment also tends to create a climate favorable to environmental sustainability projects. As a result, increased FDI in these nations can significantly reduce CO2 emissions through greater efficiency, technological innovation, and environmentally friendly economic growth strategies (Tang & Tan, 2015).

The last variable, health expenditures (HE), shows a negative association with carbon emissions that is highly statistically significant across all income groups, implying that higher health care expenditures are associated with lower carbon emissions. Several factors may explain this negative relationship. First, according to the Environmental Kuznets Curve, environmental degradation initially worsens as a nation's income rises, but then improves beyond a particular income level. Higher health spending improves overall health outcomes, which support higher labor productivity and economic growth in the context of health expenditures and carbon emissions. Carbon emissions are reduced as the economy expands through the adoption of greener technologies and more ecologically friendly activities (Apergis et al., 2018). Increased health expenditures that result in better health outcomes boost worker productivity. Healthier people are probably more productive, which boosts the economy and raises wages. More economically productive people may demand greener, sustainable technologies, and governments may spend more on initiatives. These policy and preference shifts help lower carbon emissions (Ahmad et al., 2021). Higher healthcare expenditures spur innovation and technical progress in the healthcare industry. These developments also affect the energy and transportation industries, among others. Clean, sustainable technology is used to lower

carbon emissions in other sectors of the economy, such as energy production and transportation, as nations invest in it to enhance healthcare delivery (Atuahene et al., 2020). The short-run estimates in Table 5.7 describe the short-term dynamics of adjustment toward the long-run equilibrium. The error correction term has negative coefficients of -0.076, -0.206, -0.370, and -0.142 in all cases: developing countries, low-income countries, lower-middle-income countries, and upper-middle-income countries. This suggests that deviations from the long-run equilibrium due to short-run shocks can be corrected within 28 days, 2 months and 25 days, 4 months and 15 days, and 1 month and 22 days in developing countries, lower-middle-income countries, and upper-middle-income countries, respectively.

4.5 Interpretive Scope, Robustness, and Research Implications

The comparison across income categories suggests that development conditions may shape how energy investment relates to emissions. However, EIP and EIPP are very highly correlated, and their separate partial effects may therefore be sensitive to model specification. In addition, the descriptive distributions show unusually large investment observations. A useful extension would estimate the indicators separately, check sensitivity to influential observations, and compare coefficients across alternative sample definitions. Such tests are proposed as future analyses; they are not reported as completed robustness checks here.

Further work should distinguish investment in renewable generation, conventional energy, and supporting infrastructure. This distinction could help explain the different signs observed across groups and would connect the present country-level evidence to the literature on clean-energy financing (Weng et al., 2023; Yadav et al., 2024). Similarly, a clearly documented list of countries, variable codes, and reproducible estimation procedures would facilitate comparisons with related studies. The potential relevance to affordable and clean energy and climate action is substantial; nevertheless, policy conclusions must remain proportionate to the association-based empirical design.

5 Conclusions and Policy Recommendations

This study investigates the relationship between energy investment and environmental sustainability using panel observations for 88 developing countries over 1990–2022. Data were obtained from the World Development Indicators, and 46 countries initially considered were excluded because of incomplete energy-investment observations. The analysis applies the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) methodology and reports results for the full sample and three income groups. Before estimating the dynamic relationships, the study applied second-generation panel unit-root tests to examine integration properties. The reported cross-sectional dependence diagnostics indicate shared influences across countries. In addition, the significant Delta and robust adjusted Delta statistics imply rejection of slope homogeneity, rather than confirmation of identical slopes. Consequently, allowing country-specific responses is particularly relevant to interpreting the estimates.

The reported aggregate and disaggregated estimates associate GDPPC positively with CO2 emissions, whereas the GDPPC squared term and the health-expenditure indicator generally display negative coefficients. However, because the variable definition identifies GDPPC as an annual growth rate, the quadratic association alone cannot establish the standard income-level environmental Kuznets curve. The two energy-investment measures, EIP and EIPP, are generally associated with higher emissions in the full sample and lower-income groups, while the reported patterns differ for upper-middle-income economies. Similarly, FDI's association with emissions varies across income categories. These differences suggest that the environmental consequences of energy financing may depend on development conditions and the technologies financed. Nevertheless, because the investment categories do not explicitly distinguish renewable from non-renewable projects and are highly correlated, the results cannot establish that a particular energy technology causes the observed differences. Furthermore, HE refers to the share of health expenditure paid out of pocket, so its coefficient does not demonstrate that raising healthcare spending reduces emissions. The findings are best interpreted as conditional associations that inform further research and cautious policy design. Based on the reported estimates, the following policy implications are proposed. These recommendations should be interpreted as conditional on additional verification of the investment categories and underlying data:

The positive GDPPC coefficient and negative squared term are consistent with a nonlinear statistical association in the estimated specification. However, policymakers should not infer that economic growth alone will automatically reduce emissions. Instead, economic-development strategies can incorporate energy-efficiency standards, cleaner production practices, and targeted environmental regulation, while future empirical work should verify whether the GDPPC series measures income levels or growth before drawing a conventional EKC conclusion (Dinda, 2004; Guo & Shahbaz, 2024).

The estimated associations for energy investment with private participation and energy investment with public–private participation differ across income groups. Therefore, governments should assess the emissions profiles and expected environmental performance of proposed projects rather than assuming that additional private financing is inherently sustainable. In addition, financing instruments can favor investments in renewable generation, modernized electricity networks, and measurable efficiency improvements, where justified by project-level evidence (Ma et al., 2021; Weng et al., 2023). Future research should distinguish renewable and non-renewable financing to test these mechanisms more directly.

The reported FDI coefficients suggest that the association between foreign capital and emissions varies across development groups. Accordingly, governments can combine investment promotion with transparent emissions standards, environmental assessment, and incentives for cleaner production. Similarly, policies that encourage technology transfer and effective monitoring may help align foreign investment with sustainability objectives (Mahadevan & Sun, 2020; Wang et al., 2021). These recommendations are not evidence of a causal effect of FDI in the present estimates**.**

The negative coefficient reported for HE should be interpreted with particular care because this indicator captures out-of-pocket spending as a proportion of current health expenditure. It does not directly measure a general increase in healthcare resources. Therefore, the findings do not justify increasing household out-of-pocket payments as a strategy for reducing emissions. Rather, policymakers may assess environmental and public-health objectives jointly, while subsequent studies should distinguish financing composition from total health expenditure and examine the relevant mechanisms (Apergis et al., 2018; Atuahene et al., 2020).

Ethical Statement: Not Applicable

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