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Beyond the Grid: An In-depth Analysis of Economic, Demographic, and Technological Drivers of Energy Poverty in 11 Developing Countries

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ABSTRACT

This research examines the impact of critical factors, including GDP, population, internet, renewable power, human capital, and global link, on energy poverty in the New-11 nations, using a Panel ARDL technique. Energy poverty rises with GDP and population growth but is significantly reduced by internet access and renewable energy. Human resources and globalization present a mix of insignificant functions. Short-run illustrations depict initial movement in the long run, which abruptly stabilizes as renewable energy costs become apparent. The implications of the findings of energy poverty are the essential and inescapable policy calls for targeted investments in digitalization, sustainable energy, people, and intelligent globalization.

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1. Introduction

Energy poverty remains a significant challenge for most LMICs as they struggle to achieve sustainable development goals, resulting in widening socioeconomic inequalities. The phenomenon is complex and involves various aspects ranging from economic to demographical and technical factors.

The availability of reliable and affordable energy is a basic human right and fundamental necessity and the foundation for sustainable development. In the contemporary world filled with information and communication technologies, constant advancements of which recast societies, energy is now one of the core constituents of societies that not only fuels and drives economic processes but also influences the quality of life of people and institutions.

Although tremendous progress has already been made across the world in the advancement of energy infrastructure, a still large population in the developing world, especially in the N-11 countries such as Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, Turkey, South Korea, and Vietnam are still struggling with energy-poor condition.

Thus, it is possible to claim that the absence of an understanding of the mechanisms that ensure the continuation of the issue in question is a critical component in explaining its link with the degrees of socio-economic development in the N-11 countries and their access to electricity. These nations' energy profile is defined by fundamental factors such as growth rate, population density, technological incorporation, and international relations. This empowers energy poverty analysis to address modern energy for all from the UN Sustainable Development Goal 7 and determine the specific causes that require a multi-pronged approach to eradicate.

There is typically a positive and mutually beneficial connection between the growth of a country's GDP and its level of access to energy. Economic growth tends to increase the demand for and investment in electricity infrastructure, supporting further economic activities and growth. A study on South Asian countries found a long-term relationship between electricity supply and economic growth, especially in Pakistan. This implies that economic growth in these regions often leads to improved access to electricity. As economies grow, the increased industrial, commercial, and residential energy demands drive investments in electricity infrastructure, enhancing overall access (Majewski, Mentel, Salahodjaev, & Cierpiał-Wolan, 2022). According to the International Energy Agency (IEA), economic policies supporting clean energy transitions are partly driven by economic growth, which facilitates greater investments in renewable energy sources, expanding electricity access (IEA, 2023).

Urbanization and demographic factors also influence energy accessibility. Urban density significantly impacts residential energy consumption, which includes access to electricity. Higher density might reduce energy use in temperate regions, but it could increase it in colder climates due to heating needs (Narimani Abar, Schulwitz, & Faulstich, 2023). Urbanization facilitates the spread of electricity by reducing the per capita infrastructure cost. However, significant disparities remain, especially in low-income countries where rural areas lag significantly behind urban centers regarding electricity access (Ritchie, Rosado, & Roser, 2019).

On a global scale, it has been demonstrated that incorporating renewable energy sources like solar, wind, and hydropower into the existing electricity grid can improve the availability of electricity. According to Ember's Global Electricity Review, the share of renewable energy in global electricity generation has surpassed 30%, mainly driven by solar and wind energy growth (Wiatros-Motyka, 2023). Renewable electricity output positively correlates with sustainable economic development and environmental benefits. Increased renewable energy production enhances energy security and reduces reliance on fossil fuels, crucial for regions striving to improve electricity access amidst growing energy demands (Laureti, Massaro, Costantiello, & Leogrande, 2023).

Internet usage has been found to increase household electricity consumption significantly. As more devices and activities are internet-dependent, the demand for electricity rises. This correlation is particularly evident in urban households where internet penetration is higher. Enhanced internet access can increase educational and economic opportunities, driving demand for more robust and reliable electricity supplies (Gao, Han, Ye, & Li, 2023). The internet's impact on the quantity of power consumed varies on a geographical and household-specific level, depending on the type of household. Urban areas typically see a more robust correlation due to better internet access and higher device usage. In contrast, rural areas, despite increasing internet penetration, face challenges in electricity infrastructure that can limit the full potential of internet usage (Wang, Zhu, Wang, Ntim, & Liu, 2023).

Higher human capital fosters better governance and more effective implementation of infrastructure projects related to electricity. Improved education and skills enable more efficient planning, execution, and maintenance of electricity infrastructure. For instance, countries with higher human capital indices tend to have better-developed energy infrastructures, facilitating broader access to electricity (Bank, 2023). Human Capital and Economic development have a positive impact on extending the use of electricity

Higher and more efficient human resource capital contributes to better and advanced economic growth and sometimes leads to increased energy investment. This is evident in many developing countries, where developments in people's capital have also been found to directly affect the growth of electricity networks (Jabeen & Khan, 2022). Qualified specialists are vital in developing and utilising renewable electricity systems that provide enhanced and lasting power access, especially in rural and remote areas (Lin, Anser, Peng, & Irfan, 2023).

Besides electricity access, globalization also uses renewable energy and energy-efficient devices. One survey of 36 African nations found that economic globalization positively influences electricity penetration and reduces inequity (Noumba & Nguea, 2023). Energy literacy and the imparting of relevant information concerning energy access are a function of knowledge exchange and social globalization. Better communication networks in the planning and implementation of the projects also enhance the electrification undertaking. They discover that the release of fee-based electricity is growing due to financial globalization (Noumba & Nguea, 2023).

Global changes in the dynamics of energy systems due to factors such as increasing urbanization, digitalization, and world shifts to renewable energy sources make it necessary to consider the dynamics of the N-11 countries. However, the current knowledge gap in this field will be closed in this study through a comprehensive analysis of the economic, demographic, and technological factors that cause energy poverty. It will also give a holistic picture of the electricity access indicators missing in the present scenario.

Despite the definite efforts to increase energy infrastructure and expand access to it, the energy poverty issue remains relevant within the N-11 countries. The countless number of factors that fuel this process include limitations of the financial plan, the density of the population, and technological advancements. Therefore, it is critical to understand these elements and how they interact with one another to create effective policies and interventions that address the causes of energy poverty in the mentioned countries.

The findings of this study have significant implications for the politicians, researchers, and practitioners involved in energy planning and poverty eradication fight. The work tries to answer the research questions by understanding the economic, demographic, and technological aspects of the problems the N-11 countries face by defining and exploring energy poverty. Thus, the outcomes identified in this research can offer knowledgeable information for policy choices based on such research. This can help in emerging programs that enhance the provision of energy and other socioeconomic objectives within society.

Given this rationale, this study aims to review the energy poverty in the N-11 countries from many front angles. Thus, while the research will compare and evaluate these facets, it will also describe the complex interrelation by analyzing the effects of economic development on energy poverty. Also, it shall seek to determine demographic characteristics of energy accessibility by looking at the population density concerning energy scarcity. Also, the project will look at the effects of internet connection on energy behaviour and its prospects in managing the energy poverty challenge. Furthermore, the study will determine the effectiveness of renewable energy sources in eradicating energy poverty, with particular attention paid to sustainable solutions. Specifically, the paper will focus on the capacity of investing in individuals’ talents to reduce energy poverty. Last but not least, this research proposal will look into how this phenomenon of globalization has affected the pace of energy policy and its consequent effect on energy-deprived N-11 countries.

2. Literature Review

There are many correlations between unfamiliarity with energy and the economy's growth in several different regions. The research on Energy poverty in South Asia by Shafiullah and Rahman (2021) and Energy poverty in Eastern Indonesia by Leiwakabessy and Payapo (2022) reveals that long-term economic growth may help reduce energy poverty. However, on the downside, the short-term impact of industrialization may increase energy poverty. Moreover, the studies carried out on each of the ASEAN countries reveal that economic prosperity positively impacts poverty elimination (Anancharoenkij & Chinnakum, 2021), thus underscoring the centrality of energy security in driving economic growth to eliminate poverty. However, the connection between energy and poverty has received little research attention in the past (Clancy, Mohlakoana, & Matinga, 2013). For instance, people experiencing poverty in Nigeria suffer from challenges, including bad energy production and consumption, affecting their energy access (Ayinde, Celik, & Gylych, 2019). Energy poverty is associated with economic growth, which defines the ability to access energy, health, education and income, as observed in the SADC countries study by Nkomo (2007). Economic development and energy poverty have a clear connection in SADC nations, given that the availability of energy resources depends on economic growth, affecting health, education, and income (Al-Tal et al., 2021). The panel modelling done on the BRICS economies from 1990 to 2018 revealed a causality between economic development and the energy poor by enhancing the availability of electricity.

Population growth has varied effects on energy poverty in the short and long run. As indicated concerning the short-term dynamics of the relationship between population and energy consumption, energy poverty increases. But beyond a certain level, the proportion of people in the energy-poor situation – given the correlation between population growth and energy use — continues to increase rather than decrease. In a way, population expansion often increases energy demand; however, it may help with economic growth and reduce energy insecurity by increasing the accessibility of energy sources (Nwamaka & Orhewere, 2022). Moreover, population growth has also been seen to influence the world’s CO2 emissions and energy demand for development, underlining the helpfulness of demographic considerations when addressing energy poverty during sustainable development (Chaurasia, 2020). Population increase significantly influences short-term energy poverty through energy request, which feeds environmental issues and augments price costs, particularly among adding nations to address these concerns (Holdren, 1991). Population increase can worsen short-term energy poverty and may result in an energy deficit because the per-capital energy consumption might be outstripped by population growth, especially in developing countries (Lizunkov, Politsinskaya, Malushko, Kindaev, & Minin, 2018).

The availability of the Internet significantly influences many aspects of poverty, especially in terms of energy. Based on the literature, the availability of the Internet may enhance farmers’ perceived usefulness towards energy and carbon reduction initiatives (Li, He, Zhu, Zhang, & Gao, 2023) along with poverty alleviation with the ability to access household electricity (Christiani & Nainupu, 2021). Also, research has demonstrated that locations with high degrees of digital economic development have lower rates of energy poverty, thanks to the Internet and the digital economy (Qu & Hao, 2022). According to the research, access to the internet, namely IP traffic, dramatically reduces energy poverty. ICT significantly impacts energy poverty, mainly through IP traffic (Postuła, Chmielewski, Puczyński, & Cieślik, 2021). These findings indicate that internet connectivity influences individual behaviour toward energy-related projects and adds to broader poverty alleviation efforts, emphasizing the interdependence of technology, poverty, and energy availability in society development.

Renewable energy is crucial in mitigating energy poverty by offering cost-effective and environmentally sustainable alternatives. A study shows that forming Renewable Energy Communities will help minimize energy poverty by introducing cheap energy rates and increasing energy density. Moreover, it has been established that adopting renewable energy technologies, namely solar and wind, has been associated with high human development indices, particularly among countries with low to medium HDI (Hmida & Rey, 2023). However, the transition of the new renewable energy systems may bring costs that impact incomes, and thus, energy poverty may be aggravated where support levies are poorly designed (Priesmann, Spiegelburg, Madlener, & Praktiknjo, 2022). Substantial improvements can be observed in the alleviation of energy poverty and policy application by choosing the promising renewable schemes for each specific country, namely large hydropower systems, with the help of improved tools like IVIF-QFD conceptual approach for renewable energy prioritization (Priesmann et al., 2022). In conclusion, strategies that seek to popularize the use of renewable energy ensure energy poverty is reduced, the environment is conserved, and society becomes stable economically and socially, thus improving the well-being of all individuals (Lu, Zhou, & Ren, 2023).

Human capital is important in energy poverty since it relates to access to power and energy consumption. The findings show that increased levels of human development, including human capital and education, as well as the HDI, decrease energy poverty in Africa and other (Yavuz, ALTINER, & Bozkurt, 2022) developing countries. Further, a repeated association of education with the accessibility of electricity and a favorable relationship between Human capital and energy conservation accentuates the importance of human capital in eradicating energy poverty in many places, including China (Gao, Yuan, & Zheng, 2022; Wang, Huang, & Cai, 2022). Just like physical capital, human capital can be categorized in three ways concerning energy; scale effects which result in energy consumption, and technical and structural effects, especially from education that results in energy pressure and technological progress to lower the consumption levels of energy (Wang et al., 2022).

From the previous research, it has been ascertained that globalization significantly affects energy poverty. Globalization, as found in the study by Yavuz et al. (2022), raises energy usage, further deepening poor situations if not properly checked. In addition, infrastructure quality is another important factor when determining globalization’s role in reducing poverty because high-quality infrastructure must be implemented before globalization’s positive impact on poverty reduction can be realized (Middlemiss, 2022). In addition, economic globalization impacts energy costs and restrictions on fuel access in Europe’s needy people, illustrating the non-linear interaction of globalization and energy accessibility (Schislyaeva & Saychenko, 2022). As a result, resolving the issues created by globalization in terms of energy poverty necessitates a holistic approach that considers factors like infrastructure quality, energy accessibility, and price.

3. Data and Methodology

The current study evaluates the impact of economic growth, population density, internet connectivity, renewable energy, human capital, and globalization on energy poverty in 11 emerging nations. EPOV is energy poverty and measured by Access to electricity (% of the population), GDP is economic growth measured by GDP growth (annual %), POP is population density measured by Population density (people per sq. km of land area), IA is internet access and measured by Individuals using the Internet (% of the population), RE is renewable energy and measured by Renewable electricity output (% of total electricity output), HC is human capital. It is measured by the human capital index, based on years of schooling and returns to education, and GLOB is globalization, measured by the KOF index. The 11 developing countries are examined in this analysis from 1990 to 2021. The econometric model serves the following function:

$$EPOV = f(GDP, POP, IA, RE, HC, GLOB) \quad (1)$$

3.1. Estimation technique

This study aims to evaluate the presence of cross-sectional dependency using the CD test and identify the level of integration using the CIPS unit root test. We utilize the cointegration technique created by Pedroni and Westerlund to examine the relationship between economic growth, population density, internet accessibility, renewable energy, human capital, globalization, and energy poverty. Ultimately, we evaluate the model by employing the PMG approach.

3.2. CD and CIPS test

First, we look for evidence of cross-sectional dependence or independence in the data. Pesaran, Schuermann, and Weiner (2004) proposed the cross-sectional dependence test to accomplish this goal. Doing this is the first and foremost need for running the panel unit root test. Panel series with a cross-sectional dependence problem are not amenable to the old unit root test because of its limited capacity. This information is derived from two sources: one by Bhattacharya, Paramati, Ozturk, and Bhattacharya (2016). Therefore, this study used the CIPS unit root test proposed by (Pesaran, 2007). This test is based on the cross-sectional dependence theory. The panel unit root test plays a crucial role in panel cointegration models. Using this test, we can verify the integration order of the variables. The data set becomes stuck after a single differentiation if all the variables are added to the same level, I (1), and a unit root problem exists at that level. Therefore, it is reasonable to assume that there may be a long-term equilibrium relationship between all the dataset variables.

3.3. Panel Cointegration Technique

The long-term relationship among the variables of eleven different countries was examined in this work using the panel cointegration approach, which was first developed by Westerlund (2007). In contrast, conventional wisdom holds that cointegration does not exist, even though solid evidence suggests otherwise. Instead of looking at residual dynamics, Westerlund (2007) created a panel cointegration test focusing on structural dynamics. This contradicts the traditional approaches that have been employed previously. Based on the results, these tests have limited normal distributions and demonstrate more reliability than currently available tests. Westerlund (2007) states that the new test yields accurate size measurements and is more effective than (Pedroni, 1999, 2004) residual-based testing. Westerlund's explanation is located in the subsequent sentence. The evidence provided will provide the foundation for the ongoing research, which aims to examine how economic growth, population density, internet access, renewable energy, human capital, and globalization collectively contribute to energy poverty. The panel cointegration test is utilized for this investigation.

Furthermore, Westerlund (2007) proposed this test, which was also recommended by Persyn and Westerlund (2008). This assessment evaluates the extent to which error correction is present in the entire group and each panelist to ascertain whether there is a lack of cointegration. The panel PMG econometric model utilizes cointegration to estimate the long-term parameters.

3.4. Pooled Mean Group

This study examines the connections between energy poverty and many factors, such as economic growth, population density, internet connectivity, renewable energy, human capital, and globalization in the short and long term. Pesaran, Shin, and Smith (1999) previously developed the ARDL-PMG framework, which will be used to achieve this. The ARDL model is an example of an error-correcting model; it can detect both strong and weak relationships. This method is applicable for evaluating possible long-term linkages regardless of the integration order of the variables. All variables except the dependent one must be integrated of order 1 (I(1)), although the others can be mutually integrated (I(0) and I(1)) or of order 1. This method, however, does not work when the series are integrated into an order of 2 (I (2)). Also, this method eliminates endogeneity-related issues by factoring in latency duration for both exogenous and endogenous variables, leading to efficient and accurate estimators. The following is the ARDL (p, q) model that accounts for the long-term relationship between variables, as stated by Pesaran et al. (1999):

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{it-1} + \sum_{l=2}^{k} \delta_i X_{l,it-1} + \sum_{j=1}^{p-1} \vartheta_{ij} Y_{l,it-j} + \sum_{j=0}^{q-1} \sum_{l=2}^{k} \theta_{it-j} X_{it-j} + \epsilon_{it} \quad (2)$$

The dependent variable, Y, is determined by the exogenous variables, Xi, where l represents the different l values (l=1,2,3,4...). The error term, ϵ_it, and the difference operator, Δ, are also involved in the relationship. For instance, when using energy poverty as the dependent variable, the ARDL model is organized in the following manner:

$$\Delta EPOV_{it} = \alpha_i + \beta_1 EPOV_{it-1} + \beta_2 GDP_{it-1} + \beta_3 POP_{it-1} + \beta_4 IA_{it-1} + \beta_5 RE_{it-1} + \beta_6 HC_{it-1} + \beta_7 GLOB_{it-1} + \sum_{j=1}^{p} \delta_1 \Delta EPOV_{it-j} + \sum_{j=0}^{q} \delta_2 \Delta GDP_{it-j} + \sum_{j=0}^{q} \delta_3 \Delta POP_{it-j} + \sum_{j=0}^{q} \delta_4 \Delta IA_{it-j} + \sum_{j=0}^{q} \delta_5 \Delta RE_{it-j} + \sum_{j=0}^{q} \delta_6 \Delta HC_{it-j} + \sum_{j=0}^{q} \delta_7 \Delta GLOB_{it-j} + \epsilon_{it} \quad (3)$$

The Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (SBC) are both utilized to select the lagged variables that will be used. Conventional cointegration studies in the presence of variables I (0) and I (1) do not support the existence of plausible long-term links between variables, as demonstrated by Pedroni (1995, 1999, 2004), Kao (1999), and Bai and Ng (2001). Since these tests do not yield statistically significant results, this is indeed the case. To find out if there are any long-term relationships, you can use the ARDL limits test, on the other hand, to look into these other hypotheses:

$H_o: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$
$H_a: \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq 0$

The bound's testing procedure is founded on the Fisher statistics (F-statistic) or Wald statistic. Pesaran, Shin, and Smith (2001) have investigated two critical value bounds for a specific significance level. A stationary order of integration (I(0)) is assumed for all ARDL variables in the first assumption, while a non-stationary order of integration (I(1)) is considered for them in the second assumption. The null hypothesis (H0) is rejected solely when the estimated F-statistic surpasses the upper critical boundary value. The cointegration test is deemed inconclusive if the F-statistic is within the margin of error. The null hypothesis cannot be rejected if the F-statistic is less than the lower bound value. The long-term equation is approximated in the second stage by determining whether or not the cointegration relationships have been established.

In the third stage, an error correction model (ECM) estimates a short-term dynamic connection. The ECM is described as follows:

$$\Delta Y_{it} = \alpha_i + \sum_{j=1}^{p-1} \vartheta_{ij} Y_{l,it-j} + \sum_{j=0}^{q-1} \sum_{l=2}^{k} \theta_{it-j} X_{it-j} + \mu_i ECT_{;,it-1} + \epsilon_{lit} \quad (4)$$

In this context, the residuals $\epsilon_{lit}(l = 1,2,3,4)$ are considered to be independent and normally distributed, with a mean of zero and a contact variance of one. Additionally, the word $ECT_{;,it-1}$ where (l=1,2,3,4….) represents the error correction term determined by the long-term relationship. Furthermore, the term μ_i This signifies the rate at which the model adjusts itself. According to this study, the error correction model will be:

$$\Delta EPOV_{it} = \alpha_i + \sum_{j=1}^{p} \delta_1 \Delta EPOV_{it-j} + \sum_{j=0}^{q} \delta_2 \Delta GDP_{it-j} + \sum_{j=0}^{q} \delta_3 \Delta POP_{it-j} + \sum_{j=0}^{q} \delta_4 \Delta IA_{it-j} + \sum_{j=0}^{q} \delta_5 \Delta RE_{it-j} + \sum_{j=0}^{q} \delta_6 \Delta HC_{it-j} + \sum_{j=0}^{q} \delta_7 \Delta GLOB_{it-j} + \mu_i ECT_{;,it-1} + \epsilon_{it} \quad (5)$$

According to equation 5, the ARDL model's estimators and parameters are derived using the PMG technique, as documented by Pesaran et al. (1999). The maximum likelihood technique is often regarded as the most reliable estimation tool since it incorporates individual factors such as nation and location. This approach provides a more comprehensive evaluation of the long-term correlation. Pesaran et al. (1999) assert that the PMG estimators acquired possess an asymptotic and normal distribution.

4. Result and Discussion

This study examines the long-run relationship between economic growth, population density, internet access, renewable energy, human capital, globalization, and energy poverty. Initially, we check the indicators' cross-sectional dependency and stationery, and Table 1 shows the results of the CD test and CIPS unit root test.

Table 1
Unit Root Test and Cross-sectional Dependency Test

Variables	Level	1st Difference	CD-test	p-value	corr	abs(corr)
EPOV	-3.132		24.290	0.000	0.579	0.628
GDP	-3.68		7.740	0.000	0.185	0.223
POP	0.376	-2.899	41.590	0.000	0.991	0.991
IA	-0.525	-3.222	38.640	0.000	0.921	0.921
RE	-1.879	-5.509	18.660	0.000	0.445	0.530
HC	-1.152	-2.275	39.570	0.000	0.943	0.943
GlOB	-2.255	-4.992	39.380	0.000	0.939	0.939

Table 1 presents the results of the CD test and the CIPS unit root test, together with their respective results. The results of the CD tests demonstrate that the null hypothesis of cross-sectional independence is rejected at a significance level of 1%, respectively. It substantiates the fact that all of the indicators are dependent on cross-sectional data. To determine whether or not the variables were stationary, this research chose to use the second-generation unit root test rather than the conventional unit root test. According to the findings of the CIPS, energy poverty and economic growth have both remained unchanged at their current levels. Additionally, population density, internet availability, renewable energy consumption, human capital, and globalization have consistently remained unchanged at their initial differences.

Table 2
Pedroni and Westerlund Cointegration Test

Pedroni	t- Statistic	p-value	Westerlund	t- Statistic	p-value
Modified Phillips-Perron	1.720	0.043	Variance ratio	-1.348	0.089
Phillips-Perron	-4.031	0.000			
Augmented Dickey-Fuller	-3.755	0.000			

A presentation of the findings from the Pedroni and Westerlund cointegration experiments can be found in Table 2. The results of the Pedroni test conducted when the level of significance is set at 5% show that there is cointegration, as the null hypothesis that there is no cointegration is rejected. On the other hand, the Westerlund test gives the conclusion of rejecting the null hypothesis in 10% significance level, hence establishing the cointegration inside the model.

Table 3
PMG-ARDL Estimates

Long Run Results				
EPOV	**Coef.**	**Std.**	**Z-stat**	**Prob.**
GDP	0.077	0.035	2.170	0.030
Pop	0.197	0.023	8.500	0.000
Internet Access	-0.072	0.014	-4.950	0.000
Renewable Energy	-0.352	0.056	-6.310	0.000
HC	-3.714	2.309	-1.610	0.108
Glob	-0.049	0.060	-0.820	0.412
Short Run Results				
EC	-0.283	0.094	-3.010	0.003
D1. GDP	-0.050	0.040	-1.250	0.211
D1. Pop	-0.015	0.125	-0.120	0.903
D1. Internet Access	-0.129	0.102	-1.260	0.208
D1. Renewable Energy	0.099	0.055	1.790	0.073
D1. HC	17.811	42.368	0.420	0.674
D1. Glob	-0.064	0.123	-0.520	0.605
Constant	13.768	7.618	1.810	0.071

4.1. Long-Run Results

The assessment of long-run estimates offers the big picture of the trends in energy poverty under the economic, demographic, and technological frameworks for 11 developing countries. This was observed to be the case concerning GDP estimates, with its coefficient being 0 regarding energy poverty. 077 (p=0. 030). This leads to the conclusion that a 1% GDP rise is linked to a 0. Energy poverty emerged as an increase of 077%. This supports the previous findings from South Asia and Eastern Indonesia, where several scholars pointed out that, despite benefiting from improved economic status in merely one decade, energy poverty might be deepened at the beginning of the economic development and industrialization process (Leiwakabessy & Payapo, 2022; Shafiullah & Rahman, 2021). Therefore, the work reiterates that the notion of economic development has dual effects on energy poverty, thus advocating for mechanisms that seek to mitigate any negative effects in the short run but at the same time foster the positive effects seen in the long run.

It becomes quite apparent that energy poverty is directly related to population increase, its coefficient. 197 (p=0. 000). This means that energy poverty is said to increase by 0. 197 percent for each one percent population increase. The augmenting population poses a heavy burden on energy consumption, especially among developing nations, due to population increase outcompeting the availability and development of infrastructure and energy sources (Nwamaka & Orhewere, 2022; Shao & Gao, 2010). This discovery sheds light on the need to link population growth and stabilization concerns with energy strategies as they deal with the consequences of frequent demographic changes.

Internet connection is flagged as strongly associated with reducing energy poverty, which yields a negative coefficient of -0. 072 (p = 0. 000). Thus, an increase in internet connection by 1% leads to a 0. A percentage of 072% reduced energy poverty. This finding aligns with the existing literature about the importance of digital technology in addressing poverty and improving energy resources (Li et al., 2023; Qu & Hao, 2022). Internet connection positively enhances information acquisition and service delivery and fosters energy conservation and practice in energy-related projects.

Renewable energy reduces energy poverty by a significantly large degree, with a coefficient of -0. 352 (p = 0. 000). For each 1% rise in the utilization of renewable energy sources, energy consumption decreases by 0. 352%, reducing energy poverty. This research contributes to the body of work which underlines the role of renewable energy in providing sustainable and affordable energy solutions (Ceglia, Marrasso, Samanta, & Sasso, 2022; Hmida & Rey, 2023). The transition to renewable power can minimize energy needs, especially in regions with high energy deficits and pollution problems.

The Human Development Index is one of the measures of human capital, and it impacts energy poverty since its coefficient is -3. 714; p-value: 0. 108, though the result is insignificant. While the literature recommends that human capital development can help in the fight against energy poverty through enhancing education and skills (Khan & Ghardallou, 2023; Opoku, Dogah, Kufuor, & Acheampong, 2024), the absence or insignificance of the study results could mean that the effectiveness of human capital differs across countries. This calls for a more complex identification of human capital development requirements, including local context and processes.

The results confirm that globalization has a negative but statistically insignificant effect on energy poverty. It has been revealed that if energy poverty is not addressed correctly, globalization can lead to higher energy consumption and the worsening of energy poverty (Schislyaeva & Saychenko, 2022; Yavuz et al., 2022), but the case of the research shows that there are complexities. While arguing the effects of globalization on energy poverty, it is essential to include aspects like infrastructure quality, energy accessibility, and pricing.

4.2. Short-Run Results

The short-run estimates contain relevant data regarding many factors' initial impact on energy poverty. The coefficient of EC is statistically significant and negative and is equal to – 0. 283 (p=0. 003), which means deviations from the long-run equilibrium are corrected at a rate of 28. 3% each period. This shows that in the short-term, get shocks are defined by a relatively fast movement back to the long-run equilibrium.

Examining the coefficients for the short-term analysis, it is possible to state that GDP has no strong negative correlation with energy poverty, at least concerning the coefficient of - 0. 050 (p=0. 211). This conclusion agrees with similar studies showing that economic development might have differential impacts on energy poverty at the initial level of analysis because of variables like industrialization and infrastructure development (Shafiullah & Rahman, 2021). The lack of major impact in the short term underlines the necessity of long-term economic policies that will be free from the negative consequences of excessive focus on GDP and fair availability of energy.

Likewise, the index stands at - 0. Population increase has no impact on energy poverty in the short-run, as the p=0 evidences it. 903> 015. This may mean that the effects of population growth on energy poverty will be felt in the distant future when the collective effect of the population increases on the energy demand and stress on the resources is experienced.

In the short run, the effect of Internet access on energy poverty is very weak and insignificantly different from zero, with a t-statistic value of -0.129. This means that the positive impact of enhanced internet connection on energy poverty reduction may only start to reveal itself in the years that follow, thus requiring continued funding for internet networks and education (Li et al., 2023; Qu & Hao, 2022).

Considering the aspect of energy poverty, these results show that, in the short run, renewable energy has a positive impact, as presented below: The coefficient for this influence is equal to 0.099 (p=0.073). This could mean that the short-term costs of the shift to renewable energy deepen the effects of energy poverty before the benefits of making energy more sustainable and accessible shine through (Priesmann et al., 2022). This view implies that regulations and incentives supporting renewable energy technology are important in easing costs in the short run and making using renewable energy systems possible.

As shown in the table below, when the human capital measure is added to the model, the coefficient stands at 17, meaning there is no correlation between human capital and energy poverty in the short run at 0.05 significance levels. It seems that human capital development could have a more extensive positive effect on eradicating energy poverty since the growth in education and skills will eventually lead to improved employment and energy access (Wang et al., 2022).

Globalization also has no direct effect on energy poverty in the short term, as it stands at -0. 064 (p=0. 605). This shows that globalization positively correlates with energy poverty, and important issues that define it are the cost and quality of the infrastructure. Thus, according to Middlemiss (2022); Schislyaeva and Saychenko (2022).

The constant is significant and marginally positive at 13. The analysis results based on the above model are shown in the table below. 768 (p = 0. 071), which goes a long way in implying that other unobserved factors affect energy poverty. This means that even though the variables included here are vital when creating dynamics about energy poverty, different aspects and contextual factors might also exist.

5. Conclusion and Policy Recommendations

This study investigates how GDP, population, internet availability, renewable energy, human capital, and globalization influence energy poverty in the N-11 countries. The long-term relationship between the different factors reveals that GDP and population increase have the worst effect on energy poverty, while the availability of the Internet and renewable energy has a positive impact. The roles of human capital and globalization appear to be interacting and insignificant. Short-run outcomes depict quick fluctuations in long-run positions for any business, and here, costs arising from renewable energy consumption are strategic and easy to see.

For such a strategy to work well, policymakers need to target energy poverty through numerous initiatives that boost the economy and include energy improvements, such as constructing energy facilities and energy conservation measures. Thus, combining family planning and education efforts with energy policies can significantly facilitate population control. Broadening Internet connectivity and advancing the level of information possessed contributes to raising energy efficiency. In Gillingham's opinion, the correct strategy is to use appropriate incentives that promote the use of renewable energy technologies and the creation of renewable energy communities. Also, increasing access to education and vocational training may help improve human development and fight energy poverty. The quality of infrastructure and predictable access to energy are required to optimize the outcomes of globalization. By following these recommendations, the N-11 countries can meet the objectives of combating energy poverty, furthering sustainable development, and enhancing the population's well-being.

Author's Contribution:
Ramaisa Aqdas: Conceptualized the study, designed the research framework, and led the writing of the manuscript.
Wan Zhalkiatul Aida Binti Ishak: Conducted data collection and analysis, and contributed to the interpretation of results.
Syed Muhammad Salman: Provided technical expertise and reviewed the literature on technological drivers.
Rashid Sultan: Assisted with demographic data analysis and contributed to the writing and revision of the manuscript.

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