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

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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. The investment in energy through corporate partnerships and public-private partnerships serves as proxies 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 ($GDPPC^2$) 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.

1 Introduction

Currently, a primary impediment to attaining global equitable growth is climate change (World Bank, 2000; Rahman et al., 2019). The consequences of global warming will encompass a decrease in biodiversity, an elevation in sea levels, a diminishment of the global food supply, and an escalation in disease-related morbidity and mortality. The substantial emissions of carbon dioxide, a greenhouse gas, resulting from the combustion of fossil fuels such as coal and oil, as well as the destruction of ecosystems like forests, are the principal contributors to these irreversible calamities. A significant amount of greenhouse gases has been generated due to human error. These gases exhibit strong transmittance for visible solar radiation and significant absorbance for long-wave radiation emitted by the Earth. They can significantly absorb infrared light from the Earth, thereby elevating global temperatures and ultimately contributing to climate change. The usage of fossil fuels is a primary contributor to greenhouse gas emissions. As a result, there is a shift in the sources of energy production, and this phenomenon is attracting the attention of academics, governments, and corporations everywhere. As the economy transitions to a low-carbon economy, capital is a crucial building block (Capalino & Fulton, 2014) and a key component of it is low-carbon investing (McCollum et al., 2013; Jaegler & Burlat, 2014).

Investing in energy through public-private partnerships is a key strategy for accelerating technological advancement worldwide. Though it hasn't gotten much attention lately, public-private partnerships' investments in the energy sector are a major source of technical advancements. Investments made in energy by public-private partnerships can influence technical advancements in several ways: i) By improving energy efficiency, it lowers energy costs; ii) It can spread clean energy innovations and technologies to neighboring countries, whose carbon dioxide emissions are expected to decrease as a result of using these technologies; iii) It enhances environmental quality and encourages the use of clean energy sources by deploying technological innovations; iv) It may also help in the generation of jobs. v) By collecting taxes from the private sector, governments can better serve the general public in areas like healthcare, education, innovation, infrastructure development, and research and development.

In a similar vein, technical advancements combined with renewable energy sources reduce environmental pollution and increase energy efficiency. Using renewable energy lowers sea levels and safeguards the world's food supply. The cost of energy will go down if alternative or clean energy is more widely available. Sustainable growth is further guaranteed by renewable energy sources and technical advancements. Thus, by investing more money in the development of clean technologies, all nations must promote both the use of clean energy sources and technical advancements (Raghutla et al., 2024).

Recently, developing countries have decided to accelerate the development of green technologies and renewable energy sources to significantly reduce carbon emissions. Furthermore, a lot of nations, including financial institutions and international organizations, have enhanced access to funding for the development of renewable energy resources. Furthermore, it is important to remember that environmental contamination is a worldwide issue rather than only a local or regional one. In such a scenario, energy-related investments made by public-private partnerships, technological advancements, clean energy resources, and foreign direct investment (FDI) may significantly aid in identifying strategies to boost the efficiency of energy production and improve the application of technological advancements and clean energy resources.

The following additions to the current corpus of energy economics literature are made by this study: It looks at how investments in energy from public-private partnerships and energy investment by private participations affect the state of the environment. To reduce environmental pollution, governments and policymakers must implement more effective ways to transform energy-related investments from public-private partnerships and private participation into scientific advancements and clean energy solutions. To be more precise, governments and policymakers need to know how much energy, technology, and clean energy consumption investments from public-private partnerships minimize pollution in the environment. Nevertheless, no study has examined the aforementioned goal; for this reason, we made a substantial contribution.

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.

This study is organized as: section 1 explains the problem statement and significance of the study. Section 2 provides the literature review of the existing studies. Section 3 elucidates the model specification, data, and methodology used in this study. Section 4 discusses the results of the study and section 5 presents the conclusions and policy recommendations.

2 Literature Review

This section presents the literature review of the existing studies related to energy investment and environmental sustainability. Table 1 shows the summary of the literature review.

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.
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.
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.
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. (2022)	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.
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.
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.
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.

The literature on energy investments and environmental sustainability shows a wide range of results across different regions and methodologies. Studies indicate that renewable energy investments can significantly mitigate CO_2 emissions and improve environmental quality. Conversely, public-private partnerships and other types of energy investments often correlate with increased carbon emissions and reduced environmental quality. This literature identifies several gaps. Notably, there is limited research examining the impact of energy investment on CO_2 emissions in developing countries, both through aggregated and disaggregated analyses. While most studies have used public-private partnership investments as a proxy for measuring energy investment, our approach incorporates both private participation and public-private partnership investments. Additionally, whereas many studies rely on first-generation econometric techniques, our research employs the second-generation CS-ARDL technique, which addresses cross-sectional dependence and slope homogeneity issues.

3 Model Specification, Data, and Methodology

This section elucidates the model specification, data, and methodology used in this study to estimate the results.

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:

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

This model is an environmental sustainability model with respect to the energy investment model. There are a lot of proxies to measure environmental sustainability but we have taken CO_2 emission as a proxy to measure environmental sustainability. In this model, GDPPC and $GDPPC^2$ have been inserted in the light of the environmental Kuznet curve (EKC) theory. Energy investment is the core variable in which we are interested. So, we have taken two variables to measure the energy investment i) public-private partnership investment in energy and ii) private partnership energy investment. The rationale for taking these two variables as proxy variables is that the first variable shows the overall investment in the energy sector through public and private partnerships while the second variable partially shows the energy investment by the private sector. To test the Pollution Haven Hypothesis, we have added foreign direct investment to the environmental sustainability equation. To measure the impact of social sustainability, we have taken the out-of-pocket health expenditure.

Table 2 shows the description, unit of measurement, and source of data. We have collected panel data for 88 developing nations spanning the years 1990–2022. Ten of these falls under the category of low-income countries, 38 are classified as lower-middle-income countries and 40 are designated as upper-middle-income nations. In total, there are a total 134 developing nations but we dropped out 46 countries due to the unavailability of the energy investment data. We have collected the data of all variables from the World Development Indicator database.

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	

The long and short-run coefficients are examined by estimating a cross-sectional enhanced Autoregressive Distributed Lag (CS-ARDL) model, as established by Chudik and Pesaran (2015). The main benefits of the CS-ARDL estimator include its capacity to yield dependable outcomes regardless of the co-integration status of the series, and its regressors may comprise any combination of I(0) and I(1) processes (Chudik et al., 2017). It acknowledges cross-sectional dependency as it employs the ARDL variant of the Dynamic Common Correlated Estimator, wherein estimations are derived from individual regressions incorporating lagged variables that depend and lagged cross-sectional averages (Chudik et al., 2017). Mean group estimates are permissible despite varying slope coefficients. The mean group variant of the CS-ARDL model incorporates cross-sectional averages, serving as proxies for unobserved common elements and their latencies, into the ARDL estimations of each cross-section (Chudik et al., 2017). This strategy is more robust whenever the weak exogeneity issue arises, particularly with the inclusion of the lag-dependent variable in the model. The authors assert that the issue of endogeneity can be predominantly mitigated by incorporating lags of cross-sectional averages into the model. The subsequent regression serves as the foundation for the CSARDL estimation:

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

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:

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

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 equation of this model is given as:

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

4 Results and Discussions

This section provides CS-ARDL estimates of the study.

Summary Statistics and Correlation Analysis

Table 3 shows the summary statistics of the key variables in all income groups. Upper middle-income countries have the highest mean carbon emissions, reflecting greater environmental impacts compared to other income groups. Developing countries follow, with lower-middle-income countries and low-income countries having lower mean values. Lower middle-income countries report the highest mean GDP per capita growth, indicating higher economic growth rates. Developing countries and upper-middle-income countries have lower, but relatively close mean values, while low-income countries have the lowest mean.

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
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

Low-income nations exhibit the greatest average out-of-pocket health expenditures, indicating elevated health costs as a proportion 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 exhibit the largest average investment in energy with private involvement, succeeded by developing nations, low-income nations, and upper-middle-income nations.

Lower middle-income nations exhibit the largest average investment in energy through public-private partnerships, while emerging countries, low-income countries, and upper-middle-income countries demonstrate 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.

The distributions of the majority of variables among all income groups exhibit substantial deviations from normality. Elevated skewness and kurtosis values signify heavy-tailed distributions and asymmetry. The Jarque-Bera test results consistently indicate significant p-values for all variables, demonstrating that the data for CO_2, GDPPC, HE, EIP, EIPP, and FDI are not normally distributed. This indicates that the variables possess distributions that lack symmetry and have more extreme values than those anticipated under a normal distribution.

Table 4 presents the correlation matrix of the principal variables. In developing and lower-middle-income nations, CO_2 exhibits a weak positive association with HE and FDI, and a weak negative correlation with GDPPC, EIP, and EIPP.

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	
CO_2	0.034	0.027	-0.057	-0.064	0.160	1.000

In the case of low-income countries and upper-middle-income countries, CO_2 shows a weak positive correlation with GDPPC, HE, and FDI and a weak negative correlation with EIP and EIPP.

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 into order 1. This shows that these variables are non-stationary but become stationary after the first difference. However, variables EIP and EIPP are integrated of order 0, suggesting that they are stationary and do not require differencing for stationary. In low-income countries, a similar pattern emerges with variables GDPPC, HE, and CO_2 being integrated of order 1, indicating non-stationarity requiring differencing. However, the variables EIP, EIPP, and FDI stand out as integrated of order 0, implying that it is 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
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

In lower-middle-income countries, there are mixed results of 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 it stationarity. On the other hand, EIP, EIPP, and FDI are integrated of order 0, showing that these variables are already stationary differencing.

Similarly, in the upper middle-income countries, there are also mixed results of integration properties among the variables. Variables such as GDPPC, HE, and CO_2 are integrated into order 1, indicating non-stationarity and the need first difference to become stationarity. On the other hand, EIP, EIPP, and FDI are integrated of order 0, indicating that these variables are already stationary without taking the first difference.

1.1 Cross-Sectional Dependence Test and Slope Homogeneity 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
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

The low p-values for all variables indicate a highly of statistical significance cross-sectional relationship, suggesting the presence of such reliance.

Table 7 displays the results of the Slope Homogeneity Test, utilizing the Delta test by Pesaran and Yamagat, as well as the HAC Robust Adjusted Delta Test by Blomquist and Westerlund, for developing nations, low-income countries, countries with lower to middle incomes, and countries with higher incomes according to our model.

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

For each category, the Delta Test and HAC Robust Adjusted Delta Test values, along with their p-values (all 0.00), indicate strong statistical significance, implying that the slopes are homogeneous.

1.2 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 displays the findings of a long-run Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) analysis, which seeks to examine the correlation between carbon emissions and energy investment. Across all socioeconomic levels, the initial variable, GDP per capita (GDPPC), has a positive correlation with carbon emissions (CO_2), which is statistically significant, indicating that a rise in GDP per capita results in heightened carbon emissions. This phenomenon has multiple underlying causes. Initially, this relationship is substantiated by the Environmental Kuznets Curve (EKC) hypothesis within the framework of economic theory. This hypothesis posits that in the initial phases of growth, environmental deterioration escalates concurrently with rising national affluence. As countries attain a specific degree of economic development, a tipping point occurs where environmental degradation diminishes alongside rising national income (Guo and Shahbaz, 2024). The second cause is the income effect; as countries experience economic expansion, GDP per capita rises, resulting in more disposable money for individuals. This leads to heightened individual consumption, encompassing elevated energy usage, increased transportation reliance, and larger consumption of all products and services, which subsequently results in augmented 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 frequently depend on fossil fuels, the primary source of greenhouse gases in the environment (Kahuthu, 2006).

The second variable in all income groups is $GDPPC^2$ which is negatively correlated with carbon emission (CO_2), which is highly statistically significant and indicates higher level of economic development tends to correlate with a decrease in carbon emission due to several reasons. Firstly, the environmental efficiency theory, states that as the economic growth of the countries increases and the countries achieve a higher or certain level of GDP per capita, they become efficient in managing their resources and adopt different technologies to clean the environment (Dinda, 2004). Secondly, the environmental Kuznet curve states that when the countries achieve a certain level of income their main priority is to reduce environmental degradation not to increase the income (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, more growth in income does not have a significant impact on the consumption of energy-intensive goods and services. alternatively, people place a higher priority on their well-being such as leisure time, quality of the environment and public goods, etc. 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 make investments in energy-efficient infrastructure, clean industrial methods, and renewable energy sources in order to reduce carbon emissions. This innovation and improvement in the technologies leads to an inverse relationship between economic growth and carbon emission (Hameed et al., 2024)

The third and fourth variables are energy investment with private participation and with public-private participation (EIP and EIPP), indicate a positive relationship with carbon emission which is highly statistically significant in all income groups except upper middle-income countries only, suggesting that greater energy investment contributes to higher carbon emission in the environment. The possible reasons are: the first reason is fossil fuels dominance. Energy investment prioritizes fossil fuels infrastructure such as coal plants and oil drilling, which increases the dependence on carbon-intensive sources and as a result carbon emissions increase (Zhong et al., 2024). Secondly, a lack of funding for renewable energy ignores greener options, which prolongs the use of fossil fuels and increases carbon emissions. Thirdly, older infrastructure and inefficient technologies continue to exist in the absence of energy efficiency investments, which raises energy consumption and, in turn, increases 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 result in lower CO_2 emissions primarily through a move towards cleaner energy sources like natural gas and renewables. Investments stimulate technological advancements like carbon capture and storage and improve the use of renewable energy sources, hence reducing the amount of carbon dioxide emitted per unit of energy produced. Further encouraging emissions reductions are regulatory initiatives such as carbon price and emission regulations, and decisions about investments are influenced by the growing public knowledge and demand for sustainable energy alternatives. Despite higher levels of energy production and consumption in these nations, these coordinated efforts help to 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				
Δ 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)
Δ $GDPPC^2$	-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***
	(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)

***, **, 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 are: the first theory that explains the negative impact of FDI on carbon emission is the Pollution Haven Theory. This theory states that to minimize the cost, multinational corporations invest in nations with laxer environmental regulations. These nations with laxer environmental regulations may permit more polluting-intensive production methods which raises carbon emissions (Mahadevan and Sun, 2020). Secondly, the expansion of industrial facilities is a common component of foreign direct investment, which increases production, resources, and energy consumption. Carbon emission also rises as a result of the larger size of production (Song et al., 2021). Thirdly, foreign direct investment brought 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 leads the economic growth that contributes to the consumption of energy-intensive goods and services which ultimately raises carbon emissions (Wang et al., 2021). Gaining more foreign direct investment (FDI) in upper middle-income nations can help lower CO_2 emissions by enabling the transfer of sustainable practices and cleaner technologies from wealthy nations. The introduction of cutting-edge technologies and specialized knowledge by foreign investors frequently improves industry energy efficiency and lowers the carbon footprint of manufacturing processes. Furthermore, FDI can encourage the use of greener manufacturing techniques and renewable energy sources, moving sectors away from carbon-intensive activities. Along with improving infrastructure and regulatory frameworks, this investment inflow also tends to create a climate that is favorable to environmental sustainability projects. Because of this, increased FDI levels in these nations can have a major impact on reducing CO_2 emissions through increased efficiency, technological innovation, and environmentally friendly economic growth strategies (Tang and Tan, 2015).

The last variable health expenditures (HE), demonstrates a negative association with carbon emission which is highly statistically significant in all income groups, implying that higher expenditures on health care are associated with lower carbon emission. There are several reasons for this negative relationship. Firstly, according to the Environmental Kuznets Curve, environmental degradation initially gets worse as a nation's income rises, but it then starts to get better beyond a particular income level. Higher health spending results in better 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 a result of the adoption of greener technologies and more ecologically friendly activities as the economy expands (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. People who are more productive economically might demand greener and sustainable technologies and governments might spend more money on green initiatives. This change in policies and preferences helps lower carbon emissions (Ahmad et al., 2021). Higher expenditures on healthcare spur innovation and technical progress in the healthcare industry. These developments have an impact on the energy and transportation industries, among others. Clean and sustainable technology is used to lower carbon emissions in other sectors of the economy, such as energy production and transportation, as nations invest in them 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 a negative coefficient of -0.076, -0.206, -0.370, and -0.142 in all cases i.e., developing countries, low-income countries, lower-middle-income countries, and upper-middle-income countries. It suggests that the deviation from the long-run equilibrium towards short-run shocks can be corrected within 28 days, 2 months and 25 days, 4 months and 15 days, 1 month and 22 days in developing countries, lower-middle-income countries, and upper-middle-income countries respectively.

5 Conclusions and Policy Recommendations

This study conducted a thorough examination of the complex relationship between energy investment and environmental sustainability in developing nations. The research utilized panel data from 88 developing nations spanning the years 1990 to 2022, obtained from the World Development Indicator database. In the absence of data for certain countries, we excluded them to ensure the reliability and validity of our conclusions. The study utilized the Cross-Sectionally Auto Regressive Distributed Lag (CS-ARDL) method to estimate model parameters, accompanied by thorough statistical analyses to derive significant insights. Prior to predicting the long-run and short-run outcomes, the study performs several tests. Initially, the second generation panel unit root test was employed to assess the stationarity and non-stationarity of the dataset, revealing a mixed order of cointegration. Secondly, the study used the CD test to check the cross-section dependence test, the results revealed that there exists cross-section dependence. Thirdly, the study has applied Delta and HAC Delta adjusted tests to check the slope homogeneity in the models, the result shows that slopes are homogenous among cross-sectional units.

The dependent variable is carbon emission CO_2 and results determined that in aggregated and disaggregated analysis, GDP per capita (GDPPC) is positively associated with carbon emission while squared of GDP per capita ($GDPPC^2$) and health expenditures (HE) are negatively correlated with carbon emission. The variables energy investment with private participation (EIP), energy investment with public-private participation (EIPP), and foreign direct investment (FDI) had a positive impact on carbon emission in all income groups except upper middle-income countries because upper middle-income countries invest in renewable energy technologies that reduce the carbon emission. As GDP per capita increases, economic activities expand, leading to higher energy consumption and industrial production, which often results in greater carbon emissions. Investments by private entities in energy infrastructure typically focus on expanding energy supply to meet growing demand, which can lead to increased fossil fuel consumption and higher carbon emissions, especially if these investments are in non-renewable energy sources. Similar to EIP, public-private partnerships in energy often aim to boost energy infrastructure and availability, potentially increasing carbon emissions due to higher energy use and reliance on fossil fuels. FDI brings in capital for industrial and economic development, which often leads to increased production activities and energy consumption, thus raising carbon emissions. The negative correlation between the squared GDP per capita and carbon emissions suggests the Environmental Kuznets Curve (EKC) hypothesis, where after reaching a certain level of income, further increases in GDP per capita lead to greater environmental awareness, better technologies, and stricter regulations, thereby reducing carbon emissions. Higher health expenditures reflect a society's focus on improving public health and welfare, which often includes investments in cleaner technologies, pollution control measures, and policies aimed at reducing environmental health risks, leading to lower carbon emissions.

Based on the research's findings, the following policies can be suggested:

- The outcome of the study revealed that GD per capita growth has a positive impact and squared of GDP per capita has a negative impact on carbon dioxide emission in all income groups. So, it is recommended that the government should make policies that enhance economic growth in order to reduce carbon emissions in developing countries.
- According to the results of the study, an increase in both energy investment with private participation and energy investment with public-private participation has a positive impact on carbon dioxide emission in all income groups except upper middle-income countries because developing countries mostly invest in non-renewable energy projects that increase carbon emission. So, the government should encourage people to invest in renewable energy projects to improve environmental sustainability in developing countries.
- The findings show that carbon emission is positively affected by foreign direct investment in all income groups except upper-middle-income countries as developing countries mostly used their foreign investment in non-renewable energy projects. So, it is suggested that the government should implement policies that encourage investors to invest in renewable energy projects in order to reduce carbon emissions in developing countries.

- Improvement in health expenditures leads to a reduction the CO_2 in all income groups. So, planners must make policies that increase health expenditures to reduce carbon emissions in developing countries.

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