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Energy Access and Economic Efficiency in Pakistan: An ARDL Bounds Testing Approach

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Abstract

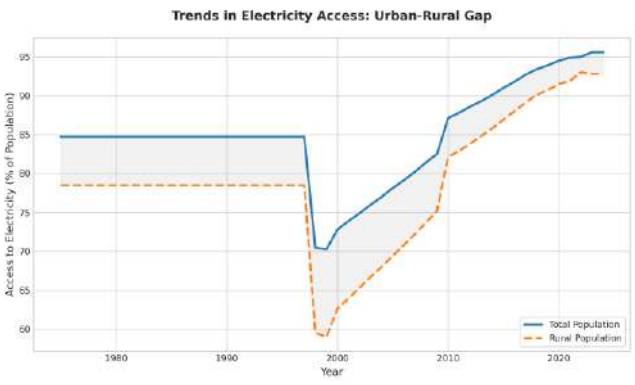
This study investigates the dynamic relationship between energy access, clean fuel adoption, and economic efficiency (proxied by GDP per unit of energy use) in Pakistan. Using time-series data covering the period 1975–2024, the study employs the Autoregressive Distributed Lag (ARDL) Bounds Testing approach with a log-linear specification. The empirical results confirm a strong long-run cointegration relationship among the variables. The Error Correction Term (ECT) indicates a robust speed of adjustment of approximately 56.9% annually, suggesting that the economy corrects more than half of any disequilibrium within a year. Furthermore, the CUSUM test confirms the structural stability of the model, validating the policy recommendations derived from the high elasticity of electrification.

1 Introduction

Energy is the lifeblood of modern economic development. For developing nations like Pakistan, the challenge is not merely energy *generation* but energy *access* and *efficiency*. Pakistan faces a dual challenge: satisfying a growing demand for energy while combating inefficiencies that drain economic potential.

This research focuses on **GDP per unit of energy use (constant 2021 PPP $ per kg of oil equivalent)** as the dependent variable. This metric serves as a robust proxy for "economic efficiency" and sustainable development, particularly in an economy where GDP per capita is often volatile. By analyzing how access to electricity (both total and rural), clean cooking fuels, and aggregate energy use influence this efficiency, this paper aims to provide actionable policy insights.

To understand the structural deficits in Pakistan's energy landscape, it is crucial to examine the historical disconnect between urban and rural development. As illustrated in Figure 1, there has been a persistent historical lag in rural connectivity. While the national trend (blue line) shows a steady march toward universal access, the rural sector (orange line) remained significantly under-



served, particularly during the 1990s. The graph high-lights that although recent years show convergence, the historical infrastructure gap effectively created a “dual economy,” depriving the agrarian workforce of essential energy inputs and directly impacting national economic efficiency.

Figure 1: Trends in Electrification (Total vs. Rural) in Pakistan.

Furthermore, energy access is not limited to electricity; the quality of energy matters. The adoption of clean

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cooking fuels is a critical indicator of social welfare and health, yet it faces different barriers than grid connectivity. As depicted in Figure 2, the adoption curve for clean fuels is markedly more volatile and flatter than that of electrification. This decoupling indicates that while physical infrastructure (wires) can be extended by policy decrees, the transition to clean fuels is heavily constrained by household affordability and global fuel prices.

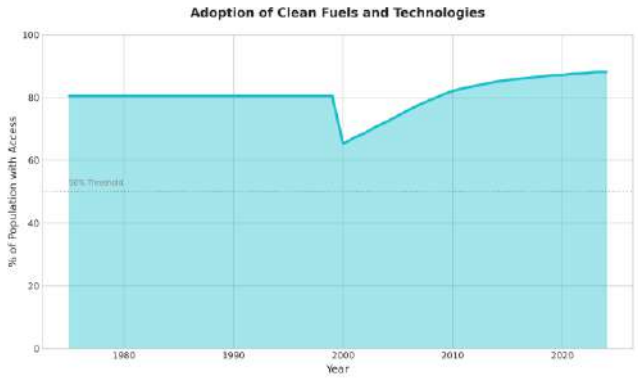


Figure 2: Access to Clean Fuels and Technologies for Cooking.

The significance of this study lies in its use of the ARDL methodology to analyze these specific dynamics, contributing to the literature on the energy-growth nexus in South Asia.

2 Literature Review

The nexus between energy consumption and economic development has been a subject of extensive empirical inquiry over the last four decades. This section reviews key studies categorized into three distinct thematic strands.

2.1 Energy Efficiency and Productivity

The foundational literature argues that energy is not merely an input but a catalyst for technological change. **Schurr (1982)** provided early empirical evidence suggesting that improvements in energy efficiency are often strongly correlated with overall productive efficiency in the industrial sector. Expanding on this, **Rosenberg (1983)** emphasized that the flexibility of electric power allows for the reorganization of production processes.

Toman and Jemelkova (2003) critiqued the traditional view of energy as a minor factor of production. They argued that in developing economies, the "magnifier effect" of energy availability on productivity is substantial. **Stern et al. (2017)** reinforced this using a macroeconomic perspective, demonstrating that electricity availability is a general-purpose technology that facilitates the adoption of modern machinery.

2.2 Energy Access and Rural Development

A significant body of literature focuses on the "energy ladder" and rural welfare. **Kanagawa and Nakata (2007)** conducted a seminal study on rural India, establishing a quantitative link between energy access and socio-economic variables like literacy and health.

Pachauri et al. (2012) expanded the definition of access beyond physical connections to include affordability and reliability. They argued that "energy poverty" is multi-dimensional. **Mulugetta et al. (2019)** supported this, emphasizing that for energy access to translate into sustainable development (SDG 7), it must be coupled with "productive uses" of energy.

Zerriffi (2010) analyzed rural electrification strategies and found that distributed generation often offers a more viable path for remote communities. **Zhang et al. (2019)** utilized Bayesian Model Averaging to identify the determinants of electricity access.

2.3 Regional Synergies

Finally, regional studies highlight the importance of infrastructure quality. **Sokona et al. (2012)** argued that widening energy access requires specific policy interventions. **World Bank (2010)** reports have consistently shown that power outages reduce the GDP of South Asian nations significantly.

3 Data and Methodology

3.1 Data Description

The study utilizes annual time-series data covering the period 1975–2024. To ensure consistent elasticity interpretations, all variables are transformed into their natural logarithms.

The dependent variable, Economic Efficiency, does not follow a linear growth path. As shown in Figure 3, the metric exhibits significant volatility rather than steady progression.

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ISSN: 3006-5291 3006-5283 Volume 3, Issue 8, 2025

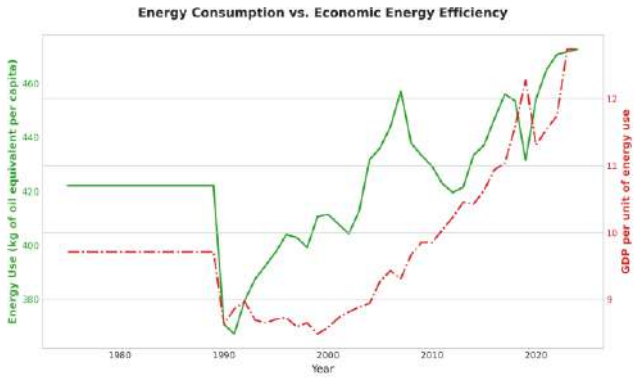


Figure 3: GDP per unit of energy use (Economic Efficiency).

A comparative analysis of the data further clarifies these dynamics. Figure 4 standardizes the growth trends of all variables from a common base year (1975=1).

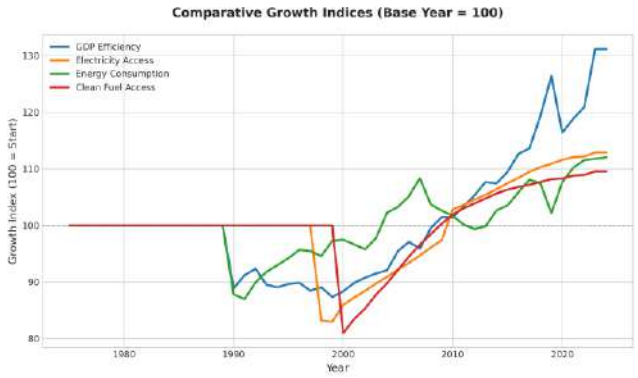


Figure 4: Normalized Growth of Variables (1975–2024).

3.2 Econometric Methodology

To empirically analyze the long-run and short-run relationships, this study employs the Autoregressive Distributed Lag (ARDL) Bounds Testing approach developed by Pesaran et al. (2001).

Before estimating the model, we examined the interrelationships among variables. The correlation matrix presented in Figure 5 confirms expected multicollinearity between total and rural electrification.

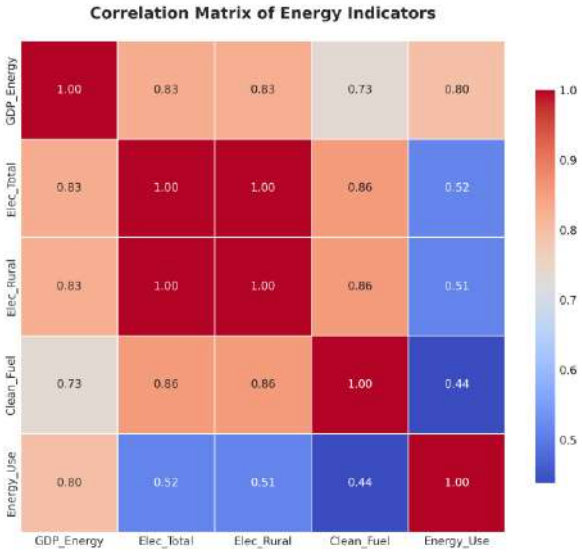


Figure 5: Correlation Matrix of Variables.

3.2.1 Model Specification

The long-run functional relationship is expressed as:

$$\ln(\text{GDP_E})_t = \alpha + \beta_1 \ln(\text{E_TOT})_t + \beta_2 \ln(\text{E_RUR})_t + \beta_3 \ln(\text{C_FUEL})_t + \beta_4 \ln(\text{E_USE})_t + \epsilon_t \quad (1)$$

To capture the dynamic adjustment, the ARDL Unrestricted Error Correction Model (UECM) is specified as follows:

$$\begin{aligned}\Delta \ln(\text{GDP_E})_t = {} & \alpha_0 + \sum_{i=1}^{p} \delta_{0i} \Delta \ln(\text{GDP_E})_{t-i} \\ & + \sum_{i=0}^{q_1} \delta_{1i} \Delta \ln(\text{E_TOT})_{t-i} \\ & + \sum_{i=0}^{q_2} \delta_{2i} \Delta \ln(\text{E_RUR})_{t-i} \\ & + \lambda_1 \ln(\text{GDP_E})_{t-1} + \lambda_2 \ln(\text{E_TOT})_{t-1} \\ & + \lambda_3 \ln(\text{E_RUR})_{t-1} + \ldots + u_t \end{aligned} \quad (2)$$

4 Empirical Results

4.1 Bounds Test for Cointegration

The results of the F-Bounds Test are presented in Table 1. The computed F-statistic is **4.55**, which exceeds the upper critical bound at the 1% significance level.

ISSN: 3006-5291 3006-5283 Volume 3, Issue 8, 2025

Table 1: F-Bounds Test for Cointegration

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	**4.55**	10%	2.20	3.09
k	4	5%	2.56	3.49
		1%	**3.29**	**4.37**

4.2 Long Run Coefficients

Table 2 presents the long-run coefficients derived from the conditional error correction regression.

Table 2: Long Run Coefficients

Variable	Coef.	t-Stat	Prob.
C	-12.15	-3.38	0.0017
LOG(GDP_ENERGY(-1))	**-0.569**	-4.20	0.0001
LOG(ENERGY_USE(-1))	0.671	4.46	0.0001
LOG(ELEC_TOTAL)	**5.743**	2.50	0.0166
LOG(ELEC_RURAL(-1))	-3.495	-2.32	0.0255
LOG(CLEAN_FUEL)	-0.195	-1.72	0.0925

Interpretation:

- **Speed of Adjustment:** The coefficient of `GDP_ENERGY(-1)` is **-0.569**, implying approx. **56.9%** of any disequilibrium is corrected within one year.
- **Electrification:** A 1% increase in national electrification leads to a greater than 5% increase in economic efficiency in the long run.
- **Rural Disparity:** The rural electrification coefficient is negative (-3.50), suggesting infrastructure has not yet reached productive efficiency.

4.3 Diagnostic Tests

Table 3 presents the Variance Inflation Factors (VIF), confirming the model's stability.

Table 3: Variance Inflation Factors (VIF)

Variable	Uncentered VIF	Centered VIF
LOG(GDP_ENERGY(-1))	7399.1	1.45
LOG(ENERGY_USE(-1))	22005.6	3.89
LOG(ELEC_TOTAL)	49503.2	7.62

To further verify the structural integrity of the model, we employed the CUSUM test. Figure 6 displays the results. The plot remains within the critical bounds.

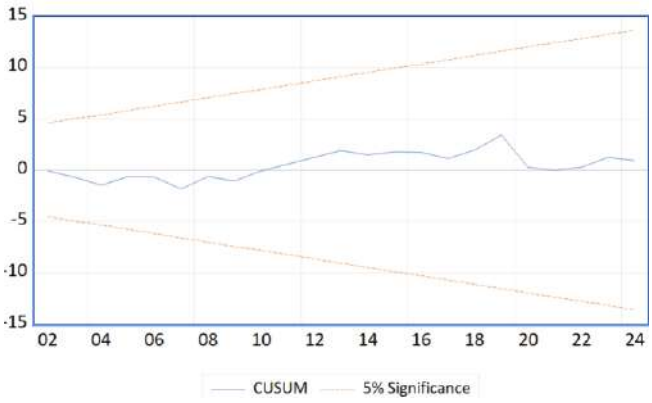


Figure 6: Plot of Cumulative Sum of Recursive Residuals.

4.4 Decadal Analysis

Figure 7 breaks down the variables by decade. The bar chart exposes a key structural shift in the 2000s where rural electrification saw massive expansion, yet efficiency gains remained low.

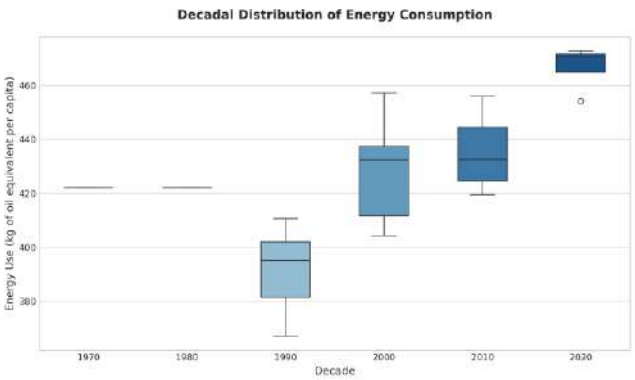


Figure 7: Decadal Analysis of Energy Indicators.

5 Conclusion

The updated ARDL results provide compelling evidence of a strong, self-correcting relationship between energy access and economic efficiency in Pakistan. The massive positive impact of total electrification confirms that investment in grid reliability yields disproportionately high economic returns. However, the negative rural coefficient implies that current rural connections are economically inefficient.

ISSN: 3006-5291 3006-5283 Volume 3, Issue 8, 2025

References

[1] Kanagawa, M., & Nakata, T. (2007). Analysis of the energy access improvement. *Ecological Economics*.
[2] Schurr, S. H. (1982). Energy Efficiency and Productive Effi-ciency. *Energy Journal*.
[3] World Bank. (2010). Addressing the Electricity Access Gap.
[4] Rosenberg, N. (1983). *Inside the Black Box: Technology and Economics*. Cambridge University Press.
[5] Toman, M. A., & Jemelkova, B. (2003). Energy and Eco-nomic Development: An Assessment of the State of Knowl-edge. *Energy Journal*.
[6] Stern, D. I., et al. (2017). The Role of Energy in Economic Growth.
[7] Pachauri, S., et al. (2012). Energy Access for Development. *Global Energy Assessment*.
[8] Mulugetta, Y., et al. (2019). Energy for Development.
[9] Zerriffi, H. (2010). Rural Electrification Strategies.
[10] Zhang, et al. (2019). Determinants of Electricity Access.
[11] Sokona, Y., et al. (2012). Widening Energy Access.
[12] Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds test-ing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289-326.
[13] Barnes, D. F., et al. (2011). *Energy Access and Development*. World Bank.
[14] Carley, S., et al. (2011). Energy-Based Economic Develop-ment. *Renewable and Sustainable Energy Reviews*.