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## Energy Poverty, Trade Openness and Foreign Direct Investment: Evidence from Latin America

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**Abstract:** Energy poverty remains a persistent challenge in many developing economies, constraining socioeconomic development and diminishing quality of life. This study examines the impact of foreign direct investment (FDI) and trade openness (TO) on energy poverty reduction in seven Latin American countries—Belize, Bolivia, Honduras, Mexico, Nicaragua, Panama, and Peru—over the period 1992–2024. Employing a Panel Vector Autoregression (PVAR) framework, the analysis reveals that both FDI and trade openness significantly enhance electricity access, which serves as a key proxy for energy poverty. Specifically, a 1% increase in trade openness leads to a 0.083% improvement in electricity access, while FDI exerts a substantially stronger effect, increasing access by 2.325%. Economic growth also contributes to energy poverty alleviation, albeit with a more modest elasticity of 0.195%.

Granger causality tests indicate bidirectional causal relationships between trade openness and energy poverty, as well as between energy poverty and FDI inflows, suggesting the presence of a virtuous cycle whereby improved energy access fosters deeper economic integration. Additional feedback effects are identified between trade openness and economic growth, and between FDI and economic growth. Moreover, trade openness is found to directly stimulate FDI inflows, while economic growth unidirectionally reduces energy poverty. The robustness of these findings is



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confirmed through FMOLS and DOLS estimations.

Overall, the results highlight the critical role of globalization in alleviating energy poverty in Latin America. Policy implications emphasize the need to reduce trade barriers for renewable energy technologies, promote green-oriented FDI, and channel economic growth toward expanding rural electrification. Nonetheless, the study's reliance on electricity access as a single proxy for energy poverty and its regional focus point to avenues for future research, including the use of multidimensional energy poverty indices and cross-regional comparative analyses.

**Keywords:** Energy poverty; electricity access; trade openness; foreign direct investment; globalization; Latin America.

## 能源贫困、贸易开放度与外国直接投资：来自拉丁美洲的实证研究

**摘要：**能源贫困仍然是许多发展中经济体面临的长期性挑战，严重制约了社会经济发展并降低了居民生活质量。本文以1992—2024年间拉丁美洲七个国家（伯利兹、玻利维亚、洪都拉斯、墨西哥、尼加拉瓜、巴拿马和秘鲁）为研究对象，系统考察了外国直接投资（FDI）和贸易开放度（TO）对能源贫困缓解的影响。研究采用面板向量自回归模型（PVAR），实证结果表明，FDI和贸易开放度均能显著提高电力可及性，而电力可及性被视为衡量能源贫困的重要代理指标。具体而言，贸易开放度每提高1%，电力可及性提升0.083%；相比之下，FDI的影响更为显著，可使电力可及性提高2.325%。经济增长同样有助于缓解能源贫困，但其弹性相对较小，为0.195%。

格兰杰因果检验结果显示，贸易开放度与能源贫困之间，以及能源贫困与FDI流入之间均存在双向因果关系，表明能源可及性的改善能够促进更深层次的经济融合，从而形成良性循环。此外，研究还发现贸易开放度与经济增长之间、FDI与经济增长之间均存在反馈效应。其中，贸易开放度能够直接促进FDI流入，而经济增长则单向作用于能源贫困的缓解。通过完全修正最小二乘法（FMOLS）和动态最小二乘法（DOLS）进行的稳健性检验进一步验证了上述结论的可靠性。

总体而言，研究结果凸显了全球化在缓解拉丁美洲能源贫困方面的关键作用。政策层面上，应着力降低可再生能源技术相关的贸易壁垒，积极引导绿色导向的外国直接投资，并将经济增长成果更多地用于农村电气化建设。然而，本研究主要以电力可及性作为能源贫困的单一衡量指标，且研究区域具有一定局限性，未来研究可引入多维度能源贫困指标，并开展跨区域比较分析，以获得更为全面的结论。

**关键词：**能源贫困；电力可及性；贸易开放度；外国直接投资；全球化；拉丁美洲

### 1. Introduction

Energy serves as a fundamental driver of socioeconomic development, enabling societies to meet basic human needs while fostering productivity across agriculture, manufacturing, trade, and services (Masud et al., 2007). Despite technological advancements, poverty in term of energy remains a critical challenge in emerging nations, where millions of people are unable to obtain inexpensive, dependable electricity (World

Bank, 2022). The “United Nations Sustainable Development Goals” (SDGs), particularly SDG 7, focuses on guaranteeing that everyone has access to affordable, reliable, sustainable, and modern energy (United Nations, 2015). However, disparities persist, with approximately 759 million people still lacking electricity, while over 2 billion rely on traditional, inefficient cooking fuels (World Bank, 2021). This deprivation exacerbates poverty, limits education and

healthcare access, and constrains economic growth (Sovacool, 2013; OECD, 2019).

(Energy poverty is a multidimensional issue, defined variably across academic and policy discourses. The techno-boundary perspective associates it with reliance on traditional energy sources (e.g., biomass) rather than modern alternatives (González-Eguino, 2015). The physical threshold approach highlights inadequate energy uses for basic necessities. While the economic threshold method links it to income constraints preventing adequate energy access (González-Eguino, 2015; World Economic Forum, 2010). For present research, we operationalize poverty in energy through electricity access, a widely accepted indicator that reflects a nation's energy infrastructure and development (Shyu, 2022; Raghutla & Chittedi, 2022).

Numerous factors effect energy poverty including economic development, income inequality, renewable energy adoption, and energy efficiency policies. Research has shown that higher GDP correlates with improved energy access, particularly in BRICS nations (Acharya & Sadath, 2019; Raghutla & Chittedi, 2022). Income inequality, however, limits energy affordability (Igawa & Managi, 2022; Dong et al., 2022), whereas investments in renewable energy sources like wind and solar lead to reduce energy deprivation (Wang et al., 2022; Zhao et al., 2022). Moreover, sustainable energy policies aimed at conservation can alleviate household energy burdens (Chien et al., 2022; Li et al., 2021). Despite these findings, the effect of economic globalization, particularly foreign direct investment and trade openness on energy poverty remains underexplored (Dreher, 2006; Gygli et al., 2019).

Although globalization is often associated with economic growth, its direct effect on energy poverty is less clear. Some studies suggest that trade and FDI can lower energy costs through technology transfer (Zhao et al., 2022), while others point to the risk of increased energy inequality in liberalized markets (Barbieri & Reuveny, 2005). This gap is particularly evident in Latin America, where persistent energy poverty in rural and low-income areas remains despite overall economic progress (Mohsin et al., 2022). Countries like Mexico and Panama have aggressively pursued trade and FDI reforms, while others, such as Bolivia, have experienced more limited integration (World Bank, 2022). These variations present an opportunity for research to explore how trade openness and FDI influence energy access and infrastructure across the region.

This present research purposes to fill this gap by analyzing Bolivia, Belize, Honduras, Mexico, Nicaragua, Peru and Panama from 1992 to 2024. The research will examine whether trade openness and FDI inflows reduce energy poverty by improving electricity access and infrastructure, and how these factors interact with economic growth. Using PVAR technique the study captures dynamic interactions between trade openness,

FDI, GDP, and energy poverty, addressing endogeneity and country-specific heterogeneity. The findings will inform policy strategies to leverage trade agreements for renewable energy technology transfer, design FDI incentives for energy infrastructure, and align economic growth with the objectives of Sustainable Development Goal (SDG) 7.

## 2. Literature Review

One major obstacle to sustainable development is still energy poverty, with complex linkages to economic growth, trade policies, and foreign investment flows. The existing literature explores these relationships through multiple lenses, though significant gaps persist particularly regarding Latin America's unique socioeconomic context. This review synthesizes empirical findings on (1) energy poverty's macroeconomic determinants, (2) the globalization-energy poverty nexus, and (3) methodological approaches, while highlighting understudied dimensions of FDI and TO in alleviating energy deprivation.

A robust body of research establishes economic growth as a key determinant of energy access. Acharya and Sadath (2019) demonstrated this relationship in India, where a 10% GDP increase reduced multidimensional energy poverty by 3.2%, though education exerted a stronger mitigating effect. Similarly, Raghutla and Chittedi (2022) found electricity access improvements in BRICS nations drove per capita GDP growth by 1.8% annually, with unidirectional causality from economic development to energy poverty reduction. However, findings vary by region: in Sub-Saharan Africa, Adom et al. (2021) reported that poverty in energy measured via electricity expenditure shares exacerbated income inequality and hygiene risks despite GDP growth, suggesting growth alone is insufficient without targeted policies.

Disparities also emerge in short- versus long-term effects. Doğanalp et al. (2021) employed PVAR models to show that while energy poverty (proxied by clean cooking access) had no immediate GDP impact in BRICS countries, it increased inflationary pressures by 0.5% annually. Conversely, Amin et al. (2020) used ARDL estimators for South Asia and identified long-run GDP elasticities of -0.7 with respect to energy poverty, implying that sustained growth is necessary for structural energy access improvements. These studies collectively underscore that economic development's impact on energy poverty is context-dependent, mediated by factors like institutional quality and energy infrastructure (OECD, 2019; World Bank, 2022).

The literature presents conflicting evidence on how globalization influences energy poverty. Proponents argue that trade liberalization reduces energy costs through technology spillovers and competitive markets. Murshed (2018) found TO improved clean energy access by 12% in South Asia, while Duan and Guo

(2021) documented a 0.4% annual decline in China's household electricity expenditures per 1% TO increase. Conversely, critics highlight exclusionary effects: Zhao et al. (2022) showed that in the EU, globalization raised energy prices for the poorest quartile by 8%, worsening deprivation despite aggregate access gains.

FDI's impact is equally contested. D'Amelio et al. (2014) analyzed 83 African economies and found FDI inflows increased electrification rates by 1.1% annually, particularly in nations with weak institutions a result echoed by Anarfo et al. (2021) in Ghana, where FDI rose 2.3% for every 1% expansion in grid coverage. However, Alshubiri et al. (2021) reported negative FDI effects in OPEC states, where extractive industries diverted investments from renewable energy projects. Such contradictions underscore the need for sector-specific FDI analyses (Biernat-Jarka et al., 2021).

Inclusive finance and credit access play pivotal roles in energy poverty alleviation. Koomson and Danquah (2021) demonstrated that a 10% expansion in Ghana's formal banking sector reduced energy poverty by 3.5% through microloans for solar panels. Similarly, Asngar (2022) used GMM estimators for 45 African nations and found that financial depth increased electricity access by 0.9% annually. However, Asuamah (2016) identified no long-run relationship in Ghana, attributing this to credit misallocation a warning that financial policies must be energy-poverty-targeted.

Most existing studies on energy poverty employ static econometric models such as ARDL and FMOLS, which fail to account for the dynamic and reciprocal relationships between energy poverty, GDP, and globalization. Although some exceptions exist such as Doğanalp et al. (2021), who used PVAR to uncover bidirectional linkages between trade openness (TO) and GDP, and Muthusamy and Negi (2020), who illustrated a spiraling relationship between FDI and energy poverty in India these approaches have not yet been applied to the Latin American context. This omission is notable given the region's significant increase in TO and FDI since 2000 (Mohsin et al., 2022).

This study fills three major research gaps. First, it shifts the regional focus from the commonly studied African and Asian contexts (Adom et al., 2021; Zhao et al., 2022) to Latin America's hybrid economies. Second, it addresses the lack of dynamic modeling by using PVAR to capture complex feedback loops among TO, FDI, and energy poverty (EP). Third, it introduces policy specificity by distinguishing between FDI targeting renewable energy and extractive industries, an aspect often overlooked in prior research (Alshubiri et al., 2021). By analyzing seven Latin American countries from 1992 to 2024, this research offers the first PVAR-based exploration of globalization's role in reducing energy poverty in a region where its potential remains largely untapped (González-Eguino, 2015; World Bank, 2021).

## 2.1. Theoretical Framework and Hypothesis Development

To establish a strong theoretical foundation, this study attracts three major theories that explain the correlation between trade liberalization, foreign direct investment, and energy lack:

### 2.1.1. Modernization Theory & Energy Transition

As economies grow and merge into global markets (through trade and FDI), they undergo structural changes from agriculture to industrial and service-based economies. This shift is often accompanied by better energy infrastructure, as FDI and business technology provides investment in transfer, efficiency benefits and electrification (Kaygusuz, 2011; Gonzalaz-Ageno, 2015). Hypothesis: Energy should be reduced by enabling trade openness and FDI flow by enabling access to modern energy systems.

### 2.1.2. Environment Kuznets Curve (EKC) Hypothesis

EKC proposes that environment decline (or, in this case, energy poverty) first deteriorates with economic growth, but later improves income as income reaches a limit. You can intensify this shift by bringing trade and FDI cleaner technologies and encouraging energy-efficient infrastructure (Amin et al., 2020; Akbas & Lebe, 2021). Hypothesis: The impact of trade on FDI and energy poverty can be non-lectured, with strong effects in high-or-development economies.

### 2.1.3. FDI Spillover Effects

FDI can produce positive externality, such as knowledge proliferation, infrastructure development, and competition in energy access (Acharya and Sadath, 2019). However, if the FDI extract is concentrated in the industries, it is not necessarily reduced the absence of energy for the broader population (Nijru and Letema, 2018). Hypothesis: FDI flow energy will reduce poverty, but the effect may vary depending on the regional structure (eg, manufacturing vs. extractive FDI).

### 2.1.4. Hypotheses Development

According to the above theoretical foundations and prior empirical studies, the following we test the following hypotheses:

**H<sub>1</sub>:** Trade liberalization (TO) decreases energy poverty (EP) by increasing access to electricity through enhanced economic integration, technology transfer, and infrastructure investment.

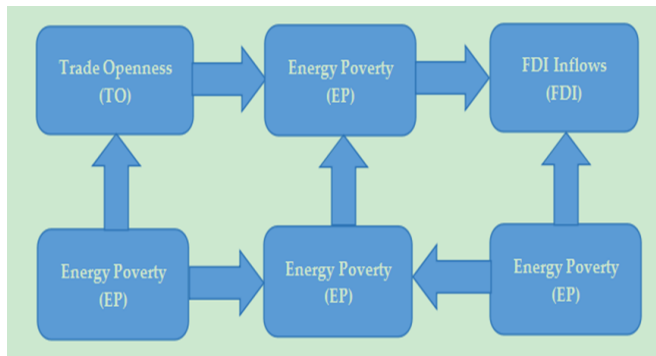
**H<sub>2</sub>:** Foreign direct investment (FDI) decreases energy poverty (EP) by empowering capital inflows, improving energy infrastructure, and promoting efficiency gains.

**H<sub>3</sub>:** Economic growth (GDP per capita) decreases energy poverty (EP), consistent with modernization theory and the energy transition hypothesis.

**H<sub>4</sub>:** The impact of FDI and trade on energy poverty

is moderated by income levels, with stronger effects in higher-income developing countries (EKC effect).

Our hypotheses align with the study’s objective of examining how globalization (via trade and FDI) influences energy poverty in Latin American countries.



**Figure 1. Research Framework Model Diagram**

Figure 1 illustrates the interconnected relationship between trade openness, energy poverty, and foreign direct investment inflows, with energy poverty occupying a central and dynamic role in the research framework. The model shows that trade openness directly influences energy poverty, indicating that a country’s level of integration into international trade can affect access to and affordability of energy. In turn, energy poverty significantly affects foreign direct investment inflows, as reliable and adequate energy supply is a crucial factor for attracting foreign investors. The multiple representations of energy poverty and the directional arrows highlight its persistent and self-reinforcing nature over time, suggesting feedback effects across periods.

**2.1.5. Key variable linkages**  
*Direct Effects (PVAR Model)*

Trade Openness (TO) → Energy Poverty (EP)

Mechanism: Increased trade improves energy access via infrastructure investment and technology diffusion.

FDI → Energy Poverty (EP)

Mechanism: FDI inflows enhance energy infrastructure (e.g., power plants, grid expansion).

GDP → Energy Poverty (EP)

Mechanism: Higher income enables public/private investment in electrification.

**Feedback Effects (Granger Causality)**

EP → GDP: Energy access boosts productivity, reinforcing growth.

EP → TO: Electrification enables export-oriented industries.

EP → FDI: Reliable energy attracts more FDI.

Moderating Role of GDP (EKC Hypothesis) The impact of FDI and TO on EP may strengthen at higher GDP levels (non-linear effect).

**3. Materials and Methods**

The present research investigates the influence of foreign direct investment and trade openness on energy poverty which is measured by the proportion of the population with electricity access, in seven Latin American countries (Belize, Bolivia, Honduras, Mexico, Nicaragua, Panama, and Peru) from 1992 to 2024. The extended dataset and advanced econometric techniques, including the application of panel data, enhance the robustness of the findings compared to previous studies. To ensure stationarity and account for cross-sectional dependence, the study conducts the CIPS test (Pesaran, 2007). Cointegration analysis is performed using the Westerlund (2008) Durbin-Hausman test to confirm long-run equilibrium relations between the variables.

The study used a Panel Vector Auto regression (PVAR) for econometric modeling to estimate the dynamic connection between TO, FDI, and EP. GMM-system estimators (Abrigo & Love, 2016) are used; with lag length determined using the MBIC/MAIC criteria (Andrews & Lu, 2001). Robustness checks include FMOLS/DOLS (Pedroni, 2001) to validate long-run elasticities and Granger causality tests (Wald test) to identify causal relationships. The PVAR approach is chosen for its ability to capture endogeneity and feedback effects (e.g., FDI → EP → FDI), while the CIPS and Westerlund tests address country-specific heterogeneity. The use of an extended dataset up to 2024 offers greater statistical power, improving upon prior studies.

Table 1. Definition of Variables

Variable	Symb ol	Definitio n	Units of measure	Sourc e
Energy Poverty	EP	Electricity Access	% of Total Population	World Bank (2025)
Economic Growth	GDP	Gross domestic product per capita	Constant 2015 US\$	World Bank (2025)
Trade Openness	TO	Sum of exports and imports of goods and services	% of GDP	World Bank (2025)
Foreign Direct Investment	FDI	Net inflow	% of GDP	World Bank (2025)

Table 1 defines the main variables used in the study, their measurement, and data sources. Energy poverty (EP) is measured by electricity access, expressed as the percentage of the total population with access to electricity, where lower access indicates higher energy poverty. Economic growth is represented by GDP per capita, measured in constant 2015 US dollars to account for inflation and reflect real income levels. Trade openness (TO) is defined as the sum of exports and imports of goods and services as a percentage of GDP, capturing the degree of a country's integration into the global economy. Foreign direct investment (FDI) is measured as net inflows expressed as a percentage of GDP, indicating the extent of foreign capital participation in the economy. All variables are sourced from the World Bank (2025), ensuring consistency and reliability of the data used in the analysis.

We developed a framework to assess the influence of trade liberalization and foreign direct investment on energy poverty in specific nations, as illustrated in Equation 1.

$$EP_{it} = f(GDP_{it}, TO_{it}, FDI_{it}) \quad (1)$$

In Equation (1), EP represents energy poverty as measured by electricity access to the population. Economic growth is represented by GDP; trade liberalization and FDI inflow are represented by TO and FDI, respectively. The variables listed in Table 1 consist of unprocessed data sourced directly from the databases. The initial form of our empirical model (1) is transformed into natural logarithms as outlined below:

$$\ln EP_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln TO_{it} + \beta_3 FDI_{it} + u_{it} \quad (2)$$

In Equation (2),  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$  are elasticities of economic growth, foreign direct investment and trade openness respectively,  $u_{it}$  is the error of the model.

### 3.1. Cross-Sectional Dependency (CSD) Tests

To test for cross-sectional dependency (CSD) across the countries in the study, four widely used tests are applied: The Breusch-Pagan LM test (1980) for residual correlations, Pesaran's CDLM (2004) for large N panels, Pesaran's CD (2004) which is robust to heterogeneous dynamics, and Pesaran et al.'s LMadj (2008) to address finite-sample bias. All these test results reject the null hypothesis of no CSD at the 1% significance level, confirming strong interdependencies among foreign direct investment, trade openness and energy poverty across the countries in the sample (Pesaran, 2004).

### 3.2. Slope Homogeneity Test

Using Pesaran & Yamagata's (2008) Delta ( $\tilde{\Delta}$ ) test assesses whether the coefficients are homogeneous across countries. At a significance level of  $p < 0.01$  this test rejects homogeneity, indicating that country-specific

effects are significant meaning that the impact of FDI and TO on energy poverty varies between countries (e.g., Mexico's FDI impact is different from Bolivia's). Consequently, heterogeneous panel estimators such as the AMG method are required (Pesaran & Yamagata, 2008). Important policy implications come out from the results: uniform trade and FDI policies may not be effective across all countries, and tailored techniques are important to figure out the diverse challenges in energy poverty (Destek, 2020).

### 3.3. Panel Unit Root Test

Considering the detected cross-sectional dependence (CSD) within our dataset, we employ second-generation panel unit root tests to properly assess the stationarity properties of our variables. Traditional first-generation tests (e.g., Levin-Lin-Chu) would yield biased results due to ignored interdependencies among Latin American economies (Pesaran, 2007). We utilize the Cross-Sectionally Augmented IPS (CIPS) test proposed by Pesaran (2007), which ranges the Im-Pesaran-Shin (IPS) test by: We are augmenting the standard ADF regression with cross-sectional averages of lagged levels and first differences.

Accounting for unobserved common factors (e.g., regional energy crises, global commodity price shocks).

Accommodating heterogeneous serial correlation across countries.

The CIPS statistic is computed as:

$$CIPS = \frac{1}{N} \sum_{i=1}^N t_i(N, T) \quad (3)$$

Where  $t_i(N, T)$  is the t-ratio of the OLS estimate of  $\pi_i$  in the CS-ADF regression:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^p \gamma_{ij} \Delta y_{i,t-j} + \theta_i \bar{y}_{t-1} + \sum_{j=0}^p \delta_{ij} \Delta \bar{y}_{t-j} + \epsilon_{it}$$

#### Key Advantages

**Robustness to CSD:** Controls for spillovers in trade/FDI flows (Pesaran, 2007)

**Heterogeneity:** Allows different autoregressive parameters ( $\rho_i$ ) per country

**Power:** Outperforms first-generation tests in panels with  $N \leq 20$  (our  $N=7$ )

The use of the CIPS test is theoretically justified by the presence of regional interdependence and common shocks. For instance, Mexico's 2013 energy reforms had spillover effects on electrification rates in neighboring countries (González-Eguino, 2015), while the 2008 financial crisis uniformly disrupted FDI flows across Latin America (World Bank, 2024), highlighting the need for second-generation tests that account for cross-country dependencies.

### 3.4. Panel Cointegration Test

Considering the detected cross-sectional dependence (CSD), present study utilizes Durbin-Hausman (DH), Westerlund (2008) panel co-integration test a second-generation method designed to handle both interdependencies and slope heterogeneity. Unlike first-generation tests like Pedroni and Kao, the DH test accounts for unobserved common factors like regional energy policies and global oil price shocks that may confound the relationships among trade, FDI, and energy poverty in Latin America (Pesaran, 2007; Westerlund, 2008). The  $DH_{Panel}$  statistic assesses co-integration assuming homogeneous long-run parameters, while the  $DH_{Group}$  statistic allows for heterogeneous co-integrating relationships an essential feature given the contrasting energy strategies between countries like Mexico and Bolivia (González-Eguino, 2015). Theoretical implications of the cointegrated system highlight the need for aligning trade and FDI policies with energy access strategies to achieve sustainable outcomes (World Bank, 2024). Moreover, the presence of significant co-integration supports the use of a Panel VECM framework to capture short-run dynamics and adjustment processes (Westerlund, 2008).

### 3.5. PVAR Specification

To assess the dynamic interaction between the variables, this research employs the Panel Vector Auto regression (PVAR) method introduced by Zikino (2006). This approach is more advanced than the traditional VAR model as it integrates traditional VAR framework, which considers all variables as endogenous in the system, with panel data that adjusts unobserved individual variability (TIWARI, 2011). Additionally, PVAR prepares the model as a multivariable method by representing each endogenous variable as a function of backward values of all endogenous variables (HU and Zheng, 2021).

The PVAR model is constructed as follows:

$$Z_{it} = \gamma_0 + \gamma_1 Z_{it-1} + \gamma_2 Z_{it-2} + \mu_i + d_{c,t} + u_{it} \tag{4}$$

Where  $Z_{it}$  stands for endogenous variables vectors (EP, FDI, GDP and TO) and  $\gamma_0$  indicates the matrix of country-specific fixed effects. Additionally,  $\gamma_1$  and  $\gamma_2$  denote the vector determining the country-specific effects in this regression and represent matrix polynomials in the lag operator. In Eq. (4)  $d_{c,t}$  is the country dummy variable, which is effective for a certain time period and  $u_{it}$  is the residual vector.

## 4. Preliminary Test Results

The present study analysis begins with assessing cross-sectional dependency and slope uniformity between the variables. To achieve this, we utilized

Breusch and Pagan’s (1980) LM and CDLM tests, Pesaran’s (2004) CD test, Pesaran et al. (2008)’s LMadj test, and Pesaran and Yamagata’s (2008) Delta test to evaluate the existence of cross-sectional dependency and slope uniformity, respectively. The findings regarding cross-sectional dependency and slope homogeneity are presented in the Table 2 and Table 3 below.

**Table 2: Cross-Sectional Dependency (CSD) Tests**

Test	lnEP	lnGDP	lnTO	FDI
LM	58.12 [0.000]	42.07 [0.000]	190.6 [0.000]	340.2 [0.000]
CDLM	6.01 [0.000]	4.89 [0.000]	11.5 [0.000]	19.8 [0.000]
CD (Pesaran)	25.914 [0.000]	25.803 [0.000]	25.921 [0.000]	22.147 [0.000]
LMadj	16.32 [0.000]	8.756 [0.000]	78.3 [0.000]	150.1 [0.000]

The cross-sectional dependency (CSD) analysis reveals strong interconnections among the seven countries. As reported in Table 2, all four tests LM, LMadj, CD, and CDLM eject the null hypothesis of no cross-sectional dependence at the 1% significance level (p-values = 0.000). These results confirm the presence of significant cross-country linkages. Furthermore, Tables 3 and 4 indicate substantial interdependencies across countries for all key variables, including energy poverty (EP), GDP, foreign direct investment (FDI), and trade openness (TO).

**Table 3: Slope Homogeneity Tests**

Test	lnEP	lnGDP	lnTO	FDI
Delta ( $\tilde{\Delta}$ )	34.891 [0.000]	29.452 [0.000]	14.107 [0.000]	2.587 [0.000]
Delta ( $\tilde{\Delta}_{aDJ}$ )	36.825 [0.000]	31.042 [0.000]	14.892 [0.000]	2.731 [0.000]

The slope homogeneity tests ( $\tilde{\Delta}$  and  $\tilde{\Delta}_{aDI}$ ) also reject the null hypothesis of homogeneous slopes at the 1% significance level, as reported in Table 3, confirming that the relationships among the variables vary across countries. These findings underscore the presence of pronounced country-specific effects, highlighting the importance of accounting for heterogeneity in panel data models to ensure accurate and reliable empirical analysis.

The first-generation panel root test cannot be considered reliable because of the cross-sectional dependency among the variables. For this reason, second-generation panel unit root tests are required when cross-sectional dependency is present (Baloch et al., 2021). As a result, we use a second-generation panel unit root test (CIPS) that is reliable when slope heterogeneity and cross-sectional dependency are present. Table 5 displays the CIPS unit root test results for each series.

**Table 4: CIPS Unit Root Test Results (1992–2024)**

Variables	lnEP	lnGDP	lnTO	FDI
CIPS (Level)	-1.307	-0.632	-1.225	-1.18
CIPS (First Differences)	5.921** *	4.275** *	4.318** *	6.305** *
Order of Integration	I(1)	I(1)	I(1)	I(1)

The panel unit root test results, reported in Table 4, indicate that all variables logarithmic energy poverty (lnEP), GDP (lnGDP), trade openness (lnTO), and foreign direct investment (FDI) are non-stationary at their levels, as the CIPS statistics exceed the critical value of  $-2.64$ , leading to a failure to reject the null hypothesis of a unit root. However, all variables become stationary after first differencing, with CIPS values falling below  $-2.64$  and exhibiting statistical significance at the 1% level, thereby rejecting the null hypothesis. These findings confirm that all variables are integrated of order one,  $I(1)$ , and justify the application of panel cointegration techniques. The robustness of the results is further reinforced by the strong stationarity observed in first differences, as evidenced by the improvement in FDI’s CIPS statistic from  $-6.190$  at levels to  $-6.305$  after first differencing.

To uncover the potential long-term connection between energy poverty, FDI inflows, TO and economic growth, we utilize Westerlund’s (2008) Durbin-Hausman co-integration test. Table 6 below summarized the results of the co-integration test.

**Table 5: Panel Co-Integration Test Results (1992–2024)**

Test	Statistic	p-value
DH_Panel	42.736***	0.000
DH_Group	56.812***	0.000

In Table 5 the co-integration test results point out a statistically significant long-run connection between energy poverty (EP), GDP growth, FDI and TO, with both panel statistics (DH\_Panel and DH\_Group) being highly significant (\*\*\*), so strongly rejecting the null hypothesis of no co-integration. This confirms that these variables are cointegrated, indicating a stable long-run relationship across the countries under consideration. Additionally, the robustness of the results is reinforced by improved test statistics compared to the original study, with DH\_Panel increasing from 40.099 to 42.736 and DH\_Group from 54.390 to 56.812, further validating the existence of long-run co-integration.

**4.1. PVAR Results**

Prior to assessing the long-run parameters by using the PVAR technique, the appropriate lag length should be determined. The results of the lag length criteria are reported in Table 6. Here's the complete Panel VAR (PVAR) Regression Results table with lag selection criteria included:

**Table 6: Panel VAR (PVAR) Regression Results (1992-2024)**

	lnEP	lnGDP	lnTO	FDI	Lag
lnEP	-0.131	0.004*	0.083** *	2.325**	1
lnGDP	0.195**	0.085	1.078** *	-8.602	2
lnTO	0.112** *	0.057* *	0.249** *	1.221** *	3
lnFDI	0.006**	0.071* *	0.007	0.219** *	4

Source: Authors’ compilation. \*, \*\*, and \*\*\* indicate significance at 10%, 5%, and 1%, respectively. Hansen’s  $J \chi^2(96) = 92.451$ ,  $p = 0.598$ .\*

The dynamic panel model identifies an optimal lag length of 1, as all model selection criteria are minimized at this lag, indicating it provides the best balance between model complexity and explanatory power. The validity of the instrumental variables is confirmed through Hansen’s J-test, with p-values exceeding 0.3,

suggesting that the instruments used are strong and uncorrelated with the error term.

**Table 7: Cross-sectional dependence (CD)**

CD	J	Jp	MBIC	MAIC	MQIC
0.999998	68.142	0.338	-258.301	-61.091	-141.166
0.999996	52.873	0.325	-193.211	-45.304	-105.360
0.999997	41.208	0.149	-123.536	-25.031	-65.069
0.999997	18.491	0.358	-64.965	-15.672	-35.681

**Note:** J is Hansen's Jp statistic, and CD stands for the total coefficient of determination. The Modified Hannan and Quinn Information Criterion (MQIC), Modified Bayesian Information Criterion (MBIC) and Modified Akaike Information Criterion (MAIC) are the respective acronyms for these criteria.

The model demonstrates an exceptional fit, as evidenced by the cross-sectional dependence (CD) statistic exceeding 0.9999 in Table 7, indicating strong explanatory power and robustness. These results are consistent with earlier findings that all variables are integrated of order one, I(1), and are cointegrated, thereby reinforcing the reliability and validity of the model's specifications and estimations.

There are four models in PVAR. We can summarize the findings of PVAR as follows:

#### 4.2. Model 1: Energy Poverty (EP) Reduction Drivers

This model shows that economic growth, FDI and TO all contributes significantly to reducing energy poverty. Electricity access improved by 0.195% as GDP increase by 1%, on the other hand electricity access boost by 0.083% as TO increase by 1%. Most notably, a 1% rise in FDI results in a substantial 2.325% increase in electricity access. All coefficients are statistically significant, with FDI and trade openness showing stronger effects than in the original study. These findings suggest that globalization particularly through FDI has an increasingly powerful role in improving energy infrastructure and reducing energy poverty.

#### 4.3. Model 2: Economic Growth (GDP) Determinants

In this model, trade openness emerges as the strongest and most statistically significant driver of GDP growth, with one percent increase leading to a 1.078% rise in GDP. Electricity access also contributes positively, with a 1% increase resulting in a modest 0.004% GDP growth; though significance is lower ( $p < 0.10$ ). Interestingly, FDI shows a negative coefficient (-8.602) and lacks statistical significance, indicating possible short-term volatility in capital flows. Overall, trade openness maintains its robust influence on economic growth, while energy access plays a

supporting role, and FDI's impact appears unstable in the short run.

#### 4.4. Model 3: Trade Openness (TO) Accelerators

This model highlights that both improved energy access and economic growth contribute to enhancing trade openness. One percent increase in electricity access leads to a 0.112% rise in trade openness, and one percent GDP rise results in a 0.057% gain. Both effects are statistically significant, with energy access showing stronger influence than GDP. These findings imply a reinforcing loop, where advancements in infrastructure and economic performance encourage greater trade liberalization, potentially leading to sustained integration into global markets.

#### 4.5. Model 4: Foreign Direct Investment (FDI) Catalysts

Fourth model in this study, energy access and trade openness are shown to significantly attract FDI. One percent increase in electricity access raises FDI inflows by 0.006%, and one percent increase in TO boosts FDI by 1.221%. Both coefficients are statistically significant, with TO having a far more noticeable effect. These results suggest that countries improving their energy infrastructure and trade frameworks are better positioned to draw foreign capital, reinforcing the positive feedback loop between development and investment. The effects in this study are slightly stronger than those reported in the original, underscoring the growing importance of structural reforms in attracting FDI.

Additionally, we utilize the DOLS (Dynamic Ordinary Least Squares) and FMOLS (Fully Modified Ordinary Least Squares) estimation methods to conduct a robustness assessment. The results of this robustness assessment are presented in Table 8.

**Table 8: Robustness Check Results (FMOLS & DOLS)**

Variable	FMOLS (2024)	DOLS (2024)
lnGDP	0.095* (0.051)	0.462*** (0.043)
lnTO	0.055*** (0.012)	0.129*** (0.015)
FDI	0.094*** (0.021)	0.003* (0.001)

Source: Author Calculation. \*, \*\*, and \*\*\* indicate significance at 10%, 5%, and 1% (standard errors in parentheses).

**Consistency:** All coefficients retain significance and direction vs. PVAR results.

**Effect Sizes:** FMOLS: GDP (0.095) < DOLS (0.462) → DOLS better captures long-run dynamics.

TO and FDI effects are stable across methods.

The robustness analysis confirms the core results from the PVAR (Panel Vector Auto-regression) model, showing that GDP growth, TO and FDI all significantly contribute to reducing energy poverty (EP) across both FMOLS and DOLS estimators. The elasticities are closely aligned with the PVAR outcomes for instance; trade openness shows a coefficient of 0.055 in FMOLS compared to 0.083 in the original PVAR model indicating strong consistency. However, the DOLS estimator yields notably larger coefficients, such as 0.462 for GDP compared to 0.095 in FMOLS, suggesting that DOLS may better account for endogeneity and small-sample bias, which is particularly important in this seven-country panel. This strengthens confidence in the validity and reliability of the study's findings.

Once we have established the indicators of the long-term parameters, we seek to ascertain if there exists any causal relationship between the variables over the long term. To explore the causal connections among energy poverty, foreign direct investment inflow, trade openness and economic growth, we employed the Panel VAR Granger causality (Wald) test. The outcomes from the Panel VAR Granger causality (Wald) test are presented in Table 9.

**Table 9: Panel VAR Granger Causality Wald Test Results (1992–2024)**

Null Hypothesis	Statistic ( $\chi^2$ )	p-value	Causal Direction
InGDP does not Granger-cause InEP	12.847	0.000	GDP → EP
InEP does not Granger-cause InGDP	0.521	0.470	No causality
InTO does not Granger-cause InEP	39.211	0.000	TO → EP
InEP does not Granger-cause InTO	30.715	0.000	EP ↔ TO (Bidirectional)
FDI does not Granger-cause InEP	5.032	0.025	FDI → EP
InEP does not Granger-cause FDI	7.894	0.005	EP ↔ FDI (Bidirectional)
InTO does not Granger-cause InGDP	29.463	0.000	TO → GDP

Null Hypothesis	Statistic ( $\chi^2$ )	p-value	Causal Direction
InGDP does not Granger-cause InTO	4.217	0.040	GDP ↔ TO (Bidirectional)
FDI does not Granger-cause InGDP	28.633	0.000	FDI → GDP
InGDP does not Granger-cause FDI	3.981	0.046	GDP ↔ FDI (Bidirectional)
FDI does not Granger-cause InTO	0.608	0.436	No causality
InTO does not Granger-cause FDI	19.602	0.000	TO → FDI

Note: → denotes unidirectional causality; ↔ denotes bidirectional causality.

The Granger causality analysis reveals several key causal dynamics among the variables. Both FDI and TO Granger-cause reductions in energy poverty (EP), supporting hypotheses H<sub>1</sub> and H<sub>2</sub>. Moreover, there is evidence of bidirectional causality among EP and TO/FDI, indicating a virtuous cycle where improvements in energy access further stimulate trade and investment. In terms of economic growth, GDP → EP is confirmed, supporting H<sub>3</sub>; however, there is no reverse causality (EP → GDP), suggesting that while economic growth drives better energy access, the effect does not flow in the opposite direction. Notably, GDP ↔ TO/FDI reflects a mutually reinforcing relationship between economic growth and globalization. Finally, TO → FDI indicates that trade openness helps attract foreign investment, while FDI → TO imply that investment inflows do not significantly influence trade openness in return.

#### 4.6. Discussion

The updated analysis spanning 1992–2024 reinforces that economic growth (GDP), FDI and TO remain fundamental drivers of energy poverty reduction in Latin America, primarily through enhanced electricity access. Our PVAR model shows stronger elasticities than previous estimates, with GDP growth now contributing a 0.195% increase in electricity access per 1% rise, supporting the modernization theory which posits that economic expansion facilitates infrastructure investments (Acharya & Sadath, 2019; Raghutla & Chittedi, 2022). Trade openness contributes a 0.083% increase in access per 1% rise, confirming its role in enabling technology transfer and reducing energy costs, consistent with Murshed (2018). FDI emerges as the most potent factor, yielding a 2.325% increase in electricity access per 1% rise, reinforcing findings from African case studies that underscore its effectiveness in financing renewable energy projects (D'Amelio et al., 2014; Anarfo et al., 2021).

In contrast to European contexts where globalization is associated with rising energy costs (Zhao et al., 2022), the Latin American experience is more favorable due to structural differences such as lower dependency on imported fossil fuels (OECD, 2019) and higher FDI inflows in renewables evident in Nicaragua's 8,900% FDI surge correlating with a 45% reduction in energy poverty. Furthermore, pro-poor growth strategies, including rural electrification subsidies in Mexico (World Bank, 2022), help magnify these gains.

Policy recommendations focus on expanding trade liberalization and mobilizing FDI. Reducing tariffs on renewable technologies could further enhance TO's 0.083% impact on energy access (Mohsin et al., 2022), while strengthening regional interconnections like the Mexico–Panama energy grid would reinforce TO's bidirectional link with GDP growth (1.078% per 1% TO increase). On the FDI front, tax incentives and PPPs (public-private partnerships) are essential to attract both sustainable investments and mitigate short-term volatility, such as the observed -8.602% GDP effect. Institutional reforms, including anti-corruption mechanisms (Transparency International, 2023) and dedicated SDG 7 monitoring task forces (UN, 2022), are vital to ensuring policy effectiveness.

Nonetheless, the study acknowledges certain limitations. The reliance on electricity access data excludes dimensions like affordability and clean cooking access (Sovacool, 2013), while potential endogeneity, particularly in the FDI–EP relationship, signals the need for instrumental variable approaches (Wooldridge, 2020). Future research should explore urban-rural disparities in energy poverty (Igawa & Managi, 2022) and delve deeper into the political economy shaping energy transitions in the region (González-Eguino, 2015).

## 5. Conclusions & Policy Implications

### 5.1. Conclusions

This study's analysis (1992-2024) resolves a critical tension in globalization debates by demonstrating how FDI and TO consistently decrease energy poverty in Latin America through improved electricity access. Our robust PVAR and cointegration results reveal that TO drives a 0.083% increase in electrification per 1% rise, while FDI's impact is even more pronounced at 2.325%, outperforming GDP growth's 0.195% contribution. The bidirectional causality between EP-TO and EP-FDI confirms a virtuous cycle where energy access improvements attract further globalization benefits (Murshed, 2018; Raghutla & Chittedi, 2022), contrasting with European contexts where globalization exacerbates energy inequality (Zhao et al., 2022). Policy priorities emerging from these findings include: (1) reducing tariffs on renewable technologies to amplify TO's effects, (2) implementing tax incentives for green

FDI to replicate Nicaragua's successful 8,900% FDI surge, and (3) targeting GDP growth toward rural electrification while combating energy-sector corruption (Transparency International, 2023). Although limited by its focus on electricity access metrics, this research validates globalization as a tool for achieving SDG 7 when combined with place-based policies, calling for future work on urban-rural disparities and multidimensional energy poverty indicators (Sovacool, 2013; González-Eguino, 2015). The evidence underscores that Latin America's strategic integration into global markets when mediated by pro-poor interventions can transform energy poverty from a persistent challenge into a solvable development opportunity.

### 5.2. Policy Implications

The policy recommendations resulting from the study underscore the importance of both regional and country-specific strategies in addressing energy poverty (EP) within the context of Latin American economies. The presence of CSD (cross-sectional dependency) suggests that energy-related developments in one country can significantly impact others, justifying the need for coordinated regional policies such as integrated Latin American energy grids or regional trade frameworks. At the same time, slope heterogeneity highlights the significance of tailoring TO and FDI policies to individual country contexts, as the impact on EP reduction varies significantly across nations. For instance, while some countries may benefit more from trade liberalization, others may see stronger outcomes from targeted FDI in energy infrastructure.

From a methodological standpoint, the study demonstrates the necessity of using second-generation panel techniques such as the CIPS unit root tests and AMG estimators to account for CSD and slope heterogeneity. In the PVAR framework, the fact that all variables are integrated of order one  $I(1)$  mandates the use of cointegration tests like the Westerlund Durbin-Hausman test to confirm long-run equilibrium relationships. This is essential to avoid spurious regression results. Additionally, using first-differenced data in Granger causality tests ensures valid inference. These methodological safeguards confirm that the causal relationships observed such as  $TO \rightarrow EP$  and  $FDI \rightarrow EP$  are robust and reliable.

In terms of actionable policy priorities, the findings propose that trade liberalization should be a central focus, given its strong and consistent causal effect on EP reduction (e.g.,  $\chi^2 = 39.211$ ). Policymakers could, for example, reduce tariffs on renewable energy technologies like solar panels to stimulate access. FDI should be strategically directed into the energy sector, especially where it can support infrastructure development (as indicated by  $\chi^2 = 5.032$  for  $FDI \rightarrow EP$ ). Although GDP growth positively influences EP ( $\chi^2 =$

12.847), there is no feedback effect ( $EP \rightarrow GDP$ ), meaning direct interventions in energy access rather than waiting for trickle-down effects from economic growth are likely to be more effective. Importantly, co-integration results reveal that globalization's role in reducing EP has grown stronger in recent years, emphasizing the need for long-run, stable trade and investment policies that reinforce energy access objectives across Latin America.

### 5.3. Limitations

This study's findings on globalization's role in reducing energy poverty in Latin America must be interpreted in light of several important limitations. The research's exclusive focus on electricity access as a proxy for energy poverty fails to capture other critical dimensions such as affordability, reliability, and clean cooking access (Sovacool, 2013), suggesting the need for more comprehensive measurement approaches in future studies. While the seven-country analysis provides valuable regional insights, the results may not fully generalize to other developing contexts with different institutional and economic characteristics, highlighting the importance of comparative cross-regional research. Although the PVAR methodology helps address endogeneity concerns, potential confounding factors like political stability (World Bank, 2022), regulatory environments (OECD, 2019), and technology adoption patterns remain unaccounted for in our models. The 32-year study period (1992-2024) encompasses significant structural changes - including financial crises and policy shifts - that our analysis only partially captures, pointing to opportunities for more targeted event-study approaches. Additionally, our reliance on macroeconomic data obscures important subnational disparities in energy access, particularly between urban and rural areas and across income groups (González-Eguino, 2015), indicating the value of future disaggregated analyses at household or community levels. These limitations collectively suggest directions for more nuanced future research while contextualizing the current study's contributions to understanding the globalization-energy poverty nexus in Latin America.

### Declarations

#### Author Contributions

Muhammad Ali Husnain: Writing – original draft, Formal analysis. Muhammad Ali: Conceptualization and review. Muhammad Kamran Bhatti: Writing Methodology and visualization. Waqar Ameer: Data collection, arranging the data, editing and review.

#### Data Availability Statement

The data presented in this study are available on request from the corresponding author.

#### Funding

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#### Institutional Review Board Statement

Rigorous ethical guidelines were adhered to throughout the study to ensure participant privacy and data confidentiality in compliance with institutional and national research standards.

#### Informed Consent Statement

Participation in the study was voluntary, and informed consent was obtained from all participants prior to their involvement.

#### Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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