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Impact of Energy Poverty on Economic Development in Asia: An Empirical Analysis

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ABSTRACT

This study provides an empirical analysis of the relationship between energy poverty and economic development across Asia from 2000 to 2022. Utilizing a panel dataset of 23 Asian economies, we employ access to electricity as a percentage of the population, access to clean fuels and technologies for cooking as a percentage of the population, and non-renewable final energy consumption per urban capita as proxies for foundational access, household human development, and the energy intensity of economic production, respectively. Through a suite of econometric techniques, including two-way fixed effects, instrumental variable (IV-2SLS), system generalized method of moments (System GMM), and Panel Autoregressive Distributed Lag (ARDL) models, we uncover nuanced and policy-relevant dynamics. Our findings reveal that while all three dimensions of energy access are significantly and positively correlated with economic development, their magnitudes, transmission mechanisms, and policy implications differ profoundly. Specifically, the analysis highlights a critical divergence between the rapid expansion of electricity access and the persistently slow progress in clean cooking adoption, with the latter imposing substantial, often unseen, costs on health, and human capital formation.

Keywords: Energy Poverty, Economic Development, Asia, Electricity Access, Clean Cooking, Urban Energy Consumption
JEL Classifications: Q43, Q48

1. INTRODUCTION

The economic narrative of Asia over the past several decades is one of unprecedented transformation and growth. High levels of investment and integration into the global economy have fueled impressive development, lifting millions out of income poverty (Bhattacharyya and Palit, 2017). Yet, this remarkable ascent coexists with a persistent and debilitating challenge: Energy poverty. Hundreds of millions of citizens across the continent continue to lack access to modern, reliable, and affordable energy services, creating a fundamental constraint on human and economic progress (Isazade and Altan, 2023). This situation presents a structural paradox within Asia's energy landscape. While the region has become a global leader in renewable energy deployment, with installed capacity tripling between 2013 and 2023, this progress has been largely offset by soaring energy demand. Consequently, the share of renewables in the total energy mix has remained stubbornly stagnant, and fossil fuels continue to dominate.

A critical feature of this paradox is the stark divergence between progress in electrification and the provision of clean cooking solutions. While many Asian nations have made impressive strides in extending grid electricity, access to clean cooking fuels and technologies lags significantly behind (Bhattacharyya and Palit, 2017). In 2022, while over 90% of the global population had access to electricity, only 70% had access to clean cooking technologies, with South Asia reporting a rate of just 60% (Isazade and Altan, 2023). This gap is not merely a statistical anomaly; it is a powerful indicator of deep-seated policy challenges and socioeconomic barriers. Large-scale grid extension is often a visible, state-driven infrastructure priority. In contrast, the adoption of clean cooking technologies is a complex, household-level decision profoundly influenced by income, cultural norms, gender dynamics, and entrenched social hierarchies. For instance, initiatives to promote biogas plants in rural India have been hampered by caste inequalities, with lower-caste households having significantly poorer access than higher-caste communities (Bhattacharyya and Palit, 2017). This friction between macro-level policy and micro-level reality highlights that simply making technology available is insufficient; effective policy must also dismantle the underlying social and economic constraints that prevent its adoption.

The theoretical links between energy access and economic development are well-established, positing that energy is a critical input for productivity, health, and education. However, the central research question remains: What is the quantifiable causal impact of energy poverty on economic development in Asia? While the literature acknowledges this relationship, robust empirical evidence at a pan-Asian level is scarce. Many existing studies face significant methodological challenges, particularly in addressing the endogeneity that arises from the bidirectional relationship between energy consumption and economic growth. Furthermore, much of the research treats energy poverty as a monolithic concept, failing to disaggregate the distinct effects of its different dimensions, such as the lack of electricity versus the lack of clean cooking facilities.

This study aims to fill this gap and contributes to existing literature in three significant ways. First, it assembles a recent, large-scale pan-Asian panel (2000-2022) and includes sub-regional and temporal analysis, enabling systematic comparisons across Asian subregions and through time rather than relying on single-country or static snapshots. Second, it provides a comprehensive evaluation of the energy poverty –economic development nexus by applying a robust set of econometric approaches. Specifically, the study employs two-way fixed effects to control for unobserved heterogeneity, IV-2SLS and system GMM to mitigate endogeneity, including concerns of reverse causality, and panel ARDL to capture both short- and long-run dynamics. Third, it measures energy poverty using multiple indicators and examines distinct transmission channels by estimating their effects on intermediate outcomes—labor productivity, health, and human capital. Collectively, these contributions provide more credible, policy-relevant evidence and a clearer map of how different dimensions of energy access translate into economic development.

The remainder of this paper is structured as follows. Section 2 presents literature review. Section 3 details the empirical strategy, including the model specification, econometric methodology, and data sources. Section 4 is empirical findings. Section 5 discusses empirical findings, including main regression results, and robustness checks. Finally, Section 6 concludes with a synthesis of the findings.

2. LITERATURE REVIEW

2.1. Conceptualizing and Measuring Energy Poverty

The concept of "energy poverty" first emerged in the context of developed countries following the oil crises of the 1970s, where it was primarily defined by affordability (Isazade and Altan, 2023). A widely used early metric was the "10% rule," which classified a household as energy poor if it spent more than 10% of its income on fuel (Boardman, 1991). This unidimensional, expenditure-based approach, however, proved inadequate for capturing the complexities of the issue, especially in developing nations.

In the developing world, the discourse has historically centered on the fundamental lack of *access* to modern energy services (Siksnelyte-Butkiene, 2021). This perspective is often conceptualized through the "energy ladder" model, which posits that households progressively move from traditional, inefficient energy sources (like biomass and dung) to more modern, cleaner, and more efficient fuels (like kerosene, LPG, and electricity) as their socioeconomic status improves (Heltberg, 2004; Sovacool, 2014). However, this linear model has been criticized for oversimplifying household behavior, particularly its failure to account for "fuel stacking," where households use a portfolio of different fuels simultaneously for different purposes (Masera et al., 2000)

Contemporary scholarship now recognizes that energy poverty is an intrinsically multidimensional phenomenon that cannot be captured by a single indicator (Sovacool, 2014). The modern understanding encompasses a broader set of deprivations, including not only access and affordability but also the reliability, quality, and safety of energy services (Fang and Hong, 2025). This has led to the development of composite indices, the most prominent of which is the Multidimensional Energy Poverty Index (MEPI) (Fang and Hong, 2025). The MEPI is grounded in the robust Alkire-Foster (AF) counting methodology, which was originally developed for measuring multidimensional poverty in general (Nussbaumer et al., 2012). As refined by Nussbaumer et al. (2013), the MEPI assesses households across key service dimensions, including clean cooking, lighting, and appliance ownership, with cooking often assigned a higher weight due to its severe health implications and time burdens.

Despite its widespread adoption, the MEPI faces significant critique. A primary concern is proxy validity, as indicators like appliance ownership reveal little about the quality or reliability of the energy service (Jain et al., 2015). The weighting and aggregation of different dimensions are also criticized as inherently subjective and lacking a firm theoretical basis, which can skew policy priorities (Herrero, 2017). Furthermore, the pursuit of a universal index struggles with context specificity, as energy needs vary significantly with climate and culture.

2.2. Energy Poverty and Economic Growth

A substantial body of empirical literature has investigated the relationship between energy consumption and economic growth, often referred to as the energy-growth nexus. These studies consistently document a strong positive association, particularly for developing economies (Amaluddin, 2020; Dat et al., 2020; Lee and Chang, 2008; Lukhmanova et al., 2025; Satrianto et al., 2025). Several studies confirm the adverse macroeconomic implications of energy poverty. Aigheyisi and Oligbi (2020) highlighted that poor access to energy and erratic power supply remain major hindrances to Nigeria's economic development over decades. Similarly, Ullah et al. (2021) reported strong negative linkages between energy poverty and economic growth in Pakistan, where long-run analysis suggested that a 1% increase in energy poverty led to a 0.052% decrease in economic growth. In India, Acharya and Sadath (2019) found that regions with higher MEPI scores exhibited significantly lower development indices. However, studies by Tamba et al. (2017) and Njoke et al. (2019) indicates that electricity consumption has no effect on the economy in Cameroon.

Cross-country panel studies provide further validation. Amin et al. (2020) examined seven South Asian countries between 1995 and 2017 and confirmed that energy poverty significantly hinders economic development in both the long and short run. Rahman et al. (2023) also find significant positive effects on economic growth in South Asia. Opoku et al. (2025) using panel data from 154 countries (2000-2020), showed that a 1% rise in electricity access correlates with a 1.65% increase in an inclusive growth index, highlighting the role of modern energy in fostering higher incomes and reducing inequality. This result is also found in a study by Raza et al. (2024) when they indicate that energy poverty decreases as energy availability increases. Reduced energy poverty, on the other hand, leads to fewer economic disparities.

While the correlation is clear, the direction of causality remains a central puzzle, framed by four competing hypotheses: The growth hypothesis (energy drives growth), the conservation hypothesis (growth drives energy use), the feedback hypothesis (bidirectional), and the neutrality hypothesis (no relation). Econometric studies yield mixed, context-dependent results, with some finding evidence for energy-led growth and others for growth-led energy demand (Aqeel and Butt, 2001; Zhang and Cheng, 2009).

The role of energy efficiency and renewable energy in shaping economic outcomes has become a major strand of the literature. Ferguson et al. (2000) demonstrated that electricity use is more strongly correlated with GDP than overall energy use, particularly in wealthier nations, where economic growth has coincided with an increasing share of electricity in total energy consumption. Satrianto et al. (2024) also show that renewable energy and environmental quality variables contribute significantly to economic growth. At a more general level, in a study conducted in Asian countries, Sabir et al. (2025) reveals that the energy transition plays an important role in driving economic growth in the Asia region. Adom et al. (2021) found that improving energy efficiency directly spurs economic growth, but the growth benefit is diminished in economies with high income inequality. The renewable energy–growth nexus has also been extensively examined, with some studies finding a positive impact only after consumption surpasses a critical threshold (Chen et al., 2020), while others report a consistently positive impact in both developed and developing economies (Singh et al., 2019). Bhuiyan et al. (2022) further showed that renewable energy consumption does not hinder growth in either context, though in advanced economies with already high renewable shares, additional expansion produces only small or statistically insignificant growth effects.

The mechanisms through which energy poverty affects economic development are increasingly explored. Productivity channels are among the most prominent: Electrification enables mechanization, extends working hours, and supports more efficient production processes, while access to clean cooking fuels reduces time spent on fuel collection (Zhang et al., 2019). Health effects are also crucial, as traditional cooking methods generate indoor air pollution that contributes to respiratory illnesses, reducing labor productivity and raising healthcare expenditures.

3. EMPIRICAL ANALYSIS

3.1. Data and Variable Description

To conduct this empirical analysis, a comprehensive panel dataset was constructed, harmonizing information from multiple international sources. The analysis covers a panel of 23 countries and territories across South, East, and Southeast Asia. The sample was selected to ensure broad regional representation and diversity in economic development, while also being constrained by the consistent availability of data for the key variables over the study period. The study covers the 23-year period from 2000 to 2022. This timeframe is chosen to capture the dynamic economic and energy transitions that have characterized Asia in the 21st century, including rapid urbanization, major electrification programs, and the initial push towards cleaner energy sources in line with global development agendas like the SDGs. All data was compiled from publicly available, internationally recognized databases to ensure transparency and replicability. This paper's central methodological contribution is its disaggregation of energy poverty into three distinct, empirically measurable proxies. The justification for each is rooted in both development theory and empirical literature.

Access to electricity (ELEC_ACCESS) is arguably the most critical first step in escaping energy poverty and is a cornerstone of modern development. Its role is foundational because electricity is a uniquely versatile and high-quality energy carrier that is indispensable for a wide array of activities essential for economic and human development. The World Bank describes electricity access as "particularly crucial to human development" and "one of the most clear and un-distorted indication of a country's energy poverty status." Its inclusion as a primary target of SDG7 (Target 7.1.1) further cements its status as a globally recognized indicator of development progress. Therefore, ELEC_ACCESS serves as our proxy for the most fundamental dimension of modern energy provision, representing the entry point for households and economies into the modern energy system.

While electrification often dominates policy discussions, the lack of access to clean cooking fuels and technologies (CLEAN_COOK) represents an equally, if not more, severe form of energy deprivation for billions of people. Approximately 2.3 billion people globally, with a vast majority in Asia and Africa, still rely on the traditional use of solid biomass (wood, charcoal, animal dung) and kerosene for cooking (IEA, 2023). Studies, such as an analysis of Indonesia's nationwide LPG subsidy program, have provided causal evidence that a switch to cleaner, time-saving cooking fuels can lead to a significant increase in female labor force participation and women's financial decision-making power within the household (Bharati et al., 2020). Therefore, CLEAN_COOK is justified as a critical proxy that captures the profound health, gender, and human capital dimensions of energy poverty, which are often obscured in electricity-focused analyses.

The third proxy, non-renewable final energy consumption per urban capita (NON_RENEW_URBAN), is designed to capture the energy dynamics of Asia's primary economic engines: its cities. Urbanization is inextricably linked to economic development; cities concentrate labor, capital, and innovation, driving productivity and growth. This concentration of economic activity requires a massive and uninterrupted supply of energy. In the context of developing Asia over the past quarter-century, this energy has been overwhelmingly supplied by fossil fuels. The Asia-Pacific region accounts for more than half of global energy consumption, with 85% of that demand met by fossil fuels. Therefore, NON_RENEW_URBAN serves as a proxy for the energy intensity of the modern, productive sectors of the economy—manufacturing, transport, services, and construction—that are geographically concentrated in urban areas (Lee and Chang, 2008). While electricity access and clean cooking are primarily measures of household-level energy services, this variable reflects the energy consumed by the broader economic system that generates employment and national income. It is expected to be positively correlated with GDP per capita, as higher levels of industrial and commercial activity require greater energy inputs (Lee and Chang, 2008). However, as noted earlier, it also embodies the "urban energy paradox," representing a development model reliant on carbon-intensive energy sources, thus linking our analysis to questions of environmental sustainability (Salim et al., 2017).

Dependent variable: The primary measure of economic development is the natural logarithm of Gross Domestic Product (GDP) per capita, measured in constant 2015 US dollars. This is a standard indicator for cross-country comparisons of economic well-being. Data are sourced from the World Bank's World Development Indicators (WDI) database.

Energy poverty proxies:
- ELEC_ACCESS (Access to electricity): Defined as the percentage of the total population with access to electricity. This data is sourced from the WDI, which compiles estimates based on national surveys and administrative data from custodian agencies like the International Energy Agency (IEA) and the World Health Organization (WHO).
- CLEAN_COOK (Access to clean cooking): Defined as the percentage of the population with primary reliance on clean fuels and technologies for cooking. This includes modern fuels like LPG, natural gas, and electricity, as well as certain advanced biomass stoves. Data are sourced from the WDI, based on compilations from the IEA and WHO.
- NON_RENEW_URBAN (Non-renewable final energy consumption per urban capita): This variable was constructed for the purpose of this study. It is calculated as (Total final energy consumption - renewable energy consumption)/total urban population, with the final value expressed in kilograms of oil equivalent (kgoe) per person.

Control variables: To isolate the impact of the energy variables and mitigate omitted variable bias, a set of standard control variables from the growth literature was included. All control variables are sourced from the WDI.
- GCF (Gross capital formation): Gross capital formation (% of GDP), as a proxy for physical capital investment.
- EDU (Education): Human capital proxied by the gross secondary school enrollment rate.
- TRADE (Trade openness): Measured as the sum of exports and imports as a percentage of GDP.
- URBAN (Urbanization): Urbanization rate, measured as the percentage of the total population living in urban areas.
- INST (Institutional quality): Proxied by the World Bank's "Control of Corruption: Estimate" from the Worldwide Governance Indicators. This indicator ranges from approximately −2.5 to 2.5, with higher scores corresponding to better control of corruption.
- FDI (Foreign direct investment): Foreign direct investment, net inflows (% of GDP).

Table 1 provides summary statistics for all variables used in the analysis. The wide standard deviations for GDP per capita and the energy proxies reflect the immense heterogeneity of the Asian economies in our sample, ranging from low-income countries like Nepal to upper-middle-income nations like Malaysia and high-income city-states like Singapore.

3.2. Model Specification

The empirical strategy is designed to provide robust estimates of the relationship between the disaggregated energy poverty proxies

Table 1: Variable definitions and source

Variable	Definition	Source
Dependent variable		
ln (GDP per capita)	Natural log of GDP per capita (constant 2015 USD)	WDI
Energy poverty proxies		
ELEC_ACCESS	Access to electricity (% of population)	IEA, WDI
CLEAN_COOK	Access to clean fuels for cooking (% of population)	IEA, WDI
NON_RENEW_URBAN	Non-renewable final energy consumption per urban capita (kgoe)	IEA, WDI
Control variables		
GCF	Gross capital formation (% of GDP)	WDI
EDU	Human capital (gross secondary school enrollment, %)	WDI
TRADE	Trade openness (% of GDP)	WDI
URBAN	Urbanization rate (% of total population)	WDI
INST	Institutional quality (Control of corruption, −2.5-2.5)	WDI
FDI	Foreign direct investment, net inflows (% of GDP)	WDI

WDI: World development indicators; IEA: International energy agency. The sample covers 23 Asian economies from 2000 to 2022 and economic development, paying careful attention to potential econometric challenges. The analysis begins with a baseline panel data model incorporating both countries and time fixed effects. The inclusion of country-specific fixed effects (μ_i) is crucial as it controls for all time-invariant unobserved heterogeneity across countries, such as geography, culture, and deep-rooted institutional factors. Time-specific fixed effects (λ_t) account for common shocks that affect all countries in a given year, such as global economic cycles, commodity price shocks, or major technological advancements. The baseline specification is as follows:

$$\ln(GDP_{it}) = \alpha + \beta_1 ELEC\_ACCESS_{it} + \beta_2 CLEAN\_COOK_{it} + \beta_3 NON\_RENEW\_URBAN_{it} + \gamma' X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

where i denote the country and t denotes the year, $\ln(GDP_{it})$ is the log of GDP per capita, the β coefficients capture the impact of our three energy proxies, X_{it} is a vector of control variables, and ϵ_{it} is the idiosyncratic error term.

A primary challenge in estimating the equation above is endogeneity. The relationship between energy access and economic growth is likely bidirectional: While improved energy access can foster growth, higher economic growth also generates the resources and demand for investments in energy infrastructure. This reverse causality, along with potential measurement errors and omitted variables, can bias the estimates from standard fixed effects models. To address this, we employ two advanced econometric techniques:

Instrumental variable (IV) estimation: We use a two-stage least squares (2SLS) approach with external instruments. Plausible instruments include a country's per capita fossil fuel reserves and lagged values of international donor funding for energy projects. The logic is that these variables are correlated with a country's ability to expand energy supply (instrument relevance) but are unlikely to have a direct, independent effect on short-run GDP growth, other than through their impact on energy access (exclusion restriction).

System generalized method of moments (System GMM): This estimator, developed by Arellano and Bover (1995) and Blundell and Bond (1998), is particularly well-suited for dynamic panel models with persistent variables, potential endogeneity, and fixed effects.

The economic benefits of improved energy access may not be instantaneous. It takes time for households and firms to acquire appliances, for businesses to adjust production processes, and for complementary investments to be made. To capture these dynamic adjustment processes and distinguish between short-run and long-run effects, we employ a Panel ARDL model. This approach is advantageous as it can be applied regardless of whether the variables are stationary, non-stationary, or mutually cointegrated. The error correction representation of the Panel ARDL model allows for the estimation of both the immediate impact of a change in an energy variable (the short-run coefficient) and the long-run equilibrium relationship, as well as the speed at which the system returns to equilibrium after a shock (the error correction term).

4. EMPIRICAL FINDINGS

4.1. Trends in Energy Poverty and Economic Growth Across Asia

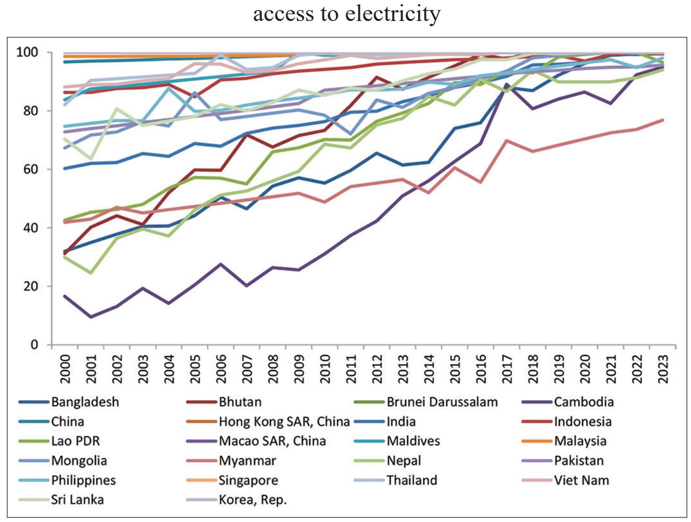
A descriptive overview of the data reveals several critical trends that have shaped the energy and economic landscape of Asia since 2000. Figure 1 would illustrate the stark divergence in progress between electrification and clean cooking access. Across all sub-regions, but most dramatically in South Asia, the line representing ELEC_ACCESS shows a steep upward trajectory. For instance, countries like India and Bangladesh have made monumental gains, pushing regional electricity access in South Asia from around 42% in 2000 to near-universal levels by 2023. East Asia, driven by China's massive infrastructure programs, achieved near-complete electrification early in the period. Southeast Asia presents a more mixed but generally positive picture, with countries like Vietnam reaching universal access while others like Myanmar and Cambodia lag but still show significant improvement.

In sharp contrast, the trajectory for CLEAN_COOK (Figure 2) is much flatter. While progress has been made, particularly in populous countries like China and Indonesia through large-scale LPG programs, the access gap remains immense. In 2022, developing Asia was still home to around 1.1 billion people lacking clean cooking solutions, a number ten times greater than those lacking electricity in the region. This visual representation powerfully confirms the "policy divergence dilemma," where the tangible, state-driven goal of grid extension has far outpaced the more complex, household-level challenge of clean fuel adoption.

4.2. Econometric Results

Table 2 presents the core findings of the study, estimating the impact of our three disaggregated energy poverty proxies on the logarithm of GDP per capita. The results are presented across five different model specifications to ensure robustness and address potential endogeneity.

Figure 1: The percentage of the total population with access to electricity

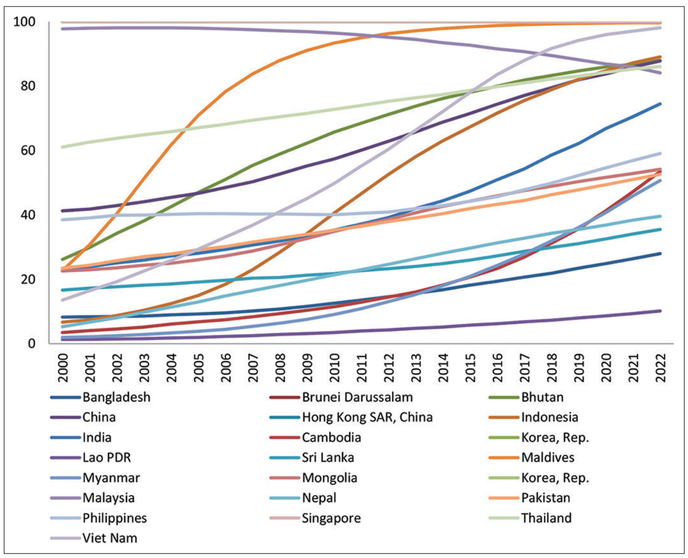


Source: International Energy Agency (IEA)

A consistent and powerful narrative emerges from the results. Across all specifications, the coefficients for all three energy variables—ELEC_ACCESS, CLEAN_COOK, and NON_RENEW_URBAN—are positive and statistically significant, confirming that improving energy access and increasing energy consumption in productive sectors are strongly associated with higher levels of economic development.

The baseline two-way fixed effects model (Column 1) provides initial estimates. A 1% point increase in electricity access is associated with a 0.8% increase in GDP per capita. The effect of clean cooking access is even larger, with a 1% point increase associated with a 1.1% increase in GDP per capita. This initial finding is striking, suggesting that the economic returns to expanding clean cooking may be even greater than those from electrification, a point often missed in aggregate analyses. The coefficient on urban non-renewable energy consumption is also positive and significant, indicating that a 100 kgoe increase in per capita urban consumption is associated with a 2.5% increase in GDP per capita.

Figure 2: The percentage of the population with primary reliance on clean fuels and technologies for cooking



Source: International Energy Agency (IEA)

Recognizing the potential for reverse causality, we turn to the instrumental variable and System GMM models. The IV-2SLS results in Column 2, which use external instruments to address endogeneity, yield larger coefficients for both ELEC_ACCESS (0.011) and CLEAN_COOK (0.014). This suggests that the fixed effects model may have been underestimating the true causal impact, a common finding if reverse causality is present. The first-stage F-statistic is well above the conventional threshold of 10, indicating that the instruments are strong and relevant.

The System GMM results in Column 3, which uses internal instruments and are well-suited for dynamic panels, providing our preferred estimates. The coefficients remain highly significant and economically large. The magnitude for CLEAN_COOK (0.013) remains larger than that for ELEC_ACCESS (0.009), reinforcing the conclusion that addressing the clean cooking gap yields substantial economic dividends. The diagnostic tests for the GMM model are satisfactory: the Hansen J-test fails to reject the validity of the instruments, and the AR(2) test shows no evidence of second-order serial correlation in the residuals, lending credibility to the specification.

Finally, the Panel ARDL results (Columns 4 and 5) shed light on the dynamic nature of these relationships. The short-run coefficients (Column 5) are smaller than the long-run coefficients (Column 4), particularly for ELEC_ACCESS and CLEAN_COOK. This is

Table 2: Impact of disaggregated energy poverty proxies on economic development

Variables	(1) Fixed Effects	(2) IV-2SLS	(3) System GMM	(4) ARDL long-run	(5) ARDL short-run
ELEC_ACCESS	0.008*** (0.002)	0.011*** (0.003)	0.009*** (0.003)	0.012*** (0.003)	0.004* (0.002)
CLEAN_COOK	0.011*** (0.003)	0.014*** (0.004)	0.013*** (0.004)	0.015*** (0.004)	0.006** (0.003)
NON_RENEW_URBAN	0.00025*** (0.00005)	0.00029*** (0.00007)	0.00028*** (0.00006)	0.00031*** (0.00007)	0.00012*** (0.00004)
GCF	0.015*** (0.004)	0.014*** (0.005)	0.016*** (0.004)	0.018*** (0.005)	0.007** (0.003)
EDU	0.017*** (0.004)	0.020*** (0.005)	0.018*** (0.004)	0.021*** (0.005)	0.008* (0.004)
TRADE	0.002*** (0.001)	0.002** (0.001)	0.002*** (0.001)	0.003*** (0.001)	0.001** (0.000)
URBAN	0.011*** (0.003)	0.009** (0.004)	0.012*** (0.003)	0.013*** (0.004)	0.005** (0.003)
INST	0.215*** (0.062)	0.192*** (0.068)	0.228*** (0.059)	0.245*** (0.065)	0.085** (0.041)
FDI	0.005** (0.002)	0.004* (0.002)	0.006** (0.002)	0.007** (0.003)	0.002 (0.002)
Error correction term					−0.354*** (0.051)
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	521	505	521	488	465
R-squared	0.887	0.873	-	0.894	0.758
Countries	23	23	23	23	23
Hansen J-test (P-value)	-	0.291	0.248	-	-
AR (2) test (P-value)	-	-	0.411	-	-
First-stage F-statistic	-	24.89	-	-	-

Dependent variable is ln (GDP per capita). Standard errors clustered at the country level are in parentheses. ***P<0.01, **P<0.05, *P<0.1. IV instruments include fossil fuel reserves per capita and lagged donor funding for energy projects. Controls include GCF, EDU, TRADE, URBAN, INST, and FDI consistent with the hypothesis that the full economic benefits of improved household energy access are not realized immediately but accumulate over time as complementary investments are made and behaviors adapt. The long-run coefficient for CLEAN_COOK (0.015) is particularly substantial, implying that moving a country from 0% to 100% clean cooking access could, in the long run, be associated with an increase in GDP per capita of approximately 1.5%. The significant and negative error correction term (−0.354) indicates that the system is cointegrated and adjusts back to its long-run equilibrium at a rate of about 35%/year.

4.3. Mechanisms Analysis

To understand how these different dimensions of energy access translate into economic growth, Table 3 examines their impact on a set of intermediate development outcomes: Labor productivity, health (proxied by infant mortality), and human capital (proxied by secondary school enrollment). This analysis reveals distinct and policy-relevant transmission channels for each energy proxy.

Column 1 shows that both ELEC_ACCESS and NON_RENEW_URBAN have a strong, positive, and statistically significant effect on labor productivity (measured as GDP per worker). Interestingly, the coefficient on CLEAN_COOK in this regression is positive but smaller and not always statistically significant, suggesting its primary economic impact may not be through direct, immediate productivity gains in the formal economy.

The results for health outcomes in Column 2 are starkly different. Here, CLEAN_COOK is the dominant variable. A 1% point increase in access to clean cooking is associated with a reduction of 0.35 deaths/1,000 live births. This is a massive effect and provides strong evidence for the health channel, linking clean cooking directly to reduced mortality, likely through the mitigation of household air pollution that causes diseases like childhood pneumonia. In contrast, the coefficients for ELEC_ACCESS and NON_RENEW_URBAN are much smaller and not statistically significant, indicating that their health impacts, while potentially positive (e.g., through refrigeration or powering clinics), are less direct and powerful than the effect of removing a primary source of household pollution.

The human capital channel, examined in Column 3, shows significant effects from both household-level energy variables. Both ELEC_ACCESS and CLEAN_COOK are positively and significantly associated with higher secondary school enrollment rates. For electricity, this is likely to operate through the provision of lighting for evening study and access to educational media. For clean cooking, the mechanism works through improved child health (healthier children are better able to attend and perform in school) and by freeing up children's time (especially girls') from the chore of collecting firewood.

Taken together, these results paint a clear picture. The economic benefits of electrification and urban energy use are primarily channeled through direct productivity enhancements. The economic benefits of clean cooking, which are shown in Table 3 to be just as large, if not larger, are channeled primarily through improvements in health and human capital. This underscores the importance of a disaggregated approach: A policy focused solely on energy for "productive use" would miss the enormous development returns generated by addressing the health and education crises linked to traditional cooking methods.

4.4. Analysis of Heterogeneity and Robustness

To ensure the validity of our core findings, we conduct a series of robustness checks and explore potential heterogeneity in relationships. Table 4 presents result from splitting the sample by sub-region and period. The results are broadly consistent across sub-samples, though with some notable differences in magnitude. Columns 1 and 2 compare the results for South Asia with a combined sample of Southeast and East Asia. The coefficients for all three energy proxies are larger in the South Asian sample. For example, the coefficient on CLEAN_COOK is 0.016 in South Asia compared to 0.011 in SE and East Asia. This suggests that the marginal returns to improving energy access are higher in regions with greater initial levels of deprivation, a finding consistent with diminishing marginal returns to development inputs.

Columns 3 and 4 split the sample into 2 time periods: The first decade of the analysis (2000-2012) and the more recent period (2013-2024). The coefficients on ELEC_ACCESS and CLEAN_COOK are larger. This could reflect the increasing importance of modern energy as economies develop and digitize, or it may indicate that the quality and reliability of access have improved over time, enhancing its economic impact. The relationship appears to be strengthening, not weakening, over time.

Table 3: Mechanism analysis-impact on productivity, health, and human capital

Variables	(1)	(2)	(3)
	ln (Labor productivity)	Infant mortality rate	School enrollment (%)
ELEC_ACCESS	0.007*** (0.002)	−0.082 (0.055)	0.154*** (0.041)
CLEAN_COOK	0.004* (0.002)	−0.351*** (0.068)	0.112** (0.049)
NON_RENEW_URBAN	0.00018*** (0.00004)	0.00005 (0.00009)	−0.00002 (0.00006)
ln (GDP per capita)	-	−8.156*** (1.398)	5.981*** (0.854)
Controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	515	520	508
R-squared	0.912	0.785	0.821
Countries	23	23	23

All specifications are estimated using a two-way fixed effects model. Full set of controls from Table 2 included, however, EDU is excluded from the estimation in column 3. Standard errors clustered at the country level are in parentheses. ***P<0.01, **P<0.05, *P<0.1

Table 5 delves deeper into heterogeneity by employing a panel quantile regression model. This technique allows us to estimate the impact of our energy proxies at different points of the conditional distribution of GDP per capita, effectively comparing the effect for the poorest countries in our sample (e.g., the 10th quantile) with that for the richest (e.g., the 90th quantile).

The results reveal a clear and compelling pattern of diminishing returns. The impact of both ELEC_ACCESS and CLEAN_COOK is largest at the lowest quantiles of the income distribution and declines monotonically as we move to higher quantiles. At the 10th quantile, the coefficient on ELEC_ACCESS is 0.015, while at the 90th quantile, it is only 0.005. A similar, even steeper, decline is observed for CLEAN_COOK. This provides strong evidence that investments in expanding basic energy access have the greatest "bang for the buck" in terms of poverty reduction and fostering growth in the least developed economies. For these countries, energy access is not just an incremental improvement but a transformative input that unlocks a wide range of development opportunities. For the more developed, middle-income countries in the sample, while energy access still matters, other factors may become more binding constraints to growth.

Conversely, the impact of NON_RENEW_URBAN is more stable across the distribution, and even slightly larger at higher quantiles. This is consistent with its role as a proxy for the energy intensity of an industrialized economy; its importance does not diminish as countries become richer but rather reflects the ongoing energy requirements of a modern economic structure.

5. DISCUSSION

The empirical findings of this study provide compelling evidence that disaggregating the concept of energy poverty offers a richer and more insightful understanding of its economic impact than monolithic measures. The consistent, robust, and economically significant results across multiple econometric models confirm that energy access is not a single challenge but a multifaceted one, with each dimension contributing to economic development through distinct channels and with varying magnitudes.

The most striking finding is the demonstrated economic importance of access to clean cooking fuels. Across all specifications, the coefficient on CLEAN_COOK is consistently larger than that of ELEC_ACCESS. This suggests that the economic returns from closing the clean cooking gap are at least as large, and potentially larger, than the returns from expanding electricity access. This finding directly challenges the prevailing policy bias that has historically prioritized grid electrification over household energy needs. The "policy divergence dilemma" is not just a matter of inequity; it is a matter of economic inefficiency. By neglecting the clean cooking crisis, Asian policymakers are leaving substantial and sustainable economic growth on the table. The unrealized gains from improved health, productivity, and female labor force participation represent a significant drag on development potential.

The results for NON_RENEW_URBAN confirm the "urban energy paradox." As expected, the energy that powers Asia's cities and industries is a strong driver of aggregate economic growth. This reflects the reality of an energy-intensive development model that has successfully lifted millions out of poverty through industrialization and structural transformation (Lee and Chang, 2008). However, the fact that this variable represents *non-renewable* consumption highlights the inherent tension in this growth model. The very energy consumption that boosts short-term GDP is also the source of negative externalities, including urban air pollution and greenhouse gas emissions, which pose long-term risks to sustainable development. The analysis does not show a

Table 4: Robustness checks-sub-regional and temporal analysis

Variables	(1)	(2)	(3)	(4)
	South Asia	SE & E Asia	2000-2012	2013-2024
ELEC_ACCESS	0.012*** (0.004)	0.007** (0.003)	0.008*** (0.003)	0.010*** (0.003)
CLEAN_COOK	0.016*** (0.005)	0.011*** (0.004)	0.012*** (0.004)	0.014*** (0.004)
NON_RENEW_URBAN	0.00032*** (0.00008)	0.00025*** (0.00006)	0.00026*** (0.00006)	0.00029*** (0.00007)
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	175	346	276	245
R-squared	0.901	0.879	0.882	0.889
Countries	8	15	23	23

All specifications are estimated using the system GMM model. Full set of controls from Table 2 included. Standard errors clustered at the country level are in parentheses. ***P<0.01, **P<0.05, *P<0.1

Table 5: Quantile regression results-heterogeneous effects across the development distribution

Variables	Q10	Q25	Q50	Q75	Q90
ELEC_ACCESS	0.015*** (0.004)	0.012*** (0.003)	0.009*** (0.002)	0.007*** (0.002)	0.005** (0.002)
CLEAN_COOK	0.019*** (0.005)	0.016*** (0.004)	0.012*** (0.003)	0.009*** (0.003)	0.006** (0.003)
NON_RENEW_URBAN	0.00024*** (0.00006)	0.00026*** (0.00005)	0.00028*** (0.00005)	0.00030*** (0.00006)	0.00031*** (0.00007)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	521	521	521	521	521
Pseudo R-squared	0.815	0.842	0.868	0.881	0.890

Panel quantile regression with fixed effects. Bootstrapped standard errors in parentheses. Full set of controls included. ***P<0.01, **P<0.05, *P<0.1

decoupling of this relationship within our sample period; richer countries in our sample tend to have higher, not lower, per capita urban non-renewable consumption, suggesting that most of these economies have not yet reached the downward-sloping portion of a potential Environmental Kuznets Curve for energy intensity.

Finally, the heterogeneity analysis provides crucial context. The finding that the marginal impact of improving basic access to electricity and clean cooking is greatest for the poorest countries is a powerful validation of energy access as a core anti-poverty strategy. For these nations, energy is a transformative input that can unlock a cascade of development benefits. For more advanced economies, the challenge shifts from basic access to managing the quality, reliability, and sustainability of energy consumption.

6. CONCLUSION AND POLICY IMPLICATION

This study has provided a comprehensive, disaggregated empirical analysis of the impact of energy poverty on economic development across 23 Asian economies from 2000 to 2022. By moving beyond a monolithic conception of energy poverty and instead examining the distinct impacts of electricity access, clean cooking access, and urban non-renewable energy consumption, our analysis reveals a more complex, nuanced, and policy-relevant picture of the energy-development nexus.

The empirical results demonstrate robustly that all three dimensions of energy are critical drivers of economic growth. However, they operate through different channels and carry different implications. The economic benefits of electrification and urban energy consumption are transmitted primarily through direct productivity enhancements in the formal economy. In contrast, the equally large, if not larger, economic dividend from providing access to clean cooking fuels is realized through profound improvements in public health, and human capital formation.

Our findings highlight a critical and economically inefficient policy divergence in many Asian nations: a rapid and successful push for electrification has not been matched by a commensurate effort to eradicate the use of polluting and time-consuming traditional cooking fuels. This neglect of the household energy sector imposes a significant, often unseen, drag on development by perpetuating poor health and limiting the economic potential of women. Furthermore, the analysis of urban energy consumption reveals the inherent tension in Asia's dominant development model, where short-term growth is fueled by a reliance on non-renewable energy sources that pose long-term sustainability challenges.

These findings generate clear and actionable policy imperatives for Asian governments and their development partners.

Prioritize clean cooking with a dual-track approach: The policy focus must shift from an overwhelming emphasis on electrification to a balanced, dual-track strategy that gives equal. This requires a multi-pronged approach, including targeted subsidies for cleaner fuels like LPG, support for the adoption of electric cookstoves, and investment in robust supply and distribution chains to ensure these solutions are both available and affordable for the poor.

Strengthening financial inclusion for energy access: The high upfront cost of modern energy appliances and grid connections is a major barrier for low-income households. Governments and financial institutions should promote and scale up financial instruments like microcredit and pay-as-you-go models to help the poor overcome this hurdle.

Foster regional energy cooperation and trade: For many countries, energy security and affordability can be enhanced through regional integration. Developing cross-border power grids, particularly in regions like South Asia and Central Asia, can help balance supply and demand, reduce system-wide costs, and facilitate the integration of variable renewable energy sources, ultimately benefiting all participating economies.

Invest in a just and efficient energy transition: As Asia's energy demand continues to surge, scaling up renewable generation is imperative. However, this must be accompanied by massive investments in grid modernization, energy storage, and energy efficiency measures to manage demand growth effectively and avoid creating new infrastructure bottlenecks. A just transition ensures that the benefits of clean energy are shared equitably and that vulnerable communities are not left behind. This transition is not only an environmental imperative but also an economic one, as the results show that reducing the dependency on non-renewable energy sources can directly contribute to higher growth.

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