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The Role of Energy Investment in Promoting Economic Sustainability in Developing Countries: A CS-ARDL Analysis

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Abstract

Energy investment plays a pivotal role in promoting economic sustainability through a reliable energy supply to support industrial production and innovation. The current work investigates the difference in energy investment and economic sustainability between 1990 and 2022 for 88 developing countries with an income classification. Using the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) methodology, the research simultaneously tests short- and long-run dynamics while explicitly modeling cross-sectional dependence. The results suggest that although labor force participation, capital formation, human capital, and foreign direct investment have positive impacts on economic sustainability across income levels, energy investment, especially when used for creating public-private partnerships, fosters economic growth in middle-income economies but has a negative correlation with low-income economies. Policy implications drawn from the findings indicate that boosting investment in the energy sector, with special focus on the use of renewable technologies in low- income countries, would be an effective strategy for promoting sustainable development.

Keywords: Economic growth, public-private partnership in energy investment, energy investment with private participation, foreign direct investment

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1 Introduction

Achieving economic sustainability in developing countries is a critical objective of contemporary development policy. Among the key pillars supporting long-term economic growth, energy investment plays a foundational role, enabling industrial activity, public infrastructure expansion, and improvements in social welfare (Anarfo et al., 2021). Access to reliable and affordable energy catalyzes economic diversification and resilience, especially in economies historically constrained by energy poverty (Sadorsky, 2011). Therefore, energy investment is not just about powering homes; it is about giving countries the tools they need to grow and support their people (Bhattacharyya, 2013). Studies show that more energy investment often leads to more economic growth and better living conditions (Lee & Chang, 2007; Were, 2015; Wolde-Rufael, 2009).

Low-income countries show significant variability in energy investment with private participation and public-private partnership, with sharp peaks in countries like Congo and Mozambique. Lower-middle-income countries exhibit more stable investment trends, though generally lower in percentage terms than low-income countries. In contrast, upper-middle-income countries display higher and more consistent investment levels, reflecting stronger and steadier involvement from both private and PPP sectors in their energy investments. However, it is not solely about how much money is spent. The type of energy used (clean energy like solar, or polluting energy like coal) also makes a significant difference (Zhang & Cheng, 2009). Some studies have found that energy and economic growth can affect each other in both directions: countries grow because of energy investment, and then they invest more as they become richer (Narayan & Smyth, 2008). Therefore, the relationship is more complex than a single-direction association suggests.

To rigorously examine the relationship between energy investment and economic sustainability, it is essential to adopt an advanced econometric technique that can address the complexities inherent in cross-country data. Earlier studies have largely relied on first-generation models such as ARDL, OLS, and GMM. While these models have contributed valuable insights, they often fall short in capturing key dynamics, particularly when dealing with cross-sectional dependence and slope homogeneity (Mustafa & Selassie, 2016). To overcome these limitations, this study employs the Cross-Sectional Augmented ARDL (CS-ARDL) approach. This second-generation technique is more robust because it accounts for unobserved common factors and allows heterogeneity in slope coefficients, providing more accurate and reliable long-run estimates (Ahmad & Zhao, 2018a; Ditzen, 2021; Mir et al., 2024).

This study's significance lies not only in its methodological innovation but also in the novel dimensions it adds to the literature. First, although a substantial body of research has examined the nexus between energy investment and economic growth, empirical evidence remains scarce in developing nations (Varga, 2006; Zelezinskii et al., 2021). Much of the existing literature has concentrated disproportionately on China. This emphasis often overlooks the diverse experiences and challenges faced by other developing economies. Second, previous studies have primarily focused on energy investment through public-private partnerships (PPP); this study distinguishes itself by incorporating both PPP and private sector investments (Hirooka, 2006).

In addition, the comparative contribution lies in identifying whether energy investment is associated with different growth outcomes at distinct levels of development, rather than assuming a uniform response across developing economies. Existing evidence indicates that the growth implications of energy investment depend on the nature of investment, energy-sector conditions and the wider production environment (Samouilidis & Mitropoulos, 1983; Ahmad & Zhao, 2018a; Zahoor et al., 2022). Therefore, the study considers income-group differences alongside the separate measurement of investment with private participation and investment through public–private participation. These distinctions provide the basis for interpreting the estimated coefficients and developing policies appropriate to each group's financing and infrastructure constraints.

This paper is organized as follows: Section 2 reviews previous studies that analyzed the impact of energy investment on economic growth. Section 3 provides the model specification, data, and methodology. Results and discussions are presented in Section 4. Finally, Section 5 concludes the study and provides recommendations.

2. Literature Review

This section explores the relationship between economic sustainability and energy investment by reviewing earlier work in this area. Table 1 compiles research studies examining the link between energy investment and economic growth.

2.1 Theoretical Foundations of Energy Investment and Economic Growth

Energy infrastructure can contribute to economic activity by supporting production, facilitating the use of physical capital and improving access to essential services. The energy–growth literature nevertheless identifies relationships that differ across economies and empirical specifications (Lee & Chang, 2007; Narayan & Smyth, 2008; Wolde-Rufael, 2009). Similarly, investments in energy productivity may alter the accumulation of non-energy capital and, consequently, economic performance (Samouilidis & Mitropoulos, 1983). However, energy-related expenditure cannot automatically be equated with productive investment: the timing, financing arrangements and economic benefits of individual projects may differ. This study therefore interprets private and public–private energy investments within a production-based growth framework while recognizing that their estimated associations need not be identical across all income categories.

Table 1: Studies on Energy Investment and Economic Growth

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
(Samouilidis & Mitropoulos, 1983)	Global	1983	Theoretical	The analysis showed that investments in energy productivity affected the rate at which the non-energy capital stock was created, which in turn affected economic growth. When energy prices were rising, these effects seemed to be accentuated.
Lu et al. (2010)	Western China	42 sectors 2002	CEG Model MRS	The finding of the study indicated that household disposable income is growing at a rate of 0-8.94%, the GDP is growing at a rate of 0-8.92% and carbon dioxide emissions are growing at a rate of 0-11.10%. Investment growth is at a rate of 0-60%. Oil and gas production had the highest growth rate, at 0-19.47%.
Saibu (2012)	Nigeria	1970-2010	OLS	The findings showed that dependence on energy resources severely reduced investment. Furthermore, it was found that Nigeria's economic progress was hampered by energy abundance.
Markaki et al. (2013)	Greek	2010-2020	Input-output analysis	The results indicated that over the 2010–2020 period, h47.9 billion in investments would be needed; these would raise the country's GDP by an average of 9.4 billion annually and create 108,000 full-time equivalent jobs over the course of the study. Compared to the development of renewable energy sources (RES) in the power generation sector, the employment generated per h1 million investment in energy-

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
				saving projects for buildings and transportation is higher.
Hu (2014)	China	1970-2010	OLS	The study's findings revealed that, under the most basic scenario, China's economic growth rate dropped from 9.26% in 2011–2015 to 4.29% in 2021–2025. This demonstrated that China had begun a period of transformation.
Gakuo (2015)	Kenya	1990-2013	Descriptive statistics and OLS	According to the study, Kenya's economic growth throughout the study period was positively and significantly impacted by government investment in the construction of energy infrastructure.
Ahmad and Zhao (2018)	China	31 provinces 2001-2016	CCEMG	The study found that there was a positive and bilateral causal relationship between economic growth and energy investment.
He et al. (2019)	China	150 listed companies	threshold regression model	The study's findings showed that green credit had a double-threshold effect on investment in renewable energy and impacted the green economy development index, categorized as promotion, restriction and further promotion
Polyakova et al. (2019)	Russia	1998-2004 2010-2017	Regression model	The analysis concluded that over the years 1998–2004 and 2010–2017, foreign investment in the manufacture of petrochemicals and energy supplies had a higher effect on economic growth. Investment in electricity generation increased as well, while other aspects of the business, such as mining, had a statistically negligible or even negative impact on economic growth. The findings demonstrated the need for structural changes to reroute capital flows away from oil and gas in order to prevent the long-term deterioration of economic growth.

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
Darraji and Bakir (2020)	18 countries	2008-2015	FMOLS	The study's conclusions showed that, with inelastic elasticity, renewable energy had a beneficial impact on economic growth. Additionally, positive and significant relationships were found between economic growth and the other three independent variables with inelastic elasticity.
Dinçer et al. (2020)	15 most nuclear energy user	1990-2015	VAR method	The results of the study indicated that no significant causal link between nuclear energy use and economic growth was found. However, the study determined that the utilization of nuclear energy promotes a country's financial progress.
Stamopoulos et al. (2021)	15 industries	2020	Input-Output analysis	The findings showed that while the generation of lignite electricity still makes a major contribution to the Greek economy, investing in renewable energy offered a substantial chance for value addition and employment development.
Jaradat (2022)	GCC Countries	2010-2019	Simple Regression Analysis	The study discovered that while investments in renewable energy had a negligible effect on economic growth in Bahrain, Kuwait and Oman, they had a favorable and considerable influence on the economies of the United Arab Emirates, the Kingdom of Saudi Arabia and Qatar.
Zahoor et al. (2022)	China	1970-2016	robust least square multiple regression analysis	The results demonstrated a negative association between CO2 emissions and ecological footprint and investments in renewable energy and the economic growth of China. Development of financial, value added in manufacturing, urbanization and CO2 emissions were all positively connected with China's economic growth.
Cortez et al. (2022)	Europe	2008-2020	Synthetic portfolio Approach	Greener companies outperform their less eco-friendly counterparts within

Reference(s)	Country/Area	Time Period/Observation	Methodology	Main Results
				the firms with environmental ratings, even though the gap had closed recently. Similarly in the energy sector green energy portfolios outperform than non-green counterparts.
Zhang (2022)	OECD	2011-2020	GMM	According to the study's findings, investments in renewable energy resources and green financing led to positive economic consequences, including an increase in GDP, FDI inflow and trade openness. It was also clear that countries' economies performed better when their emissions of greenhouse gases and carbon dioxide fell.
Wu (2023)	OECD	2001-2019	GMM	The study's findings showed that green financing and renewable energy investment resources significantly and positively impacted the economic performance of a few OECD members.

Source: by the author

Many of the reviewed studies focus on Chinese provinces, with comparatively limited attention to a broader group of developing countries. Each study uses different approaches to measure results. However, reported effects vary across contexts, measures, and methods; therefore, the evidence does not establish a uniform positive relationship between energy investment and economic growth.

2.2 Income Heterogeneity, Energy Financing and Development Constraints

Evidence from individual countries and economic regions points to differences in the growth effects of energy investment and financing arrangements. For example, Ahmad and Zhao (2018a) examine energy investment and growth within China, while AlDarraji and Bakir (2020) investigate renewable energy investment across several countries. In addition, the contributions summarised in Table 1 use different methods, periods, and energy indicators, limiting direct comparisons. Consequently, the literature does not establish that additional energy investment will produce the same growth response in low-income and middle-income economies. Financing costs, project implementation, energy availability, and the capacity to absorb new infrastructure offer plausible contextual explanations for divergent outcomes; however, these mechanisms are not estimated separately in the present model and should not be interpreted as demonstrated causal channels.

3. Model Specification, Data and Methodology

As this model is based on the growth equation and the production function approach, we have taken labor and physical capital. To capture social sustainability, we used the human capital index. Furthermore, we have taken two variables related to investment: i) domestic investment (energy investment) and ii) foreign investment (foreign direct investment). Energy investment is the core variable in which we are interested. We used two variables for energy investment to check the robustness of the results: energy investment with public-private participation and energy investment with private participation. We use these two variables as proxies because the first reflects total energy sector investment made through public-private partnerships, whereas the second captures only private-sector energy investment. We use foreign direct investment as a determinant of economic growth based on the multiplier effect, which states that a change in investment changes income, and on balance-of-payments theory, which records FDI as capital inflows alongside other capital inflows. By comparing FDI inflows to GDP, we can evaluate the role of foreign direct investment in economic growth.

The dependent variable in the empirical model is annual GDP per capita growth. Accordingly, although the manuscript uses the term "economic sustainability" to describe its broader policy motivation, the estimated coefficients directly concern economic growth rather than a multidimensional sustainability index. Similarly, EIP and EIPP are treated as the investment indicators defined in Table 2; their precise coverage and potential overlap require particular attention when interpreting separate coefficients. This distinction preserves the study's growth-oriented research question while making the scope of inference explicit.

The functional form of the model is given as:

$$GDPPC = f(LFPR, GFCF, HCI, EIP, EIPP, FDI) \quad (1)$$

The econometric form of this model is given as:

$$GDPPC_{it} = \alpha_0 + \alpha_1 LFPR_{it} + \alpha_2 GFCF_{it} + \alpha_3 HCI_{it} + \alpha_4 EIP_{it} + \alpha_5 EIPP_{it} + \alpha_6 FDI_{it} + \varepsilon_{it} \quad (2)$$

Table 2 shows the description, unit of measurement, and data source. We have collected panel data for 88 developing nations spanning the years 1990–2022. Ten of these are low-income countries, 38 are lower-middle-income countries, and 40 are upper-middle-income countries. In total, there are 134 developing nations, but 46 countries were excluded because energy investment data were unavailable. We have collected the data for all variables from the World Development Indicator database.

The country sample reflects the availability of the energy investment series for 1990–2022. Therefore, the exclusion of 46 developing economies should be considered when generalizing the findings, particularly if missing investment observations are concentrated among countries with limited private-sector energy participation. In addition, describing the number of usable observations and how intermittent missing years are treated would make the panel construction more transparent. The income-group comparisons reported below are conditional on this selected sample and on the definitions of the World Development Indicators variables.

Table 2: Variables Descriptions, Measurement Unit and Data Sources

	Description	Unit of Measurement	Data Source
GDPPC	Gross Domestic Product Per Capita Growth	Annual (%)	WDI
HCI	Human Capital Index	Index	
LFPR	Labor Force Participation rate	(% of total population ages 15-64) (modeled ILO estimate)	
GFCF	Gross Fixed Capital Formation	Annual (%)	
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: author

The Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) technique significantly addresses cross-sectional dependence and slope heterogeneity, which previous studies often ignored. By incorporating cross-sectional averages of the dependent and explanatory variables, the CS-ARDL method effectively controls for common factors influencing all units, thereby mitigating the bias and inconsistency arising from cross-sectional dependence. Additionally, the technique allows heterogeneous slope coefficients across units, providing flexibility and robustness in capturing unique relationships between variables in diverse panels. This dual approach improves the accuracy and reliability of the econometric analysis, yielding more valid inferences than traditional panel data models that often assume cross-sectional independence and homogeneous slopes. Long- and short-run coefficients are estimated using a cross-sectionally augmented Autoregressive Distributed Lag (CS-ARDL) model, developed by Chudik and Pesaran (2015). The primary advantages of the CS-ARDL estimator are its ability to produce reliable results whether the series are co-

integrated or not, and its regressors can contain any mix of I(0) and I(1) processes (Chudik et al., 2017). It recognizes cross-sectional dependency because it is an ARDL version of the Dynamic Common Correlated Estimator, where estimations are based on individual regressions with lagged dependent variables and lagged cross-section averages (Chudik et al., 2017). Mean group estimates are allowed even with diverse slope coefficients. The CS-ARDL model's mean group version is based on adding cross-sectional averages (proxies for unobserved common components and their lags) to each cross-section's ARDL estimates (Chudik et al., 2017). Additionally, this approach performs better when weak exogeneity is a concern and the lag-dependent variable is included in the model. According to the authors, this endogeneity problem can be largely bypassed by adding lags of cross-sectional averages to the model. The following regression is the basis of the CSARDL estimation:

For interpretation, the empirical specification should also distinguish the benefits of controlling for common factors from claims of causal identification. Although cross-sectional augmentation addresses an important source of dependence, it does not by itself establish that energy investment causes subsequent growth. In addition, the high correlations between EIP and EIPP reported in Table 4, including values close to unity in the income-specific samples, suggest that including both may make their separate coefficients sensitive to model specification. Therefore, comparison with specifications that include each investment indicator separately would be a useful robustness exercise, subject to the availability of the original panel data (Ditzen, 2021; Mir et al., 2024).

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

The term $\bar{z}_{t-1}$ in Equation (3) 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 specification is given as follows:

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

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

4 Results and Discussion

4.1 Descriptive Statistics

Table 3 presents descriptive statistics for the key variables used in this study. The mean values show the average levels of the economic indicators across income groups. For GDP per capita growth (GDPPC), upper-middle-income countries have the highest average growth (3.612%), while lower-middle-income countries exhibit a near-zero mean (0.013%), suggesting stagnation. Human Capital Index (HCI) values are relatively stable across groups, with upper-middle-income countries showing higher human capital development.

Labor Force Participation Rate (LFPR) is highest in lower-middle-income countries (56.725%) and lowest in developing countries (38.012%), indicating different levels of labor market engagement. Gross Fixed Capital Formation (GFCF) varies greatly, with low-income countries showing the highest mean (13.364%) but also high dispersion. FDI inflows as a percentage of GDP are most prominent in upper-middle-income countries (5.885%), while low-income countries have a high mean (4.024%) driven by outliers.

Table 3: Descriptive Statistics

	GDPPC	HCI	LFPR	GFCF	EIP	EIPP	FDI
Developing Countries							
Mean	1.315	0.394	38.012	4.664	0.004	0.004	0.348
Median	0.541	0.393	38.573	-5.786	0.001	0.001	0.275
Maximum	22.020	0.400	39.286	29.158	0.010	0.010	1.203
Minimum	-22.584	0.389	33.648	-9.381	0.000	0.000	-0.013
Std. Dev.	9.177	0.006	1.619	21.289	0.005	0.005	0.326
Skewness	-0.059	0.244	-1.905	0.684	0.695	0.695	1.230
Kurtosis	4.165	1.500	5.118	1.500	1.500	1.500	3.985
Jarque-Bera	1.313	0.311	26.138	0.516	0.523	0.523	4.977
Probability	0.519	0.856	0.000	0.773	0.770	0.770	0.083
Low-Income Countries							
Mean	0.854	0.362	50.650	13.364	0.018	0.018	4.024
Median	1.516	0.373	52.406	6.288	0.006	0.006	1.720
Maximum	90.832	0.432	80.350	2357.675	0.192	0.192	167.329
Minimum	-48.429	0.286	14.341	-294.162	0.000	0.000	-202.824
Std. Dev.	7.782	0.036	16.531	109.221	0.040	0.040	15.463
Skewness	1.017	-0.456	-0.230	19.029	3.641	3.641	0.084
Kurtosis	36.796	2.265	2.026	406.631	15.451	15.451	88.108
Jarque-Bera	37732.220	3.942	41.438	3595510.000	546.119	546.119	176859.100
Probability	0.000	0.139	0.000	0.000	0.000	0.000	0.000
Lower-Middle-Income Countries							
Mean	0.013	0.361	56.725	4.921	0.001	0.001	3.563
Median	-0.388	0.361	57.232	4.256	0.002	0.002	2.148
Maximum	11.222	0.362	58.352	26.518	0.003	0.003	40.167
Minimum	-26.374	0.360	53.113	-19.527	0.000	0.000	-10.038
Std. Dev.	7.267	0.001	1.516	10.274	0.001	0.001	10.282
Skewness	-1.103	0.316	-1.067	-0.234	-0.447	-0.447	1.589
Kurtosis	6.353	1.500	3.041	3.276	2.022	2.022	6.118
Jarque-Bera	22.820	0.331	6.263	0.259	0.293	0.293	28.092
Probability	0.000	0.847	0.044	0.879	0.864	0.864	0.000
Upper-Middle-Income Countries							
Mean	3.612	0.607	42.021	5.957	0.026	0.021	5.885
Median	4.994	0.625	38.514	4.417	0.004	0.002	6.433

	GDPPC	HCI	LFPR	GFCF	EIP	EIPP	FDI
Maximum	14.025	0.634	55.761	42.625	0.122	0.116	11.171
Minimum	-27.567	0.544	27.534	-20.619	0.002	0.000	1.283
Std. Dev.	7.900	0.043	9.531	12.972	0.043	0.042	2.770
Skewness	-2.115	-1.099	0.178	1.084	1.656	1.936	0.007
Kurtosis	8.614	2.289	1.421	4.921	4.243	4.914	1.740
Jarque-Bera	69.994	0.889	3.601	9.440	4.169	5.440	2.117
Probability	0.000	0.641	0.165	0.009	0.124	0.066	0.347

Source: author

Standard deviation reflects data variability. GFCF and FDI show extreme dispersion in low-income countries, with standard deviations of 109.221 and 15.463, respectively, highlighting instability. GDPPC also shows high variability in developing and upper-middle-income groups. By contrast, HCI shows low variability across all categories. Skewness reveals data asymmetry; GDPPC is negatively skewed in developing and lower-middle-income groups, indicating frequent low values. LFPR shows strong negative skewness in developing and lower-middle-income groups, while FDI is positively skewed across all groups, especially in upper-middle-income countries. Kurtosis, measuring peakedness, is especially high for GDPPC and GFCF in low-income countries (36.796 and 406.631), indicating extreme outliers. The Jarque-Bera (JB) test results show that most variables, especially GDPPC, GFCF, and FDI in low- and lower-middle-income groups, reject the null hypothesis of normal distribution (p-values = 0.000), indicating non-normality and the presence of skewed, heavy-tailed distributions.

4.2 Correlation Analysis

Table 4 shows the correlation analysis between GDP per capita growth and key economic indicators across different income-level country groups. In developing countries, the correlations between GDP growth and other variables are generally weak, indicating limited interdependence. There is a minimal association with labor force participation, human capital, capital formation, and energy investments. Notably, the relationship with foreign direct investment appears slightly negative, suggesting that FDI may not consistently contribute to growth in these economies, possibly due to instability or lack of absorptive capacity.

Table 4: Correlation Matrix

Developing Countries							
	GDPPC	**HCI**	**LFPR**	**GFCF**	**EIP**	**EIPP**	**FDI**
GDPPC	1.000						
HCI	0.054	1.000					
LFPR	0.102	-0.083	1.000				
GFCF	0.094	-0.087	0.995	1.000			
EIP	0.157	0.100	0.109	0.095	1.000		
EIPP	0.023	0.028	0.036	0.044	-0.117	1.000	
FDI	-0.045	-0.012	-0.025	-0.040	0.131	-0.849	1.000

Low-Income Countries						
GDPPC	1.000					
HCI	0.007	1.000				
LFPR	0.291	0.137	1.000			
GFCF	0.046	0.236	0.046	1.000		
EIP	-0.086	0.251	-0.337	-0.223	1.000	
EIPP	-0.086	0.251	-0.337	-0.223	0.999	1.000

Developing Countries							
FDI	0.239	0.399	0.186	0.179	-0.175	-0.175	1.000
Lower-Middle-Income Countries							
GDPPC	1.000						
HCI	0.220	1.000					
LFPR	0.263	0.251	1.000				
GFCF	0.281	0.226	0.110	1.000			
EIP	-0.168	0.322	-0.135	-0.226	1.000		
EIPP	-0.166	0.120	-0.139	-0.231	0.987	1.000	
FDI	-0.215	0.167	-0.163	-0.008	-0.017	-0.018	1.000
Upper-Middle-Income Countries							
GDPPC	1.000						
HCI	-0.259	1.000					
LFPR	-0.4069	-0.301	1.000				
GFCF	0.041	0.404	-0.355	1.000			
EIP	0.070	0.168	-0.461	0.152	1.000		
EIPP	0.070	0.168	-0.461	0.152	0.988	1.000	
FDI	0.047	-0.695	0.228	-0.578	-0.003	-0.003	1.000

Source: author

In contrast, low- and lower-middle-income countries exhibit somewhat stronger associations, particularly between GDP growth and labor force participation or capital formation, reflecting their reliance on labor and physical investment to stimulate growth. However, energy-related investments tend to show weak or even negative correlations, implying underutilization or inefficiency in this sector. In upper-middle-income countries, the pattern shifts, with mixed results. While GDP growth shows some positive links with investment indicators, it appears negatively associated with human capital and labor force participation, possibly reflecting structural changes or a growing reliance on capital-intensive sectors.

4.3 Cross-Section Dependence Test

Table 5 reveals statistically significant cross-sectional dependence across all variables and income categories, indicating substantial interconnections among countries within each group.

Table 5: Pesaran's Cross-Sectional Dependence (CD) Test

Variable	Developing Countries	Low-Income Countries	Lower-Middle-Income Countries	Upper-Middle Income Countries
GDPPC	22.511***	102.384***	111.367***	110.249***
HCI	72.787***	66.625***	65.899***	74.341***
LFPR	71.391***	22.991***	39.660***	53.278***
GFCF	91.394***	92.991***	47.672***	56.286***
EIP	27.827***	59.103***	32.921***	71.659***
EIPP	28.973***	59.103***	32.922***	71.650***
FDI	11.080***	0.291***	63.881***	42.543***

Source: author

This implies that economic developments in one country may systematically influence others, necessitating models that account for such interdependence.

4.4 Slope Homogeneity Tests

Table 6 presents the results of the slope homogeneity tests based on Pesaran and Yamagata (2008) and Blomquist and Westerlund (2013).

Table 6: Slope Homogeneity Test on Developing Countries

	(Pesaran and Yamagata, 2008)	**(Blomquist and Westerlund, 2013)**
	Delta Test	**HAC Robust Adjusted Delta Test**
Developing Countries	34.123***	-1.098***
Low-Income Countries	6.081***	-2.825***
Lower Middle-Income Countries	23.794***	-3.816***
Upper Middle-Income Countries	35.680***	-4.717***

Source: author

The significant test statistics across all income groups indicate slope heterogeneity, suggesting that the relationship between variables differs across countries within each group. This highlights the need for estimation techniques that accommodate heterogeneous slope coefficients in panel data analysis. However, interpreting significance must follow the relevant test distribution and reported p-values, not the presence of significance symbols alone. In particular, the reported HAC-robust adjusted delta statistics warrant verification against the original output before making any inference about the strength of slope heterogeneity.

4.5 Unit Root Test

Table 7 indicates a mixed order of integration among the variables, with some series stationary at level while others are non-stationary. In addition, the significance indicators in the panel unit-root table should be checked against the original test output, because some positive statistics are marked significant in a way that may not correspond to the stated stationarity interpretation. This verification is especially important when establishing that the variables satisfy the integration-order requirements of the selected estimator.

Table 7: 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**	**Lags**	**Zt Statistics**
GDPPC	0	-29.804***	0	-28.440***
HCI	0	0.555***	0	0.566***
LFPR	1	-4.912***	1	-0.098
GFCF	0	0.132***	0	0.875***
EIP	1	0.410	1	0.592
EIPP	0	0.547***	0	0.381***
FDI	0	0.332***	0	0.796***
Low-Incomee-Countries				
GDPPC	0	-15.785***	0	-16.067***
HCI	1	2.972	1	3.242
LFPR	1	-1.935*	1	-1.568*
GFCF	0	-5.923***	0	-6.234***
EIP	1	3.352***	1	3.862***
EIPP	1	3.352***	1	3.862***

Second Generation Panel Unit Root Test				
FDI	0	-10.239***	0	-10.342***
Lower-Middle-Income Countries				
GDPPC	0	-17.394***	0	-16.810***
HCI	0	0.556***	0	0.495***
LFPR	0	0.923**	0	4.628***
GFCF	0	-18.585***	0	-16.179***
EIP	0	-3.699***	0	-4.012***
EIPP	0	-3.699***	0	-4.012***
FDI	1	0.220	1	0.340
Upper-Middle-Income Countries				
GDPPC	0	-18.798***	0	-16.809***
HCI	1	0.353	1	0.407
LFPR	1	-2.929***	1	-1.218
GFCF	0	-17.528***	0	-14.689***
EIP	0	2.417***	0	2.678***
EIPP	0	2.650***	0	2.987***
FDI	0	-11.602***	0	-10.360***

Source: author

This variation across country groups and variables suggests the need to apply panel estimation techniques that can accommodate both I(0) and I(1) processes.

4.6 CS-ARDL Estimates

Table 8 presents the results of the long-run cross-sectionally augmented (CS-ARDL) analysis. The objective is to explore the relationship between economic growth and energy investment. In developing countries, low-income countries, lower middle-income countries, and upper middle-income countries, the first variable is LFPR; the positive coefficient of LFPR suggests that an increase in the labor force participation rate is associated with an increase in economic growth, which is highly statistically significant in all categories of countries except upper-middle-income countries. Several factors explain this positive relationship. Firstly, according to the economic theory of the production function, when large numbers of people are involved in economic activities, the productivity of the economy increases. With more people working, there is a greater chance of specialization, innovation, and efficiency gains, which positively affects the country's overall economic activity or progress (Weiss, 1992). Secondly, a higher labor force participation rate typically implies a greater number of well-educated and skilled laborers. More people entering the workforce means that the economy's total human capital grows. This can lead to higher competence, knowledge, and skill, which ultimately increases economic output and productivity (Paudel & Perera, 2009). Thirdly, a large labor force provides diverse ideas and perspectives. This diversity fosters innovation that leads to technological advancement and development in products and production processes. As innovation is a key factor of economic growth and development, an active and growing labor force increases creative ideas and innovation, which leads to economic growth (Altaee et al., 2016). Fourthly, individual income increases when more people participate in economic activities, which in turn increases consumer spending. Increased consumption stimulates demand for goods and services, encouraging businesses to increase production to meet that demand. GDP increases as production rises, contributing to overall economic progress (Haque et al., 2019). Lastly, the dependency ratio—the proportion of working-age people to those with dependents, such as children and retirees—can decrease as the labor force participation rate increases. It is easier to support dependents when the dependency ratio is lower because a greater percentage of the population is working and contributing to the economy. In addition, this allows more resources to be allocated to profitable ventures, lessens the financial strain on social support systems, and promotes economic growth (Listiyono et al., 2021). This result is consistent with the following studies (Weiss, 1992; Paudel & Perera, 2009; Altaee et al., 2016; Haque et al., 2019; Listiyono et al., 2021).

The second variable is GFCF; the positive coefficient suggests a positive relationship between gross fixed capital formation and economic growth, and this relationship is statistically significant across all country categories. An increase in a country's physical assets over a specific period of time is called gross fixed capital formation. For several reasons, GDP per capita is positively affected by an increase in gross fixed capital formation. One main reason is investment in advanced technology and machinery. With this financial infusion, companies can update their manufacturing processes, enabling employees to produce more in less time. As a result, overall productivity increases, which propels economic growth and raises GDP per capita as the economy becomes more resource-efficient (Solow, 1962). Moreover, growth in fixed capital directly contributes to job creation, a crucial factor in economic development. More labor is needed to build new factories and infrastructure, which lowers unemployment rates and increases employment. In addition to promoting social welfare, this inflow of employment raises worker earnings, which in turn raises GDP per capita as household incomes grow (Apergis & Payne, 2010). An increase in gross fixed capital formation often emphasizes innovation and technological improvement. As capital is allocated to research and development initiatives, economies advance technologically. This technological advancement increases overall competitiveness, introduces new goods and services, and streamlines industrial processes. As a result, GDP per capita and economic growth increase due to technological advancement (Adhikary, 2011). Another economic reason is economies of scale, which are facilitated by gross fixed capital formation. Businesses can take advantage of economies of scale by expanding their fixed capital, which lowers average production costs. This maximizes resource use, which raises GDP per capita (Ali, 2015). This outcome aligns with the following studies (Solow, 1962; Apergis & Payne, 2010; Adhikary, 2011; Ali, 2015).

Table 8: Long-Run and Short-Run CS-ARDL Estimates

Variables	Developing Countries	Low-Income Countries	Lower Middle-Income Countries	Upper Middle-Income Countries
Short Run Results				
Δ LFPR	-5.277	7.655	-4.792	-22.039
	(4.662)	(5.139)	(5.699)	(22.225)
Δ GFCF	0.377***	0.097	0.130	0.527***
	(0.083)	(0.191)	(0.209)	(0.150)
Δ HCI	0.535	-0.153	-0.046	-0.040
	(0.357)	(0.185)	(0.221)	(0.067)
Δ EIP	-0.209	-1.058	-7.878	-0.214
	(0.267)	(0.937)	(7.754)	(0.533)
Δ EIPP	-0.276	-1.058	-6.778	-0.223
	(0.266)	(0.937)	(7.656)	(0.565)
c**FDI**	-5.524***	-0.256	0.054	0.237*
	(2.021)	(0.352)	(0.275)	(0.122)
Δ ECT(-1)	-0.794***	-1.142**	-0.871***	-0.862***
	(0.053)	(0.533)	(-0.162)	(0.091)
Long Run Results				
LFPR	0.069**	0.260***	0.273***	0.064
	(0.027)	(0.024)	(0.016)	(0.041)
GFCF	0.026**	0.055***	0.145***	0.067**
	(0.014)	(0.017)	(0.007)	(0.027)

Variables	Developing Countries	Low-Income Countries	Lower Middle-Income Countries	Upper Middle-Income Countries
HCI	0.030***	0.144***	0.052***	0.045***
	(0.007)	(0.007)	(0.002)	(0.010)
EIP	0.115***	-0.217***	0.077***	0.115***
	(0.025)	(0.011)	(0.003)	(0.033)
EIPP	0.119***	-0.217***	0.087***	0.128***
	(0.027)	(0.011)	(0.005)	(0.043)
FDI	0.063**	0.634***	0.148***	0.086**
	(0.028)	(0.074)	(0.007)	(0.036)

Source: Author

The third variable is HCI; there is a positive relationship between the Human Capital Index and economic growth, which is highly statistically significant across all country categories. An increase in the Human Capital Index (HCI), which measures health, education, and overall human potential, significantly enhances economic sustainability, as reflected in GDP growth. First, improved human capital leads to higher productivity. When individuals receive better education and healthcare, they acquire the skills and physical capabilities needed to perform tasks efficiently. A healthier workforce also reduces absenteeism and improves performance, enabling economies to produce more goods and services and thereby increasing GDP (Pelinescu, 2019).

Moreover, a well-educated population fosters innovation and technological progress. Education equips individuals to generate ideas, solve complex problems, and adopt cutting-edge technologies. These advancements drive economic diversification and efficiency, enabling industries to grow sustainably. Better health and education outcomes increase workforce participation. With fewer people constrained by illness or lack of skills, more individuals can actively contribute to the economy. A steady supply of skilled labor not only supports consistent economic output but also enhances the economy's ability to withstand and recover from financial shocks. This finding is matched with the following studies (Pelinescu, 2015; Sarwar et al., 2021).

The fourth and fifth variables are energy investment with private participation and energy investment with public-private participation; across all income groups, energy investment and economic growth have a significant, positive relationship, except in low-income countries. For several reasons, GDP per capita growth and overall economic development increase as energy investment rises. Industries can become more productive with more energy resources, and energy investment is one of the main factors (Pelinescu, 2015). Energy investment allows industries to operate more efficiently, which in turn raises productivity. Higher productivity then leads to greatly increased economic growth (Ahmad & Zhao, 2018b). The construction of energy infrastructure projects, including power plants and distribution networks, is often linked with energy investments. These not only stimulate economic activities but also create jobs and provide employment opportunities in local communities. These combined natural forces, rising employment, and infrastructural development lead to a significant addition to per capita income and an enhancement of GNP and GDP per capita (Ahmad & Zhao, 2018b). The higher the energy investment, the more it leads to R&D (research and development) for efficiency improvement and the use of cleaner technology; it also contributes to overall energy consumption efficiency. However, the most significant result of larger energy investment is diversification of energy sources. In other words, countries can secure their energy supply by having multiple alternative sources, including renewable ones. Diversified energy infrastructure can prevent shocks, ensuring that countries are not reliant on a single energy source. This fosters economic stability so that prosperity can finally last (Ahmad et al., 2022). Finally, countries that invest in renovating and expanding energy infrastructure have a stronger competitive position in the ever-evolving global economy. Companies will want an energy source that is both reliable and affordable for their operations, which is becoming more valuable every day for foreign investment. The economy has become more global, competitive, and active, with overall higher GDP per capita (Zahoor et al., 2022). For several reasons, increased energy investment may hinder economic growth in low-income nations. The crowding-out effect is possible, in which money is diverted from vital industries like infrastructure, healthcare, and education that are critical to long-term economic growth. Second, poorly focused energy expenditures that prioritize large-scale initiatives that exclusively benefit particular businesses or regions can lead to wasteful resource allocation, ignoring the need

for equitable development and broader economic demands. A rise in reliance on imported energy supplies may weaken the economy's overall growth by creating balance-of-payments problems and increasing susceptibility to global price swings. This result is consistent with the following studies (Ahmad & Zhao, 2018b; AlDarraji & Bakir, 2020; Samouilidis & Mitropoulos, 1983; Zahoor et al., 2022).

The last variable is FDI, and its positive coefficient indicates a positive relationship between foreign direct investment and economic growth. It is highly statistically significant across all country categories. This relationship is due to several reasons. There are two types of FDI: brown FDI and Green FDI. Brown FDI refers to foreign direct investment where a company merges with an existing domestic firm to expand its operations, whereas greenfield FDI involves establishing new business operations or facilities in a foreign country from the ground up, often to capitalize on market opportunities or leverage local resources and labor. So FDI has a significant effect on a host country's GDP because it brings capital needed to improve production methods and modernize technology. This capital injection increases the output per worker and boosts overall productivity and efficiency. Accordingly, increased productivity has been the principal source of the rise in real GDP per capita in most countries. Further, FDI frequently leads to the creation of entirely new enterprises or to the expansion of existing enterprises within the host country. The job creation associated with this expansion is also essential to economic growth. Increased employment from FDI, then, raises GDP per capita and levels of household income (Blomström et al., 2003; Javorcik, 2004). Moreover, FDI makes it easier for foreign investors to transmit innovative technologies, managerial expertise, and industry best practices to domestic sectors. This technology transfer boosts innovation in the host nation and makes domestic enterprises more competitive. In the long term, sustained economic growth can result from the adoption of cutting-edge technologies and creative behaviors (Carkovic & Levine, 2005). Furthermore, by attracting foreign companies from a range of industries, FDI encourages the diversification of a nation's economic base. This variety makes the economy less dependent on any one industry and, therefore, more shock-resistant. This capacity helps sustain robust, persistent economic growth (Keller, 2010). Lastly, FDI gives regional companies access to international markets. By starting operations in a host nation, foreign investors provide domestic businesses the chance to grow globally. This expanded market access can increase exports, raise incomes, and foster economic expansion (Alfaro & Chauvin, 2020). This outcome aligns with the following studies (Blomström et al., 2003; Javorcik, 2004; Carkovic & Levine, 2005; Keller, 2010; Alfaro & Chauvin, 2020).

In addition, the empirical interpretation should distinguish statistical significance from economic magnitude and should consider whether the investment coefficients remain stable when the strongly related EIP and EIPP variables are estimated separately. The short-run coefficients displayed in Table 8 are not consistently significant for the energy investment indicators, whereas the reported long-run results differ across income groups. Consequently, policy recommendations should principally reflect the estimated long-run associations and should not imply immediate growth effects from energy projects.

Table 8 also presents the short-run CS-ARDL analysis. In all cases i.e., developing countries, low-income countries, lower-middle-income countries and upper-middle-income countries error correction term has a negative coefficient of -0.794, -1.142, -0.871 and -0.862 respectively which implies that deviation from short shocks toward long-run equilibrium can be corrected around about one year, three months and ninety-one days in developing countries, ten months and 15 days in low-income countries, one year, one month and twenty-five days in lower-middle-income countries and one year, one month and twenty-nine days in upper-middle-income countries.

4.7 Interpretation of Income-Specific Energy Investment Effects

The central substantive result is the contrast between the positive long-run association in the middle-income groups and the negative association in low-income economies. This pattern cautions against treating energy investment as a uniformly growth-enhancing intervention. In economies where financing conditions are constrained, the benefits of energy infrastructure may take longer to materialize or may depend on complementary investment in distribution networks and productive capacity. However, the present estimates do not directly measure crowding-out, institutional quality or project-level performance. Therefore, these factors may explain the observed differences, but they are not verified mediating mechanisms. Earlier research on energy investment and economic growth provides a basis for discussing such heterogeneous effects without assuming that the same investment arrangement is equally effective everywhere (Ahmad & Zhao, 2018a; AlDarraji & Bakir, 2020; Zahoor et al., 2022).

5. Conclusions and Policy Recommendations

This study investigated the impact of energy investment on economic sustainability, using GDP per capita (GDPPC) as the dependent variable and panel data from 88 developing countries spanning 1990–2022. The

analysis included 10 low-income, 38 lower-middle-income, and 40 upper-middle-income countries, with data sourced from the World Development Indicators. After conducting preliminary analyses, including descriptive statistics and correlation tests, the study confirmed cross-sectional dependence and slope heterogeneity and identified a mixed order of integration using second-generation panel unit root tests. The CS-ARDL approach was employed to estimate both long-run and short-run effects. The results show that labor force participation rate (LFPR), gross fixed capital formation (GFCF), human capital index (HCI), and foreign direct investment (FDI) have a positive and statistically significant impact on GDP per capita across both aggregated and disaggregated income groups. Energy investment with private (EIP) and public-private (EIPP) participation also positively influences GDP per capita in developing countries and in both lower-middle- and upper-middle-income countries. However, in low-income countries, EIP and EIPP negatively affect economic sustainability, likely due to the crowding-out effect, where energy investments divert essential resources from critical sectors such as health, education, and infrastructure. Based on the research's findings, the following policies can be suggested:

5.1 Theoretical Contributions, Policy Implications and Future Research

The study's principal contribution is to document income-related differences in the long-run relationship between energy investment and GDP per capita growth within a cross-sectionally augmented panel framework. In addition, including private participation alongside public–private investment adds a financing dimension to the energy–growth debate. The findings are relevant to discussions of affordable energy access, productive employment and infrastructure development, including the policy objectives reflected in SDGs 7, 8 and 9. However, GDP per capita growth alone does not capture environmental performance, distributional outcomes, or the full sustainability of an energy system. Thus, the implications for sustainable development remain broader policy interpretations of the observed growth relationships.

- The study found that an increase in labor force participation leads to increased economic growth across all income groups. Therefore, to improve economic growth, policymakers need to implement policies that promote a higher labor force participation rate in developing countries.
- The study found that economic growth is positively affected by gross fixed capital formation across the reported income groups. Therefore, the government should introduce policies that encourage gross fixed capital formation to boost economic growth in developing countries.
- The finding shows that an increase in the human capital index improves economic growth in all categories of developing countries. Therefore, planners should implement policies that promote social sustainability to enhance economic sustainability in developing countries.
- The results indicate that increasing both energy investment with private participation and energy investment with public-private participation improves economic growth in all income categories except low-income countries. Therefore, the government should implement policies to increase investment in the energy sector, with both private and public-private participation, to promote economic growth. In low-income countries, planners should implement policies to invest in renewable energy to improve economic growth.
- The findings also show that foreign direct investment positively affects economic growth across all income categories. Therefore, policymakers must implement policies that boost foreign direct investment to promote economic growth in developing countries.

Future research could extend this analysis by distinguishing renewable from non-renewable energy investment, examining the role of institutional quality and financing constraints, and testing whether the findings are sensitive to alternative income classifications. Similarly, where data permit, separate EIP and EIPP specifications, alternative panel estimators, and sensitivity analyses excluding extreme observations would help establish the stability of the results. These extensions would build directly on the current research question without changing its focus on energy investment and economic growth in developing economies.

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