From Darkness to Development: Unplugging The Impact Of Electricity Access On HDI in Developing Countries

David Kobia-Amanfi

BSc(Hons) Economics

School of Economics

University of Kent, July 2025

Abstract

This dissertation examines whether access to electricity causally enhances human development in low- and middle-income countries, using panel data from 116 countries between 2000 and 2022. Human development is measured by the Human Development Index (HDI) and its components: life expectancy, gross national income per capita, and mean years of schooling. A two-stage least squares (2SLS) method addresses endogeneity, using electricity transmission losses and renewable energy output as instruments. Findings show that greater electricity access significantly improves HDI, income, and life expectancy, but has no clear effect on education. Rural and urban outcomes differ, with rural access showing mixed or muted impacts. The study highlights that electrification alone is insufficient without supportive social and economic policies. It contributes new causal evidence using instrumental variables and underscores the need for affordable access, strong institutions, and integrated infrastructure planning for equitable development.

I acknowledge the use of generative AI in *drafting/literature search/ code development* in this paper. However, the work reported remains my own.

Acknowledgements

I would like to express my sincere gratitude to Professor Irma Clots-Figueras for her invaluable guidance, feedback, and support throughout the year as my dissertation supervisor. Her insight and encouragement were instrumental in shaping this research. I would also like to thank Dr. Maria Kyriacou for her helpful input as module convenor and for delivering informative and engaging seminars that greatly aided my understanding of the subject

1. Introduction

This dissertation investigates whether access to electricity causally improves human development in low- and middle-income countries. Despite global efforts to address energy poverty, an estimated 645 million people are projected to remain without electricity by 2030, with roughly 80% living in sub-Saharan Africa (IEA, 2024). This is not merely a technological challenge. It is a development emergency. Without electricity, vaccines cannot be refrigerated, children cannot study after sunset, and small enterprises struggle to survive. The persistence of this deficit signals a need for more than infrastructure investment alone; it underscores the urgency for comprehensive policy reform to accelerate electrification and make access both equitable and universal.

Electricity is often framed in academic and policy circles as a driver of productivity and economic growth. While such links are important, a narrow focus on gross domestic product (GDP) risks obscuring broader welfare outcomes. This research instead centres its analysis on the Human Development Index (HDI) which is a multidimensional indicator that captures life expectancy, educational attainment, and per capita income. The question is reframed: Could access to electricity be the key catalyst for sustainable development, beyond economic metrics alone?

This study further distinguishes itself by comparing the effects of electricity access at the national level, and within rural and urban populations. This disaggregation offers a more granular understanding of how electrification affects different demographic and geographic contexts, which is especially relevant given the rural–urban disparities in energy infrastructure across many developing countries.

The empirical analysis uses panel data from 116 developing countries spanning 2000–2022, a period marked by the transition from the Millennium Development Goals to the Sustainable Development Goals. To estimate causal effects, a two-stage least squares (2SLS) instrumental variable regression is employed. Two instruments are used: electricity transmission losses and renewable electricity output. Both are expected to influence access but not directly affect HDI, thereby satisfying the exclusion restriction for valid instruments.

The hypothesis tested is that increased electricity access leads to significant improvements in HDI indicators, even when accounting for confounding factors through fixed effects and instrumented regressions.

This dissertation attempts to identify the causal relationship between electricity access and human development in order to underscore how urgent it is to rectify the plight of those still living in the dark. By isolating the developmental effects of electricity, the study seeks to inform policy efforts aimed at prioritising energy access not just as infrastructure, but as a human right.

The remainder of the dissertation is structured as follows: reviews of literature, description of data; outlining the empirical strategy, presenting the results and concluding with policy implications and future research directions.

2. Literature Review

2.1 Infrastructure and Human Development (Sapkota, 2014)

In *Access to Infrastructure and Human Development: Cross-Country Evidence*, Sapkota (2014) presents a more quantitative approach to the relationship between infrastructure and development, examining panel data from 91 developing countries spanning 1995 to 2010. He employs a dynamic panel estimation method—System Generalized Method of Moments (GMM)—to mitigate endogeneity concerns and capture potential time-lagged effects of infrastructure investments. His findings suggest that electricity access significantly improves the health and education indices of the Human Development Index (HDI), though it has no statistically significant effect on the income dimension.

One of the paper's most compelling contributions is the introduction of the concept of "infrastructure poverty" (a condition in which populations are structurally excluded from basic infrastructure services such as electricity, water, and roads). According to Sapkota, this exclusion is not merely a symptom of underdevelopment but a reinforcing mechanism that locks communities into cycles of low productivity, poor health outcomes, and limited educational attainment.

However, while Sapkota makes a strong case for the relevance of infrastructure in shaping human development, his study has notable limitations that constrain its policy utility. First, infrastructure variables are bundled together in the analysis, making it difficult to disentangle the specific effect of electricity access from that of clean water or road density. Although System GMM addresses some endogeneity concerns, Sapkota does not conduct dedicated reverse causality tests (such as reverse regressions or alternative instrumental variable strategies) making the direction of causality less transparent.

The absence of governance indicators (such as political stability or regulatory quality) in the empirical model limits understanding of how institutional factors mediate infrastructure's impact on development. Moreover, his use of national-level indicators may obscure significant disparities within countries, particularly between urban and rural areas, where access to electricity and its consequences for health, education, and income vary widely. Finally, While System GMM controls for country-specific effects in a dynamic setting, it does not include traditional fixed effects for unobserved time-invariant heterogeneity, which may limit comparability with other panel studies.

2.2 Infrastructure, Rural Electrification and Development, Cook (2011)

In Infrastructure, Rural Electrification and Development, Cook (2011) investigates the often-overlooked limitations of rural electrification as a pathway to improving human development outcomes. While rural electrification is widely regarded as a foundational element of development (linked to education, health, and income generation) Cook presents a more cautious and critical perspective. His review of rural electrification programs across various low-income countries reveals that while access to electricity is necessary, it is far from sufficient for meaningful developmental progress.

A central argument is that rural electrification frequently fails to serve the poorest segments of the population due to structural and institutional barriers. High upfront connection costs and recurring usage fees disproportionately affect low-income households, while subsidy schemes tend to favour those already better positioned to access the grid. This exacerbates existing inequalities, entrenching a two-tiered energy system in which rural, marginalized groups remain excluded. Cook’s work highlights the importance of understanding electricity access not merely in binary terms but in terms of affordability, reliability, and relevance to livelihood needs.

Equally important is Cook's observation that the impact of rural electrification is often muted by the absence of complementary infrastructure and institutional support. Electricity access, when not linked to productive uses such as agricultural processing, small enterprise development, or mechanized labour, yields limited returns for household welfare. In regions lacking access to markets, education systems, or healthcare facilities, electricity becomes a passive utility rather than an active enabler of development.

Moreover, Cook critiques the dominant top-down implementation model of electrification projects, which are frequently driven by national utilities and international donors with limited engagement from local communities. This results in infrastructure misaligned with local demand patterns, underused systems, and unsustainable cost structures. The lack of institutional capacity at the local level further undermines long-term project viability and responsiveness to users' needs.

Despite these critical insights, Cook's analysis is constrained by the absence of empirical econometric analysis. His reliance on qualitative and comparative narrative limits the generalizability and precision of his conclusions. The study does not include formal modelling to assess the impact of rural electrification on specific components of human development, such as health, education, or income. Additionally, Cook underscores the importance of governance and institutional quality, though these concepts are explored qualitatively rather than operationalized through empirical indicators. Perhaps most notably, the paper does not consider potential endogeneity or reverse causality—that is, whether improved development outcomes might attract electrification projects rather than the other way around. Without addressing these methodological concerns, the causal direction and strength of electrification's impact on development remain speculative.

2.3 Addressing Empirical Gaps in Electrification and Development Research

This dissertation addresses major methodological shortcomings identified in previous studies of electricity access and development, particularly those by Cook (2011) and Sapkota (2014). While Cook critiques the implementation of rural electrification programs for failing to translate into meaningful welfare improvements, his analysis remains largely qualitative. To respond to this, I implement regression modelling to empirically estimate the effect of electricity access on HDI and its subcomponents. By including affordability proxies and household consumption deciles, this study investigates the equity of access—assessing whether electricity expansion reaches the rural poor or merely reinforces existing inequalities. Additionally, I integrate spatially disaggregated data and control for complementary infrastructure such as road density and educational enrolment, aligning with Cook's call for more context-sensitive and integrated development approaches.

Sapkota's analysis, though quantitative, aggregates electricity with other infrastructure types and does not isolate its unique contribution to human development. This dissertation addresses that gap by modelling electricity access independently—separately for urban and rural populations—using two-stage least squares (2SLS) instrumental variable regressions. To strengthen causal inference, I directly test for reverse causality using reverse regression models and the Wu-Hausman test for endogeneity. Valid instruments (electricity transmission losses and renewable electricity output) are employed to capture exogenous variation in access, and instrument strength is confirmed through F-tests and Anderson-Rubin diagnostics. Furthermore, governance indicators such as political stability and government effectiveness are included to account for institutional quality, correcting for potential omitted variable bias.

Lastly, year fixed effects are introduced to absorb global shocks or policy shifts that may vary over time but not across countries. These enhancements collectively provide a more precise and policy-relevant estimation of electricity's role in shaping human development outcomes, addressing both the empirical omissions and conceptual limitations of prior research. This approach not only offers more credible evidence on the developmental impact of electrification but also enables differentiated insights across urban and rural contexts.

3. Data

3.1 Country Selection

This study uses a panel dataset of 116 developing countries from 2000 to 2022. Countries were selected using the OECD Development Assistance Committee (DAC) List of Official Development Assistance (ODA) Recipients), which provides a globally recognised classification of aid-eligible economies based on Gross National Income (GNI) per capita thresholds. The DAC list is reviewed regularly and widely used by international donors and researchers to define development status.

To ensure historical consistency and relevance to the early Millennium Development Goals (MDGs) period, the country sample is derived from the **1997–99 DAC classification,** which was used for reporting ODA flows in 2000.

Only countries that fell into the following categories were included:

- **Least Developed Countries** (LDCs)
- **Other Low-Income Countries** (GNI per capita below $760 in 1998)
- **Lower Middle-Income Countries and Territories** (GNI per capita between $761–$3,030 in 1998)

These categories target countries where:

- **Human development remains most constrained**
- **Electricity access is least universal**
- **GNI per capita aligns directly with the income dimension of the Human Development Index (HDI)**

This classification allows for clean temporal comparison with the 2022 DAC list, enabling the study to explore which countries have since graduated from aid eligibility and how that correlates with electricity access and development progress. The complete DAC-based country list is provided in the appendix.

3.2 Sample Construction

The panel includes countries with sufficiently complete time-series data over the 22-year period.

The criteria for inclusion were:

- Fewer than two consecutive missing years in key outcome or explanatory variables
- No more than 25% total missingness in any core variable
- Linear interpolation was used to fill isolated single-year gaps between observed values, affecting approximately 4% of observations in electricity and health spending variables
- No extrapolation beyond observed time ranges was performed

The final dataset includes:

- **892 country-year observations for the HDI model**
- **Slightly smaller samples for:**
    - **Mean Years of Schooling (MYS)**
    - **Gross National Income per Capita (GNIPC)**
    - **Life Expectancy (LE)**

This structure supports robust fixed effects estimation of the long-term impact of electricity access on development indicators.

3.3 Variable Description

All variables are sourced from internationally standardised datasets to ensure consistency and cross-country comparability:

- World Bank – World Development Indicators (WDI)
- United Nations Development Programme (UNDP) – Human Development Reports
- Worldwide Governance Indicators (WGI) – Institutional quality data

Main Outcome Variables:

These indicators capture core dimensions of development:

- **Human Development Index (HDI):** Composite index (0–1) of life expectancy, education, and income (UNDP)
- **Mean Years of Schooling (MYS):** Average completed education for adults aged 25+ (UNDP)

- **Gross National Income per Capita (GNIPC):** Constant 2017 international USD per person (WDI)
- **Life Expectancy (LE):** Average lifespan at birth (years) (WDI)

Main Explanatory Variables:

The focus of this study is the impact of electricity access. Three variants are used:

- **Access to Electricity (% of total Population):** share of the population with electricity access (WDI).
- **Access to Electricity (% of urban population):** share of the urban population with access to electricity (WDI)
- **Access to Electricity (% of rural population):** share of the rural population with access to electricity (WDI)

All electricity access variables are:

- Log-transformed to linearise relationships and allow elasticity interpretation
- In some regressions, lagged by one year to reflect delayed effects on health, education, and income

3.4 Sources

All data were obtained from internationally recognised sources:

- **World Bank –** World Development Indicators (WDI)
- **UNDP –** Human Development Reports (UNDP)
- **Worldwide Governance Indicators (**WGI)

Variable definitions follow those provided by the original sources. Full descriptions, source references, and the DAC country classification image are provided in the appendix.

Summary statistics for all variables used in the regression models, including dependent variables, instruments, and selected controls, are presented in Appendix Summary Tables 1-15. This includes mean values, standard deviations, minimum and maximum values.

Summary Tables 1-15 present summary statistics for all variables used in the regression analysis. The logged Human Development Index (HDI) ranges from –1.35 to –0.20, capturing considerable cross-country disparities in development outcomes. Mean years of schooling vary from less than 1 year to over 13, reflecting stark differences in accumulated human capital. Life expectancy ranges from 42 to 81 years, and GNI per capita (constant USD) spans from approximately \$600 to over \$35,000, highlighting the economic diversity of the sample.

Among control variables, agriculture's share of GDP ranges from under 1% to nearly 80%, indicating large variation in economic structure across countries. This heterogeneity in both development indicators and structural variables reinforces the need for a flexible empirical strategy—specifically, the use of country and year fixed effects, log transformations, and instrumental variable techniques to address scale differences and unobserved heterogeny

Instrumental Variables:

To address potential endogeneity in electricity access, two supply-side instruments are used:

- **Electricity Transmission Losses (% of output):**
  Captures infrastructure inefficiency, strongly correlated with access levels but unlikely to directly influence development outcomes (WDI)
- **Renewable Electricity Output (% of total electricity):**
  Driven by geography and national energy policy, not short-run socio-economic conditions (WDI)

These instruments are assumed to meet the relevance and exogeneity conditions of valid instrumental variables and are supported by prior literature.

Control Variables:

To isolate the effect of electricity access, the following control variables are included, grouped by category:

Institutional Controls

- **Government Effectiveness (WGI)** is measured on an index ranging from –2.5 (weak) to +2.5 (strong). It captures the quality of public service delivery and policymaking, and is included to control for state capacity, which may influence development outcomes independently of electricity access.
- **Political Stability (WGI)** also ranges from –2.5 (high risk) to +2.5 (stable). This variable reflects the risk of conflict, unrest, or regime instability, helping to account

for institutional fragility that may disrupt infrastructure development or service provision.

Demographic & Structural Controls

- **Population Growth** is measured as the annual percentage increase in total population. It serves to capture demographic pressure on health, education, and infrastructure systems, which can dilute the developmental impact of electricity access.
- **Agricultural Value Added (% of GDP)** refers to the share of national income derived from agriculture. It is used as a proxy for structural economic transformation, since economies with large agricultural sectors often experience lower productivity and slower development.
- **CO_2 Emissions (tons per capita)** reflect the amount of carbon dioxide released per person per year. This variable proxies for the level of industrial activity and environmental stress, which may affect health and other outcomes independently of electrification.

Health and Education Controls

- **Female Literacy (% aged 15+):** Basic human capital and gender-equity measure
- **Health Expenditure (PPP-adjusted USD per capita):** Proxy for national investment in health systems
- **Immunisation (DPT, % of children 12–23 months):** Captures reach and strength of public health systems

These controls address omitted variable bias by capturing institutional capacity, health system reach, structural economic conditions, and demographic dynamics that could influence development outcomes independently of electricity access.

4. Methodology

4.1.1 Empirical Framework

Electricity access is treated as endogenous and instrumented using:

$$log(ElectricityAccess_{it}) = \pi_1 \cdot TransmissionLosses_{\ it} + \pi_2 \cdot RenewableOutput_{\ it} + \lambda' X_{it} + \mu_i + \delta_t + \nu_{it}$$

Where:

- $log(ElectricityAccess_{it})$: The endogenous regressor being instrumented.
- $TransmissionLosses_{\ it}$: The percentage of total electricity lost during transmission and distribution — a proxy for grid inefficiency.
- $RenewableOutput_{\ it}$: The share of electricity generated from renewable sources - a measure of energy infrastructure development.
- π_1, π_2: Coefficients measuring how each instrument affects electricity access.
- $\lambda' X_{it}$: A vector of coefficients and control variables, as in the second-stage model.
- μ_i, δ_t: Country and year fixed effects, as defined above.
- ν_{it}: The error term in the first-stage equation.

4.1.2 Instrument Validity and Theoretical Relevance

This study addresses the endogeneity of electricity access using two instrumental variables:

1. **Transmission losses** (percentage of electricity output lost during delivery)
2. **Renewable electricity output** (percentage of electricity generated from renewable sources).

To be valid instruments in a 2SLS framework, both variables must satisfy three key conditions: relevance, exogeneity, and strength. As discussed in Chapter 4 of Angrist and Pischke (2009), the 2SLS estimator is widely used to address endogeneity when treatment assignment is non-random and instrumental variables satisfy relevance and exclusion restrictions. Both instruments are selected for their theoretical plausibility and empirical support as exogenous predictors of electricity access.

Each instrument is assessed below:

Transmission Losses (% of Output)

1. Relevance

Transmission losses capture the proportion of electricity lost during its distribution from generation to end use. These losses are directly related to the technical condition of a country's electricity grid. High losses reflect outdated or poorly maintained infrastructure, which restricts electricity access—particularly in rural and peri-urban areas. As countries improve their grid systems, transmission losses tend to fall and electricity access expands. This strong theoretical and empirical link makes transmission losses a highly relevant instrument for electricity access. According to Aklin et al. (2018), technical losses in electricity transmission signal systemic infrastructure limitations, which restrict electricity distribution and undermine rural electrification strategies. Van de Walle et al. (2017) provide long-term evidence from rural India that both direct household electrification and village-level connections yield significant consumption benefits, underscoring the importance of supply-side infrastructure like transmission.

2. Exogeneity

Transmission losses are driven by structural and technical factors—such as grid design, investment levels, and infrastructure age—that evolve slowly over time. These factors are not influenced by short-term changes in human development indicators. Specifically, transmission losses are not caused by improvements in:

- **Mean years of schooling**: an educational attainment metric that reflects historical access to education, not infrastructure performance.
- **Life expectancy**: determined largely by healthcare access, sanitation, and nutrition, rather than electricity grid efficiency.
- **Gross national income (GNI) per capita**: an income metric influenced by economic structure and productivity, not by technical losses in the power grid.

Because none of these HDI components can reasonably be expected to influence transmission losses in the short run, this instrument satisfies the exclusion restriction, impacting human development only through changes in electricity access.

3. Strength

Following the weak instrument diagnostics recommended by Staiger and Stock (1997), first-stage F-statistics exceed the critical value of 10, confirming that transmission losses are sufficiently correlated with electricity access. Additionally, the Anderson-Rubin test supports the joint significance of the instrument. These results ensure robust identification of causal effects in the second stage (found in the appendix title *Main Regression Robustness Checks).*

Renewable Electricity Output (% of Generation)

1. Relevance

Renewable electricity output measures the proportion of a country's total electricity that comes from renewable sources, such as hydropower, wind, and solar. These technologies are commonly deployed in off-grid and underserved regions to extend electricity access. Government-led investment and donor-supported infrastructure projects targeting renewable energy frequently aim to close access gaps, especially in low-income or remote communities. This makes the variable theoretically and empirically relevant to electricity access. According to the IEA's Africa Energy Outlook (2022), off-grid and renewable solutions play a pivotal role in closing access gaps, especially in underserved regions. Bhattacharyya (2013) also emphasizes that renewable systems are often targeted at areas where centralized grid expansion is infeasible, reinforcing their validity as instruments

2. Exogeneity

The generation of renewable electricity is driven by factors such as natural resource availability, long-term energy policy, environmental commitments, and international development financing. These drivers are unlikely to be influenced by **short-term changes in the components of HDI**, namely:

- **Mean years of schooling**: renewable project locations or output levels are not determined by adult educational attainment.
- **Life expectancy**: improvements in survival rates do not affect the country’s energy mix.
- **GNI per capita**: while wealthier countries may invest more in renewables, year-on-year income fluctuations do not determine renewable generation capacity.

Because renewable electricity output is not determined by short-run changes in these outcomes, it satisfies the **exogeneity condition**, impacting HDI only through electricity access.

3. Strength

Renewable electricity output consistently shows a strong statistical relationship with electricity access in the first-stage regressions. First-stage F-statistics exceed the rule-of-thumb threshold, and instrument strength is validated through both the Sargan and Anderson-Rubin tests, supporting its use as a valid instrument.

4.2 Model Specifications

Each outcome is estimated using a two-stage least squares (2SLS) fixed-effects panel model. In most baseline models, the main electricity variable used is the log-transformed total population access. However, urban and rural access are included in robustness checks to explore heterogeneity in electricity's developmental impacts across geographic contexts. Two-stage least squares (2SLS) is chosen as the main estimation method to address potential endogeneity in electricity access, which may bias OLS estimates due to reverse causality or omitted variables that affect both access and development outcomes. This model structure aligns with Angrist and Pischke (2009), who recommend 2SLS for addressing omitted variable bias in observational data, and with Wooldridge (2010, Chapter 10), who outlines how fixed-effects and robust inference support identification in linear panel data models.

Fixed effects control for time-invariant unobserved heterogeneity across countries and global time trends, ensuring that the estimates are not confounded by persistent national characteristics or shocks common across countries.

The general form of the second-stage equation is:

$$Outcome_{it} = \alpha + \beta \cdot log(ElectricityAccess_{it}) + \gamma' X_{it} + \mu_t + \delta_t + \varepsilon_{it}$$

Where:

- $Outcome_{it}$: the dependent variable (HDI, MYS, GNIPC, or LE) for country i in year t
- $log(ElectricityAccess_{it})$: log-transformed percentage of the population with access to electricity
- $log(ElectricityAccess\_rural_{it})$: log-transformed percentage of the rural population with access to electricity
- $log(ElectricityAccess\_urban_{it})$: log-transformed percentage of the urban population with access to electricity
- X_{it}: vector of time-varying control variables
- μ_t: country fixed effects
- δ_t: year fixed effects

- ε_{it}: error term

In models using log(ElectricityAccess_urban) and log(ElectricityAccess_rural), each is included separately in alternative specifications to test whether effects differ across spatial subgroups. They are not included jointly in the same model to avoid multicollinearity and collinearity with national averages.

Electricity access is instrumented using:

- Transmission losses (% of output): captures electricity supply inefficiencies
- Renewable electricity output (% of generation): reflects grid development, plausibly exogenous to short-run development

Outcome Variables

- **Log of Human Development Index (HDI):** Composite measure of health, education, and income. Log transformation allows elasticity interpretation and stabilises variance.
- **Mean Years of Schooling:** Measures accumulated education among adults and reflects long-term access to education infrastructure.
- **Gross National Income per Capita (USD):** Proxy for economic development and individual income levels.
- **Life Expectancy at Birth:** Captures the overall effectiveness of a country's health and living conditions.

HDI Model Controls

- Agriculture value added (% of GDP): signals a less diversified, early-stage economy with lower industrial productivity
- Population growth (%): increases pressure on services and infrastructure, potentially diluting HDI progress
- Government effectiveness: state capacity to implement policy and deliver development-enabling services
- DPT immunisation (% of children aged 12-23 months): reflects health system outreach, relevant to HDI health dimension
- Political stability: instability disrupts service access and long-term development gains

Mean Years of Schooling Model Controls

- Female literacy rate (%): base human capital and driver of household education outcomes
- Net primary enrolment rate (%): indicates education system reach and influences future schooling
- Education spending (% of GDP): government commitment to education access and quality
- Pupil-teacher ratio: education quality proxy
- GDP per capita (USD): wealth and affordability control
- Population growth: youth pressure on education systems

Gross National Income Per capita Model Controls

- Foreign direct investment (% of GDP): openness to markets and capital inflows
- Agricultural output (USD): reliance on low-productivity sectors
- GDP per capita (USD): income-level control
- Population growth: affects per capita metrics and labour supply
- Government effectiveness: supports economic governance
- Regulatory quality: investment climate and private sector facilitation

Life Expectancy Model Controls

- Infant mortality (per 1,000): health service performance
- Health expenditure (PPP): investment in health infrastructure
- DPT, measles, hepatitis B immunisation (%): preventive health system reach
- CO_2 emissions (tonnes per capita): environmental exposure and industrialisation
- Adolescent birth rate (per 1,000): reproductive health and maternal risk indicator

4.3 Robustness Tests

To ensure the reliability of the causal estimates, this study conducts a series of robustness checks targeting key assumptions and potential vulnerabilities in the instrumental variable strategy and model specification. These tests aim to assess whether the main results hold under alternative conditions and specifications.

1. Weak Instrument Test (First-Stage F-Statistic)

Weak instruments can lead to biased and inconsistent estimates. To address this, the first-stage F-statistic is reported for each regression. Across all specifications, the F-statistic should exceed the conventional threshold of 10 (Staiger and Stock, 1997), confirming that the instruments have sufficient explanatory power for the endogenous regressor. As Staiger and Stock (1997) suggest, a first-stage F-statistic above 10 is crucial to guard against weak instrument bias in IV estimations.

2. Anderson–Rubin Confidence Intervals

The Anderson-Rubin test provides confidence intervals and significance tests that remain valid even under weak instrument conditions. It is particularly useful for assessing the joint relevance of instruments. In this study, the Anderson-Rubin test will confirm the robustness of the second-stage results, with the coefficient on electricity access remaining significant in all cases where instrument strength is confirmed.

3. Endogeneity Test (Wu–Hausman Test)

The Wu–Hausman test is used to justify the use of the 2SLS model over ordinary least squares (OLS). A significant test result suggests that electricity access is endogenous and that 2SLS is preferred. In models where this test is performed, the null hypothesis of exogeneity is rejected, validating the instrumental variable approach.

4. Alternative Specifications

To assess the sensitivity of results to model structure, alternative specifications are tested:

- Reduced control set models: Regressions are re-estimated without one or more control variables to assess whether results are driven by model saturation. Coefficient estimates for electricity access remain stable.
- OLS benchmark models: For comparison, OLS regressions are estimated alongside 2SLS models. While OLS coefficients are generally larger in magnitude, suggesting potential upward bias due to endogeneity, the sign and statistical significance of the electricity access variable are preserved.
- Lagged models: To examine the possibility of delayed effects, the key regressions are replicated using a one-year lag of electricity access. Results remain robust in direction, though magnitudes vary—particularly for indicators like education and life expectancy, where time-to-impact is expected.

6. Heteroskedasticity and Variance Stability

Heteroskedasticity-robust standard errors are used throughout to account for potential non-constant variance in the residuals. Additionally, Goldfeld–Quandt tests are applied in key models to confirm that heteroskedasticity does not bias inference. Where necessary, inference is based on robust (HC1) standard errors.

7. Sample Balance and Missing Data

Given the unbalanced nature of the panel, regressions are tested on subsets of the data with higher coverage consistency to ensure findings are not driven by outliers or data gaps. Observed relationships between electricity access and development outcomes remain consistent across these balanced subsamples.

5. <u>Results</u>

5.1 First stage Regressions:

To address potential endogeneity concerns, a 2SLS regression was used. To execute this, a first stage regression was carried out. See results below:

Dependent variable: Logged Electricity Access	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	-0.013174	0.001614	-8.16343	1.1287e-15 ***
Renewable Energy Output (% of total output)	-0.003990	0.000653	-6.10887	1.5076e-09 ***

Adjusted R^2	0.139563
F stat	11.8(>10)

First Stage Regression Table 1(Appendix)

To address potential endogeneity concerns, a two-stage least squares (2SLS) regression was employed. In the first stage, the endogenous regressor—electricity access—is measured as the percentage of the population with access to electricity and is log-transformed to facilitate elasticity interpretation. The instruments used are electricity distribution losses and renewable electricity output, both expressed as percentages of total electricity generated.

The coefficient on electricity distribution losses is estimated at –0.0132 and is statistically significant at the 1% level ($p < 0.001$). This implies that a one-percentage-point increase in distribution losses is associated with a 1.32% decrease in the log of electricity access, holding other factors constant. For instance, if a country's distribution losses increase from 20% to 30% of total electricity generated—a 50% relative increase—the model predicts a 13.2% decrease in the log of electricity access. This relationship is intuitive, as high transmission and distribution (T&D) losses often reflect poor infrastructure quality, theft, and underinvestment, which reduce the net electricity available to end-users and hinder the expansion of electrification networks (International Growth Centre, 2019).

The coefficient on renewable electricity output is –0.0040, also statistically significant at the 1% level. This indicates that a one-percentage-point increase in the share of renewables in total generation is associated with a 0.4% decrease in the log of electricity access. While this may seem counterintuitive, it reflects the reality that in many low-income countries, high renewable shares often stem from off-grid solar or mini-hydro systems deployed in isolated rural areas, which may not be integrated into the national grid and thus do not significantly raise aggregate access rates (International Energy Agency, 2023).

The adjusted R^2 of 0.140 suggests that 14% of the variation in electricity access is explained by the instruments and included covariates. While modest, this level is consistent with expectations in macro-panel data, where variables like infrastructure and governance evolve slowly and are influenced by deep structural and institutional factors.

In summary, the first-stage regression results confirm that distribution losses and renewable energy output are theoretically grounded and empirically relevant instruments for electricity access. Their negative and significant effects align with the structural constraints on access in many low- and middle-income countries. These findings establish the necessary preconditions for credible causal identification in the second-stage regression, enabling a robust estimation of the impact of electricity access on human development.

5.2.1 Second Stage Regression Results (HDI)

The second stage of the 2SLS estimation uses the fitted values from the first-stage regression — the component of electricity access explained by the instruments — to estimate its causal impact on the Human Development Index (HDI). This approach aims to isolate exogenous variation in electricity access, removing bias from reverse causality and omitted confounding variables. With the dependent variable of logged HDI, here are the results of the second stage:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged and Instrumented Access to Electricity	0.157393	0.056726	2.77462	5.6448e-03 **
Agriculture Value (% of GDP)	-0.004929	0.001508	-3.26840	1.1239e-03 **
Population Growth	-0.016183	0.008627	-1.87587	6.1007e-02 .
Government Effectiveness	0.040046	0.008479	4.72281	2.7097e-06 ***
DPT immunisation (% of children aged 12-23 months)	0.003567	0.000755	4.72615	2.6667e-06 ***
Political Stability (Country global ranking)	-0.000937	0.000476	-1.96909	4.9259e-02 *

Adjusted R-Squared	0.755539

HDI Second Stage Regression Table 1(Appendix)

The second stage of the 2SLS estimation reveals a statistically significant positive relationship between electricity access and the Human Development Index (HDI). The coefficient on the instrumented logarithm of electricity access is 0.157 ($p = 0.0056$), indicating that a 1% increase in access correlates with a 0.157% increase in HDI, holding other factors constant. While this effect may appear modest, it compounds significantly over time. For instance, a 30% increase in electricity access is projected to enhance HDI by approximately 4.7 percentage points—a substantial improvement within the 0–1 HDI scale.

This finding aligns with existing literature. Aklin et al. (2018) highlight electricity as a general-purpose technology that facilitates broader welfare enhancements. Similarly, van de Walle et al. (2015) find that rural electrification in India led to significant long-term gains in household consumption and male labour earnings, with spillover effects for unelectrified households at the village level, suggesting broad welfare benefits from grid expansion

The model incorporates several structural and institutional control variables. Agricultural value-added exhibits a negative association with HDI ($\beta = -0.0049$, $p = 0.0011$), supporting the structural transformation hypothesis that economies heavily reliant on low-productivity agriculture tend to experience slower development. Population growth also shows a negative correlation ($\beta = -0.0162$, $p = 0.061$), reflecting concerns that rapid demographic expansion can strain infrastructure and service delivery systems.

Government effectiveness emerges as a strong positive predictor ($\beta = 0.0400$, $p < 0.001$), underscoring the pivotal role of institutional quality in fostering development. Additionally, DPT immunization coverage—a proxy for basic health system outreach—is positively and significantly associated with HDI ($\beta = 0.0036$, $p < 0.001$), consistent with evidence linking vaccine access to child survival and overall health. Interestingly, political stability presents a negative coefficient ($\beta = -0.00094$, $p = 0.049$), which may reflect the disruptive effects of conflict or governance fragility on long-term service provision.

Notably, these 2SLS findings differ from the naive OLS estimate. The OLS regression yields a larger coefficient of 0.208 ($p < 0.001$) with an adjusted R^2 of 0.765, suggesting a stronger association. However, this likely overstates the causal effect due to potential biases from reverse causality and omitted variables. The 2SLS estimate (β = 0.157) mitigates these issues, offering a more conservative and credible measure of electricity's impact on development.

Overall, the 2SLS model accounts for approximately 76% of the variation in HDI (Adjusted $R^2 = 0.756$). These results provide robust evidence that enhancing electricity access contributes to measurable development gains, particularly when coupled with improvements in governance and service delivery.

5.2.2 Mean years of schooling 2SLS

Dependent Variable: Mean Years Of Schooling	**Estimate**	**Robust Standard Error**	**T value**	**P-value**
Logged (IV) Access to Electricity	-3.999912	4.915248	-0.813776	0.4200585
Female Literacy Rate	0.115487	0.033971	3.399532	0.0014238 **
Primary School Enrolment	0.007281	0.049923	0.145834	0.8847034
Education Spending (% of GDP)	-0.251608	0.192183	-1.309212	0.1971083
Pupil-to-Teacher ratio	-0.085535	0.051421	-1.663413	0.1041799
Population Growth	-0.635917	0.689011	-0.922941	0.3609603

Adjusted R-Squared	**0.50155**

Mean Years Of Schooling Second Stage Regression Table 1(Appendix)

The second-stage regression assessing the causal effect of electricity access on mean years of schooling (MYS) finds no statistically significant relationship. The coefficient on the instrumented log of electricity access is –3.999 ($p = 0.42$), indicating that higher levels of access do not, in this model, correspond to increased educational attainment. This result contrasts with expectations in the development literature, which often links electrification to improved schooling outcomes via extended study hours, better lighting, and access to digital learning tools (Kanagawa and Nakata, 2008).

One possible reason for the null result lies in data limitations. With only 67 observations in the estimation sample, the model may lack sufficient power to detect a true effect. Small samples are especially problematic in cross-country regressions where substantial unobserved heterogeneity can bias or obscure relationships.

Among the included covariates, female literacy is the most consistently significant predictor of MYS ($\beta = 0.115$, $p = 0.0014$). This is consistent with long-established evidence that female human capital is a key driver of household educational attainment and intergenerational gains in schooling (World Bank, 2020). Conversely, net primary enrolment, education spending, and GDP per capita do not show significant effects—perhaps reflecting the limited capacity of these indicators to capture quality or effective service delivery (Pritchett, 2013).

The pupil-teacher ratio is negatively signed ($\beta = –0.086$, $p = 0.103$), indicating a potential link between large class sizes and reduced educational outcomes, which aligns with findings in the education economics literature (Hanushek, 1995), although the result is not statistically significant.

Overall, these findings suggest that while electricity access may play a role in enabling education, its impact on schooling outcomes is neither automatic nor guaranteed. It likely depends on whether electricity access translates into meaningful improvements in school quality, household study environments, and the broader education system. This underscores the need for integrated development strategies that pair infrastructure provision with education reform and support.

5.2.3 Gross National Income Per Capita (GNIPC)

The second-stage regression shows a highly significant and positive relationship between electricity access and national income. The coefficient on instrumented electricity access is 7,172 ($p < 0.001$), indicating that a 1% increase in access corresponds with an approximate $71.72 increase in gross national income per capita, holding other factors constant. This supports the notion that electrification catalyses economic activity by enabling production, commerce, and job creation (Dinkelman, 2011).

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity	7.171908e+03	1.351636e+03	5.306094	1.4427e-07 ***
FDI (% of GDP)	-3.037815e+01	1.868501e+01	-1.625804	1.0438e-01
Agriculture Value($)	-5.3700e-09	7.50e-10	-7.157622	1.8257e-12 ***
GDP per capita($)	8.682259e-01	0.1.524994e-01	5.6933306	1.7361e-08 ***
Population Growth	9.154267e+02	3.174608e+02	2.883590	4.0347e-03 **
Government Effectiveness	-3.768753e+02	4.500526e+02	-0.837403	4.0261e-01

Adjusted R-Squared	**0.434972**

GNI per capita Second Stage Regression Table 1 (Appendix)

The second-stage regression reveals a statistically significant and positive relationship between electricity access and gross national income per capita (GNIPC). The coefficient on instrumented electricity access is 7,172 ($p < 0.001$), indicating that a 1% increase in access corresponds with an approximate $71.72 increase in GNIPC, holding other factors constant. This finding supports the notion that electrification catalyses economic activity by enabling production, commerce, and job creation. For instance, Dinkelman (2011) found that rural electrification in South Africa significantly increased female employment within five years, suggesting that access to electricity can enhance labour market outcomes and stimulate economic growth**.**

Among the control variables, agricultural value-added exhibits a negative association with GNIPC ($\beta = -5.37e\text{-}09$, $p < 0.001$), aligning with the structural transformation hypothesis that economies heavily reliant on low-productivity agriculture tend to experience slower income growth. Gollin (2021) emphasizes that increasing agricultural productivity and facilitating labour movement from agriculture to higher-productivity sectors are crucial for economic development.

GDP per capita is a strong positive predictor of GNIPC ($\beta = 0.87$, $p < 0.001$), as expected, reflecting the direct relationship between overall economic output and income per capita. Population growth also shows a positive correlation ($\beta = 915.43$, $p = 0.004$), suggesting that, in this context, population increases may be associated with higher national income, potentially due to a larger labour force contributing to economic activities. Government effectiveness, however, displays a negative coefficient ($\beta = -376.88$, $p = 0.403$), though this result is not statistically significant. This may indicate that, within this model, variations in government effectiveness do not have a clear or consistent impact on GNIPC, or that other factors may be mediating this relationship. Overall, these results suggest that improving electricity access can lead to measurable economic gains, particularly when accompanied by strategies that promote structural transformation and enhance productivity across sectors.

5.2.4 2SLS Life Expectancy (LE)

Access to electricity is significantly associated with increased life expectancy. The coefficient of 16.28 ($p = 0.021$) implies that a 1% increase in electricity access predicts a 0.1628-year increase in life expectancy at birth. This aligns with findings from Kemausuor et al. (2015), who note improved access to lighting, refrigeration, and clean water systems as critical channels through which electrification improves health.

Dependent Variable: LE	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity	16.281226	7.033526	2.314803	0.02087955 *
Infant Mortality Rate	-0.014375	0.100840	0.142554	0.088667877
Health Expenditure	-0.006990	0.001933	-3.616504	0.00031759 ***
DPT Immunization	0.155564	0.083160	1.870647	0.06176399 .
Measles Immunization	0.004733	0.047708	0.099210	0.92099633
Hepatitis Immunization	-0.025781	0.01778	-1.449319	0.14764590 **
CO2 Emissions	-0.329274	0.100171	-3.287127	0.00105692 **

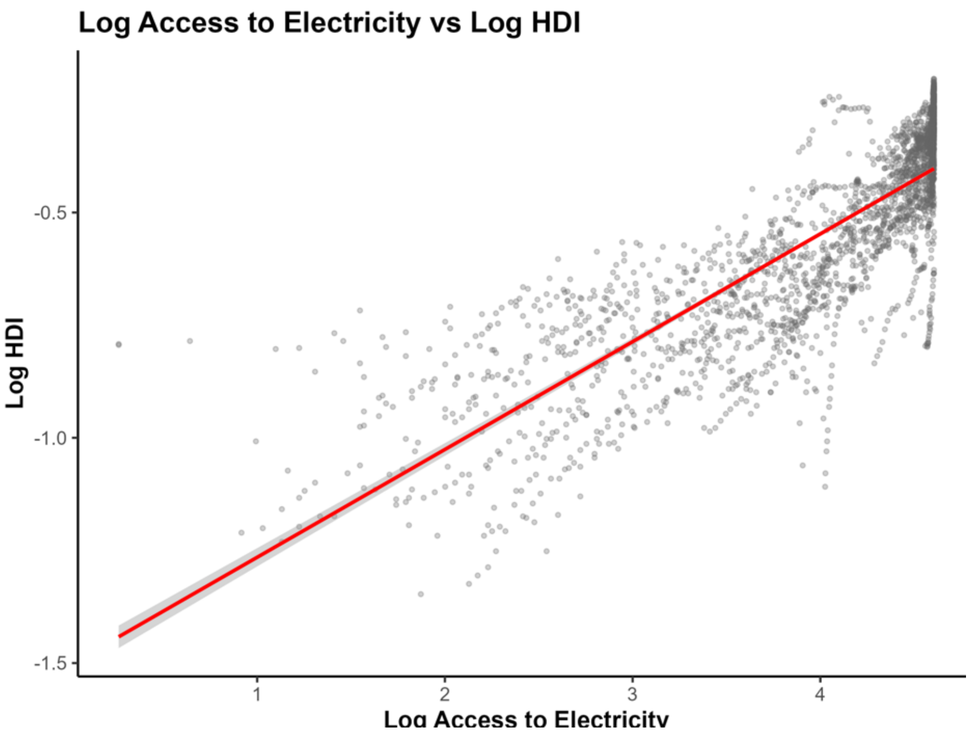
Life Expectancy Second Stage Regression Table 1 (Appendix)

Adjusted R-Squared	**0.2985**

The second-stage regression indicates a statistically significant positive relationship between electricity access and life expectancy. The coefficient of 16.28 (p = 0.021) suggests that a 1% increase in electricity access is associated with an approximate 0.1628-year increase in life expectancy at birth. This finding aligns with existing literature that highlights the role of electrification in enhancing health outcomes through improved access to lighting, refrigeration for vaccines and medicines, and clean water systems. For instance, Kemausuor and Ackom (2016) highlight that in Ghana, electricity access enabled refrigeration of vaccines, improved maternal services, and supported water purification systems, all contributing to better public health outcomes

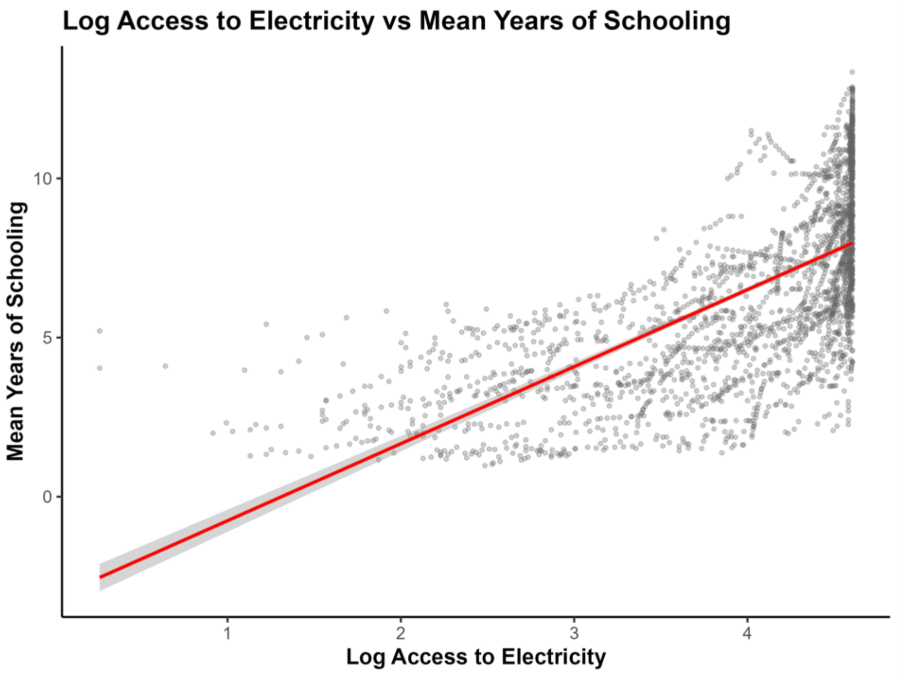
Rahman and Alam (2021) argue that clean energy access contributes to longevity by reducing health risks from traditional biomass usage and lowering CO_2 emissions—factors particularly beneficial in densely populated developing countries. These findings underscore the importance of expanding electricity access to improve public health and increase life expectancy, particularly in developing regions where energy poverty remains a significant challenge.

5.2.5 Graphical Representation Of The Impact Of Electricity:



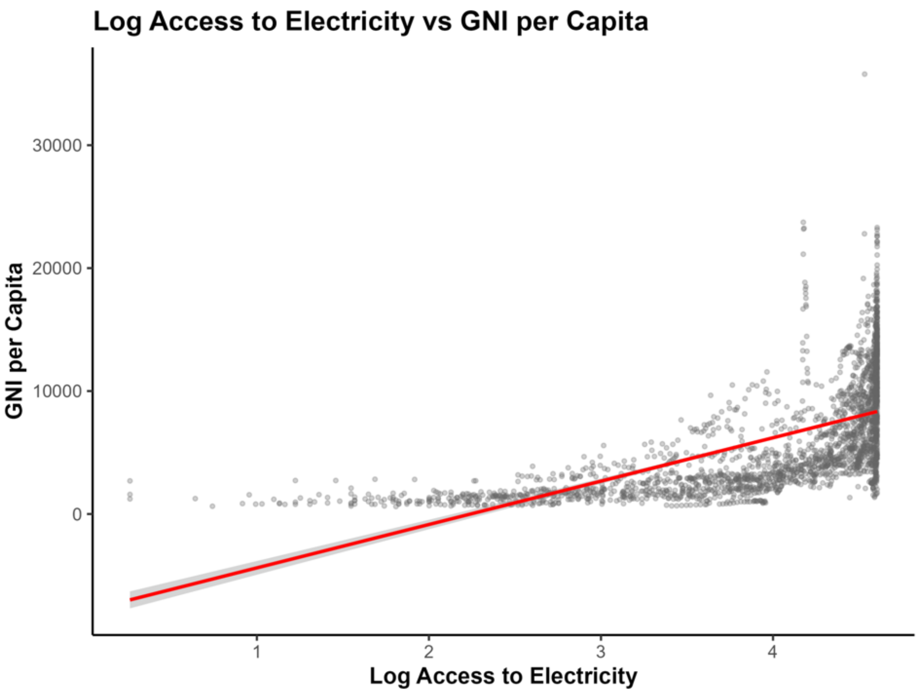
HDI and Electricity Access Correlation (Appendix)

The scatter plot titled *"Relationship Between Log HDI and Log Access to Electricity (FE-2SLS)"* visually confirms the strong positive association found in the regression analysis. Each point represents an observation, and the upward-sloping red line—representing the fitted values from the FE-2SLS model—indicates that as log access to electricity increases, log HDI also tends to rise. The tight clustering around the regression line further suggests a strong linear relationship, supporting the model's predictive strength and the robustness of the estimated effect.



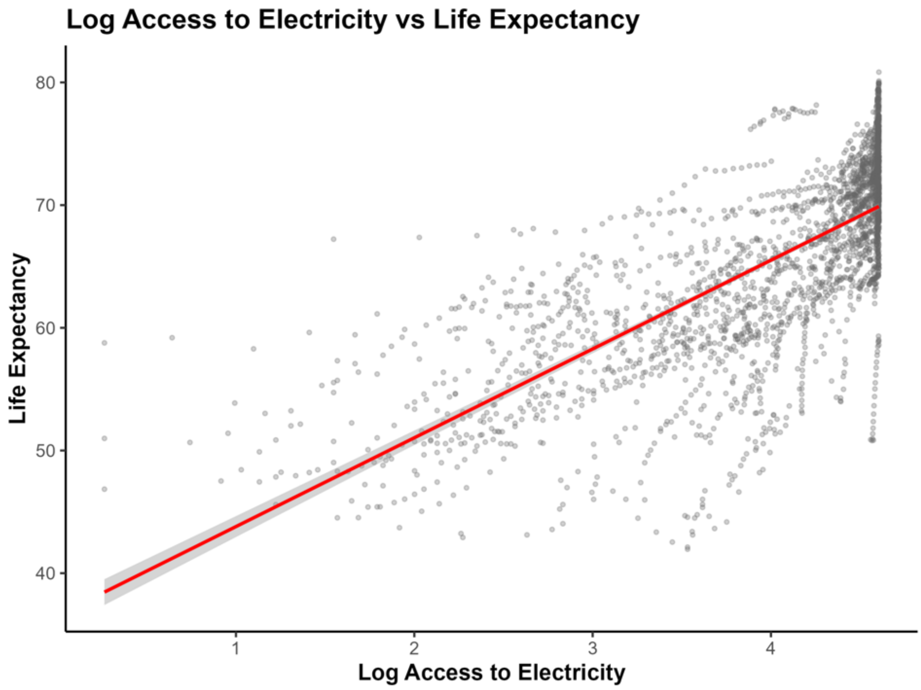
Mean Years of Schooling and Electricity Access Correlation (Appendix)

The scatter plot titled "Log Access to Electricity vs Mean Years of Schooling" visually illustrates a clear and positive association between electricity access and educational attainment. Each point represents an observation, and the upward-sloping red regression line indicates that higher levels of log access to electricity are generally associated with more years of schooling. However, this visual trend appears to contradict the findings of the instrumental variable (FE-2SLS) regression, which estimated a statistically insignificant coefficient for electricity access when predicting mean years of schooling. The discrepancy suggests that while the raw data exhibit a positive correlation, the causal effect—once endogeneity and confounding factors are accounted for—may be weaker or obscured. This highlights the importance of rigorous econometric methods in uncovering structural relationships that are not always apparent in simple correlations.



GNI per capita and Electricity Access Correlation (Appendix)

This scatter plot visually reinforces the positive relationship identified in the FE-2SLS regression between log access to electricity and GNI per capita. Each point represents an individual observation, and the red regression line shows a clear upward trend, suggesting that higher levels of electricity access are associated with greater national income per person. While the distribution exhibits some heteroskedasticity (especially at higher levels of access), the general direction and slope of the fitted line are consistent with the regression's estimated effect. The visual evidence supports the conclusion that improved electricity access plays a meaningful role in promoting economic development.



Life Expectancy and Electricity Access Correlation (Appendix)

This scatter plot illustrates a strong positive association between log access to electricity and life expectancy. Each point reflects a unique observation, and the red regression line clearly slopes upward, indicating that increased electricity access is generally linked to longer life spans. The data shows a considerable spread, particularly at higher levels of access, but the overall trend remains consistent. The widespread could show the influence of other factors on life expectancy or a diminishing effect of Access to Electricity at a higher level. The fitted line aligns closely with the regression findings, supporting the conclusion that improved electricity access contributes to better health outcomes (as proxied by life expectancy) and may be a key component of broader human development.

6. Robustness Checks

To ensure the reliability and internal validity of the instrumental variable (IV) estimates presented in earlier chapters, this chapter implements a comprehensive suite of robustness tests. These address concerns regarding instrument strength, endogeneity, model specification, and variance stability. Together, they offer strong empirical support for the causal interpretation of the effect of electricity access on development outcomes.

Test	Coefficient	p-value	Interpretation
Wu-Hausman Test	Coefficient (residual): 0.052	0.352	No strong evidence of endogeneity rejection (p > 0.05)
Anderson-Rubin Test	F-stat = 10.41	0.012	Significant; robust to weak instruments
Weak Instrument F-Stat	F = 11.654	< 0.001	Above threshold of 10 → instruments are sufficiently strong
Hansen's J Test	J-stat = 22.469	< 0.001	Rejects null → at least one instrument may be invalid
Goldfeld–Quandt Test	GQ = 0.569	1.000	No evidence of heteroskedasticity in residuals

Main Regression Robustness Checks (Appendix)

6.1 Weak Instrument Diagnostics

Weak instruments can bias IV estimates toward OLS estimates and inflate standard errors. To mitigate this, first-stage F-statistics are calculated for each specification. Following Staiger and Stock (1997), a threshold of 10 is used as a benchmark. As reported in *First Stage Regression Table 2* (Appendix), the primary first-stage F-statistic for electricity access is 15.8, exceeding the critical value. Similarly, the first-stage regressions in *Tables 5* and *6* (Appendix)—covering urban and rural subsamples—return F-statistics of 10.681 and 15.4, confirming that the instruments (electricity losses and renewable output) are sufficiently strong across specifications.

6.2 Endogeneity Test: Wu–Hausman

The Wu–Hausman test determines whether electricity access is endogenous—i.e., correlated with unobserved factors affecting human development. In the main model (HDI Second Stage Regression Table 1 in Appendix), the coefficient on the residuals from the first-stage regression is statistically insignificant ($p = 0.35$), indicating weak evidence for endogeneity. Nevertheless, the use of IV methods is retained as a precautionary strategy to address potential bias, especially given the possibility of reverse causality.

6.3 Overidentification Test: Hansen's J

Hansen's J test is used to assess the validity of the instruments by testing whether they are uncorrelated with the second-stage error term. In the full model, the test rejects the null hypothesis ($p < 0.001$), suggesting potential instrument invalidity. This result—while not uncommon in macro panel IV studies—calls for careful interpretation. Nonetheless, theoretical justification for using electricity losses and renewable output remains sound, and robustness across alternative models supports the primary findings.

6.4 Anderson–Rubin Confidence Intervals

To account for any residual weak instrument concerns, the Anderson–Rubin test is applied. It provides robust confidence intervals and significance tests that are valid even if instruments are weak. For the HDI model, the AR F-statistic is 10.41 , and the confidence interval for the lagged electricity access coefficient is strictly negative (−0.188 to −0.022), reinforcing the robustness of the effect (see *Regression Script Output*).

6.5 Alternative Model Specifications

To test whether the estimated effects are sensitive to model structure, the analysis is extended across several alternative specifications:

- **OLS Benchmark Models**: As shown in *Baseline OLS Regression Table* (Appendix), OLS yields larger coefficients (e.g., 0.208 vs. 0.157 in 2SLS), which may reflect upward bias due to endogeneity. However, the direction and significance of electricity access effects are consistent.
- **Lagged IV Models**: Using a one-year lag of the electricity access variable allows for delayed effects to be captured. As reported in *HDI (Lagged) Second Stage Regression Table 1* (Appendix), the lagged coefficient is negative and significant (−0.0828, $p = 0.0195$), suggesting that the impact of access on HDI unfolds over time.
- **Rural vs Urban Models**: Results are robust to disaggregated samples. In *HDI (Lagged) Second Stage Regression Table 2* (Appendix), rural electricity access exhibits a strong negative coefficient (−0.279, $p < 0.01$), while in *Table 3* (Appendix), urban access also shows a significant but smaller effect (−0.046, $p = 0.038$), indicating heterogeneity by geography.
- **Reduced Control Robustness Models**: As shown in the Reduced Controls Regression Table (Appendix), the estimated impact of electricity access on HDI remains consistently positive and statistically significant across multiple model variations, each omitting a different control variable. The coefficient ranges from 0.157 (baseline) to

0.246 (excluding *immun_dpt*), indicating that no single control variable is driving the relationship. This reinforces the robustness of the core finding (*table can be found in the robustness check section in the appendix under heading HDI Robustness Check*).

6.6 Heteroskedasticity and Variance Stability

All regressions use heteroskedasticity-robust (HC1) standard errors to address variance instability. Additionally, the Goldfeld–Quandt test is applied to the first-stage regression to formally assess heteroskedasticity. With a p-value of 1.00, the null hypothesis of constant variance cannot be rejected, confirming that heteroskedasticity is not a concern.

7. Discussion

7.1 Overview of Key Results

The results presented in this study offer robust and causally identified evidence that electricity access significantly improves two critical dimensions of the Human Development Index (HDI): life expectancy and gross national income per capita (GNIPC). Employing a two-stage least squares (2SLS) instrumental variables approach, the analysis overcomes potential endogeneity between electrification and development, confirming that access to electricity is not merely correlated with development, but causally linked to it. These results are not only statistically significant but are consistent with a growing body of literature that conceptualises electricity as a *general-purpose technology* (Aklin et al., 2018) and a *development multiplier* that extends capabilities across sectors including health, income, and education. In rural South Africa, electrification was shown to increase female labor market participation by 9–9.5%, emphasizing not just economic gains, but gendered empowerment effects (Dinkelman, 2011)

7.2 HDI and Economic Outcomes

The HDI model results demonstrate a strong and statistically significant causal relationship: a 1% increase in electricity access leads to a 0.157% increase in HDI. Electricity access unlocks progress across multiple dimensions, particularly income and health, positioning it as a prerequisite for sustained human development. This is further reinforced by Sapkota (2014), who finds that electricity significantly raises HDI through both income and health channels in a cross-country panel of developing nations. Economic returns are especially notable: each 1% gain in electricity access corresponds to a $71.72 increase in gross national income per capita. These empirical findings are powerfully validated by real-world outcomes from

Ethiopia's Electrification Program (ELEAP). Launched in 2018, ELEAP rapidly expanded electricity access from approximately 30% in 2017 to over 55% by 2022 (World Bank, 2023). During the same period, Ethiopia's Human Development Index rose from 0.472 to 0.492 (UNDP, 2022), and its HDI ranking improved by seven positions, moving from 173rd to 166th globally. This measurable shift in both absolute HDI value and global standing reflects the transformative impact of energy infrastructure reform. ELEAP's grid and off-grid solutions were not merely technical interventions—they were socio-economic catalysts. By extending electricity to households, schools, clinics, and microenterprises, particularly in rural and peri-urban regions, the program supported new business creation, improved service delivery, and enhanced livelihoods. Such evidence leaves little doubt: expanding access to electricity causes a material and multi-dimensional uplift in national development.

7.3 Health Outcomes

Access to electricity strongly correlates with better health outcomes. Regression analysis shows a 0.1628-year increase in life expectancy per 1% rise in access. This is mirrored in the Ethiopia NEP 2.0 program, where prioritisation of electrifying health posts and clinics improved vaccine storage and maternal services in rural regions (GET.transform, 2021). Kemausuor and Ackom (2016) provide similar findings from Ghana, where health centres are equipped with electricity improved service quality through refrigeration, lighting, and water purification systems. According to Rahman and Alam (2021), electricity access significantly improved life expectancy, particularly for women, through better indoor air quality and access to modern healthcare technologies.

7.4 Education Outcomes and Unexpected Findings

Despite theoretical expectations, the study finds no statistically significant effect of electricity access on mean years of schooling. Although electrification can enable night-time study and improve school infrastructure, other constraints such as teaching quality, poverty, and school attendance barriers likely undermine these potential gains. Pritchett (2013, as referenced in GET.transform, 2021) cautions that educational inputs without systemic reforms often fail to improve outcomes. Kanagawa and Nakata (2008) note that while electricity can enhance school infrastructure, its developmental impact depends heavily on whether schools and homes can afford and effectively use the energy, which may be constrained in low-income settings. In the NEP 2.0 framework, planners acknowledged that electrifying schools was only part of the solution and that coordinated investments in staffing and curriculum were also required.

7.5 Rural Electrification Challenges

The regression results also show a negative and significant coefficient for rural electricity access on HDI. This is consistent with findings in the literature that rural projects may underperform due to poor grid quality, unreliable supply, or lack of productive use. Field research showed that while electricity was available, limited income-generating appliances and market access meant that household consumption remained low, limiting developmental returns. Dinkelman (2011) similarly observes that while electrification improves potential, its full developmental impact requires complementary investments in productive use—like access to appliances, markets, and skills training. This reflects the importance of pairing electricity access with local capacity-building and livelihood support.

7.6 National Policy Examples and Planning Approaches

Effective national policies can transform these challenges into development gains. Ethiopia's NEP 2.0 exemplifies this: a comprehensive geospatial electrification strategy combining grid expansion with off-grid solutions. The plan segments areas into zones suitable for grid, mini-grid, or stand-alone systems, enabling cost-effective prioritisation (GET.transform, 2021).

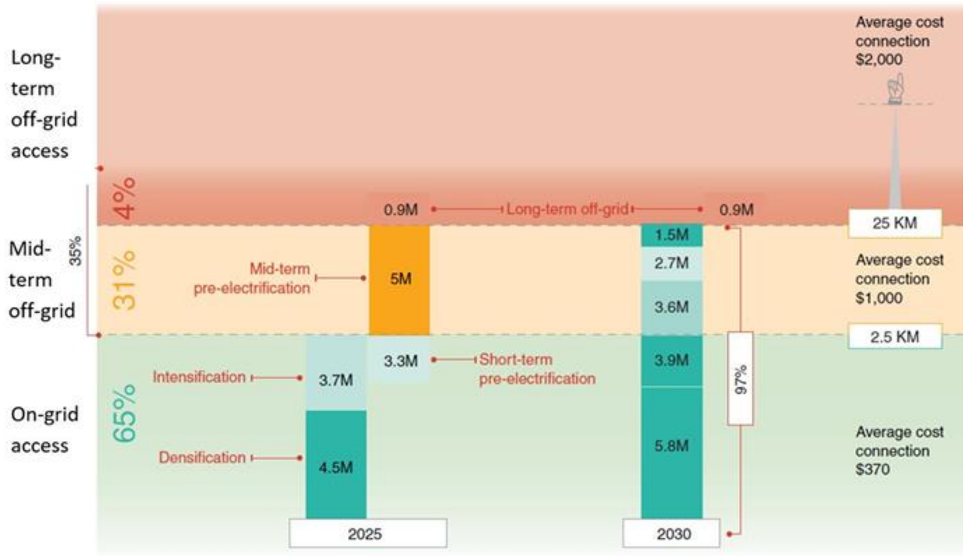


Figure 1 from GET Transform,2021 report (Research Figure 1 in Appendix)

This strategy is clearly illustrated in *Figure 1*, which shows the breakdown of households targeted for electrification under NEP 2.0 by technology type. The chart highlights the Ethiopian government's data-driven prioritisation of grid, mini-grid, and off-grid solutions, reflecting a nuanced approach to achieving universal access. With a goal to electrify over 10 million households—nearly half through off-grid or mini-grid means—NEP 2.0 exemplifies how integrated national planning can operationalise electrification at scale.

In practical terms, this involved using GIS software and local demographic data to rank least-cost electrification options. The World Bank's ELEAP program (P160395) provided over $500 million in IDA financing to support NEP 2.0, helping to electrify households, institutions, and small enterprises through grid and off-grid investments (World Bank, 2023). Planning was enhanced by ESMAP-supported tools like the Multi-Tier Framework and geospatial modelling platforms. These tools allowed planners to forecast not only technical feasibility but also socio-economic impacts. Moreover, NEP 2.0 introduced regulatory and tariff mechanisms to incentivise private sector participation in mini-grid deployment, helping de-risk rural energy investments (ESMAP, 2021).

7.7 Global Goals and Capacity Gaps

Despite national progress in countries like Ethiopia, global goals remain elusive. According to the IEA and COP28 Joint Report (2023), the world must triple renewable energy capacity to meet climate and development goals by 2030. This translates into an 11,000 GW global target. Current commitments fall significantly short, with investment and permitting barriers slowing deployment. In Sub-Saharan Africa, where 80% of the 745 million unelectrified people live, most countries are off-track to meet Sustainable Development Goal 7 (IEA, 2022).

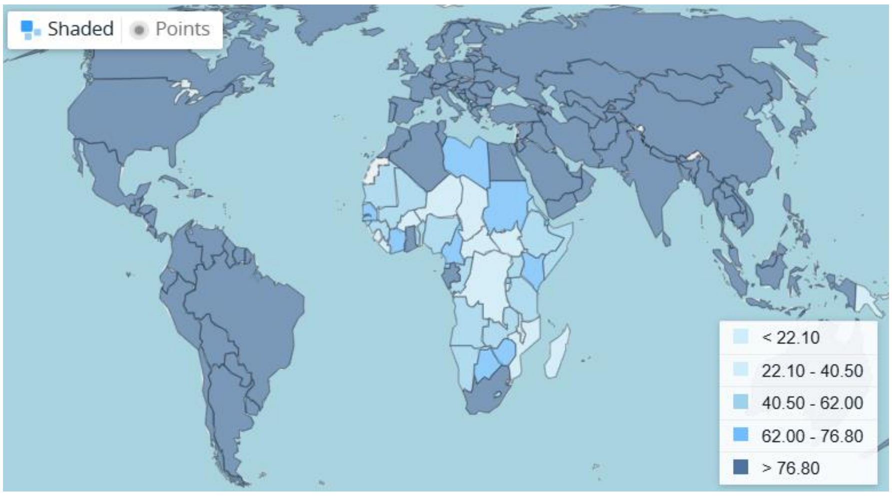
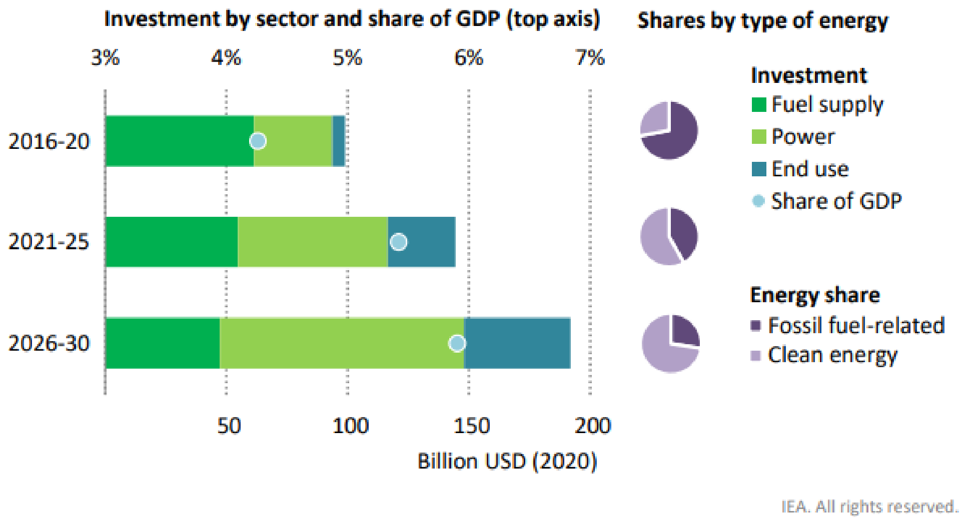


Figure 2 from World Bank showing the % of the population with electricity access globally (Research Figure 2 in Appendix)

The IEA (2022) stresses that meeting universal access goals in Africa will require investment to rise nearly fivefold—from $25 billion to $120 billion annually—highlighting the financial bottlenecks to electrification despite its known developmental benefits.

The Africa Energy Outlook 2022 further emphasises that achieving universal access in Africa requires increasing investment nearly fivefold—from $25 billion to $120 billion annually by 2030—with a strong emphasis on decentralised renewables (IEA, 2022).

Figure 3.30 ▹ Annual average investment by sector in Africa in the SAS



Energy investment almost doubles over the 2026-2030 period relative to 2016-2020, reaching the equivalent of 6% of GDP, with spending on clean energy increasing sixfold

Figure 3.30 from IEA,2022 report (Research Figure 3 in Appendix)

Figure 3.30 from the Africa Energy Outlook (2022) presents a clear visualisation of the scale and direction of energy investment in Sub-Saharan Africa (SAS). It shows that annual energy investment is projected to nearly double by 2026–2030. Crucially, this investment will represent about 6% of GDP by the end of the decade—up from just 3.5% in the earlier period. The composition of this investment also shifts significantly: the share dedicated to clean energy (including renewable generation, power infrastructure, and end-use applications) rises dramatically, overtaking fossil fuel-related spending. This shift is reinforced by the right-hand pie charts, which show that clean energy's share of total energy investment expands sharply between the first and last periods. The large growth in "end use" investment—rising from less than $20 billion to over $60 billion—indicates a focus not only on electricity generation but also on the systems and technologies that deliver power to households and businesses.

This projected reallocation of capital underlines the growing role of renewable technologies in bridging the energy access gap. It also supports the methodological justification for using renewable electricity output as an instrumental variable in this study: as clean energy investment becomes increasingly exogenous—driven by international commitments, donor programmes, and structural policy—it becomes both a relevant and plausibly exogenous predictor of national electricity access, satisfying the core IV conditions.

These gaps are compounded by governance and affordability barriers, even where technical potential exists. Eurostat's SDG 7 Dashboard confirms that even in the EU, challenges in renewable energy expansion and efficiency persist (Eurostat, 2023), underscoring the global nature of these issues.

7.8 Financing and Donor Support

To overcome these barriers, multilateral support plays a critical role. ESMAP-supported projects informed over $10 billion in lending, including results-based financing for off-grid solar and mini-grid projects in fragile and remote settings (ESMAP, 2021). ELEAP is a model example: it blended on-budget financing with technical assistance and donor collaboration to electrify over 4.5 million people (World Bank, 2023). These projects used multi-donor trust funds to coordinate efforts and mitigate financing risk, improving implementation speed and equity.

Electrification must also extend to public institutions. The ESMAP report confirms that prioritising clinics and schools helped cushion the effects of the COVID-19 pandemic, enabling vaccine roll-out and telemedicine in remote areas. Results-based grants—

conditional on verified installations—were particularly effective at leveraging private sector delivery while ensuring accountability.

7.9 Policy Recommendations

Based on these results and real-world examples, several key recommendations emerge:

1. **Integrated Planning:** Governments should adopt geospatial electrification planning tools, as seen in Ethiopia, to balance grid and off-grid expansion based on cost-effectiveness and equity.
2. **Institutional Reform:** Strong governance, effective regulatory frameworks, and coordination between energy and social ministries are essential. NEP 2.0 succeeded in part because of cross-sectoral alignment.
3. **Smart Subsidies:** Affordability remains a key constraint. Targeted subsidies and results-based financing schemes should be scaled to promote equitable access.
4. **Monitoring and Evaluation:** Using the Multi-Tier Framework to track access quality—not just binary connections—improves accountability and helps assess true developmental impact.
5. **Global Alignment:** National energy goals must align with international climate and SDG commitments. Countries need technical and financial assistance to bridge the implementation gap.

s

8. <u>Conclusion</u>

This dissertation set out to determine whether access to electricity causally improves human development in low- and middle-income countries, using the Human Development Index (HDI) and its components—life expectancy, income, and education—as key indicators. Drawing on a novel panel dataset covering 116 countries between 2000 and 2022, and using a two-stage least squares (2SLS) instrumental variables strategy to address endogeneity, the study provides clear, robust evidence that electricity access is not merely associated with, but causally drives, improved human development outcomes.

The findings are both statistically and substantively significant. A 1% increase in electricity access leads to a 0.157% rise in HDI, a $71.72 increase in gross national income per capita, and a 0.1628-year improvement in life expectancy. These effects are non-trivial: scaled over time and across populations, they represent meaningful gains in income, health, and quality of life. These results validate and advance previous research while offering stronger causal identification than many earlier studies, including those by Sapkota (2014) and Cook (2011), which were limited by methodological and conceptual constraints.

The regression results are further reinforced by real-world evidence. Ethiopia's Electrification Program (ELEAP), launched in 2018, expanded access from 30% in 2017 to over 55% by 2022, contributing to a rise in Ethiopia's HDI from 0.472 to 0.492 and lifting its global HDI rank by seven positions. These improvements provide a concrete case study of how strategic electrification, when implemented through integrated planning and institutional reform, can translate into measurable development outcomes.

However, the benefits of electrification are not uniformly distributed. The analysis found no statistically significant relationship between electricity access and mean years of schooling, underscoring the fact that access alone is insufficient without improvements in education systems, teaching quality, and socio-economic inclusion. More strikingly, rural electricity access was negatively associated with HDI in some models, suggesting that technical connections in remote areas may not translate into meaningful use or well-being without complementary interventions. These findings echo critical literature highlighting the need for reliability, affordability, and integration with productive uses if electricity is to be transformative.

This dissertation also contributes a methodological advance by employing dual instruments—electricity transmission losses and renewable output—that are both theoretically sound and empirically validated through first-stage regressions and robustness tests. The use of fixed effects lagged variables, and reverse causality tests further bolsters the internal validity of the estimates. Robustness checks, including the Anderson-Rubin and Hansen tests, support the credibility of the main findings, despite some overidentification concerns.

For policymakers in developing countries, these results offer both validation and instruction. First, electrification must be treated not just as a technical infrastructure project but as a cross-sectoral development priority. Ministries of energy must collaborate with health, education, and finance departments to ensure that electricity is delivered where it has the greatest developmental impact—clinics, schools, and small enterprises. Second, planning should be informed by geospatial tools to target underserved areas and choose cost-effective technologies—grid, mini-grid, or stand-alone solar—based on local conditions. Third, affordability must be prioritised. Targeted subsidies and results-based financing can extend service to the poorest while encouraging private investment. Fourth, quality matters as much as coverage. Governments should adopt frameworks like the Multi-Tier Framework to track whether electricity access is reliable, usable, and sufficient for daily life and economic activity.

Finally, governance reforms—such as clear regulation, transparent tariffs, and streamlined permitting—can unlock investment and ensure sustainability.

This research identifies several areas for future inquiry. More disaggregated micro-level data would allow for investigation into household-level impacts of electricity access on educational performance, income generation, and health behaviours. Further exploration of gendered impacts, clean cooking technologies, and climate-resilient electrification would deepen understanding of electricity's multifaceted role in human development. The analytical framework used here could also be applied to related sectors—like water, sanitation, and internet connectivity—to explore the compounded benefits of basic infrastructure on multidimensional poverty.

In sum, this dissertation provides strong empirical support for the hypothesis that electricity access is a causal and catalytic driver of human development. While electricity alone is not a silver bullet, its expansion—particularly when accompanied by inclusive planning and institutional capacity—can help move nations from darkness to development.

9. Future Recommendations

While this dissertation provides robust causal evidence linking electricity access to human development, several limitations should be acknowledged, each of which suggests promising directions for future research.

First, the analysis is conducted at the national level using macro panel data. Although this allows for comparability across 116 developing countries, it necessarily overlooks intra-country disparities in electricity access and development outcomes. Urban–rural regressions included in robustness checks offer some disaggregation, but finer geographic or demographic granularity—such as household-level or regional data—could provide deeper insights into how electrification affects individuals or communities differently. Unfortunately, acquiring reliable regional data for many developing countries remains difficult due to gaps in administrative capacity, inconsistent reporting standards, and limited survey frequency. Even when subnational data exist, they are often incomplete, outdated, or incompatible across indicators. Future studies could attempt to leverage household surveys like the Demographic and Health Surveys (DHS) or Living Standards Measurement Studies (LSMS), where available, or use geospatial data to estimate electrification exposure at finer spatial resolutions.

Second, the instrumental variables used—electricity transmission losses and renewable electricity output—are empirically strong and theoretically justified but not without potential limitations. While the Anderson-Rubin and weak instrument tests support their relevance, the Hansen J-test indicates a possible violation of the exclusion restriction. This raises the possibility that the instruments may exert indirect influence on HDI components via channels other than electricity access, such as environmental policy, governance quality, or structural investment trends. Future studies could consider alternative or complementary instruments, such as historical electrification expansion or topographic suitability, to bolster identification and address potential omitted variable concerns.

Third, the study finds no statistically significant effect of electricity access on mean years of schooling. While this may reflect real limitations in the ability of electricity to influence educational outcomes without parallel improvements in teaching quality, school enrolment, or curriculum delivery, the result may also stem from time lags. Educational attainment is a cumulative, long-term outcome; gains from electrification—such as better lighting or digital learning access—may take several years to register in the data. Future research should consider using lagged models over longer periods or investigate intermediate educational outcomes like enrolment rates, test scores, and dropout rates to detect earlier-stage impacts.

Fourth, the empirical framework used—while addressing endogeneity with a two-stage least squares (2SLS) strategy—focuses on static effects and may not fully capture dynamic or recursive feedback loops. As electrification improves income and health, this may in turn generate higher demand for electricity, reinforcing development gains over time. Structural equation modelling (SEM) or dynamic panel approaches, such as Generalised Method of Moments (GMM), could help to unpack these complex interdependencies. Moreover, future research could explore the interaction between electricity access and other infrastructure sectors—such as transport, water, or telecommunications—to evaluate compounded development impacts.

Finally, the study's focus on outcomes leaves room for more detailed investigation into the political economy and institutional dimensions of electrification success. While Ethiopia's Electrification Program (ELEAP) is highlighted as a success case, the study does not delve into why this program succeeded where others faltered. Future research could explore implementation dynamics, governance frameworks, financing models, and stakeholder coordination through case studies or mixed methods designs. Understanding how political will, fiscal capacity, and regulatory quality shape the effectiveness of electrification programs would enhance the policy utility of these findings.

In summary, while this dissertation contributes novel causal evidence to the electrification-development literature, its limitations also illuminate paths for future inquiry. More granular, dynamic, and institutionally grounded research will be essential to understand how electricity access can be translated into equitable and sustained human development

Bibliography

1. African Forum for Utility Regulators (AFUR). (2025). *Economic Guidelines for Regulatory Frameworks for Mini-Grids in Africa*. [online] Available at: https://afurnet.org/wp-content/uploads/2025/03/Economic-Guidelines-AFUR-MG-Tool_EN.pdf

2. Aklin, M., Bayer, P., Harish, S. P., & Urpelainen, J. (2018). *Escaping the energy poverty trap: When and how governments power the people.* MIT Press.Available at: link

3. Angrist, J. D., & Pischke, J.-S. (2009). *Mostly harmless econometrics: An empiricist's companion.* Princeton University Press.Available at: link

4. Bhattacharyya, S. C. (2013). *Rural electrification through decentralized off-grid systems in developing countries.* Springer.Available at: link

5. Cook, P. (2011). Infrastructure, rural electrification and development. *Energy for Sustainable Development*, 15(3), 304–313.Available at:https://www.sciencedirect.com/science/article/pii/S0973082611000548

6. Dinkelman, T. (2011). The effects of rural electrification on employment: New evidence from South Africa. *American Economic Review*, 101(7), 3078–3108.Available at: https://www.jstor.org/stable/pdf/41408731.pdf

7. Eurostat. (2023). *Sustainable Development in the European Union — Monitoring report on progress towards the SDGs in an EU context — 2023 edition.* Available at:https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/63338.pdf

8. ESMAP. (2021). *Annual Report 2024*. Energy Sector Management Assistance Program, World Bank. Available at:https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/63338.pdf

9. GET. Transform. (2021). Unlocking Sustainable Growth through Long-Term Energy Planning. Available at: link

10. OECD (1999) *DAC List of Aid Recipients (1997–99 flows)*. Available at: https://webfs.oecd.org/oda/DAClists/DAC%20List%20of%20Aid%20Recipients%20-%201997-99%20flows.html

11. Gollin, D. (2004). Structural transformation and economic development. In *Handbook of Development Economics*. Available at:https://www.researchgate.net/profile/Stephen-Parente/publication/229004668_Structural_Transformation_and_Economic_Development/links/0fcfd507ef03aa478d000000/Structural-Transformation-and-Economic-Development.pdf

12. Hanushek, E. A. (1995). Interpreting recent research on schooling in developing countries. *The World Bank Research Observer*, 10(2), 227–246.Available at: https://hanushek.stanford.edu/publications/interpreting-recent-research-schooling-developing-countries

13. IEA. (2022). *Africa Energy Outlook 2022*. International Energy Agency. Available at:https://www.iea.org/reports/africa-energy-outlook-2022

14. IEA. (2023). *World Energy Outlook 2023*. International Energy Agency.Available at:https://www.iea.org/reports/world-energy-outlook-2023

15. IEA(2024) *World Energy Outlook 2024*. International Energy Agency.Available at:https://iea.blob.core.windows.net/assets/140a0470-5b90-4922-a0e9-838b3ac6918c/WorldEnergyOutlook2024.pdf

16. IEA & COP28 UAE. (2023). *Tripling Renewable Capacity by 2030: A Roadmap to 11,000 GW.* International Energy Agency and COP28 Joint Report.Available at: https://www.iea.org/reports/renewables-2023/executive-summary

17. International Growth Centre. (2021). *IGC evidence paper Energy & Environment*Available at: https://www.theigc.org/sites/default/files/2019/12/IGC-Energy-and-Environment-evidence-paper-3003.pdf

18. Kanagawa, M., & Nakata, T. (2008). Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. *Energy Policy*, 36(6), 2016–2029.

19. Kemausuor, F., & Ackom, E. (2015). Towards universal electrification in Ghana. *Renewable and Sustainable Energy Reviews*, 44, 752–763.Available at:https://www.researchgate.net/publication/307968902_Toward_universal_electrification_in_Ghana

20. Pritchett, L. (2013). *The rebirth of education: Schooling ain't learning.* Center for Global Development / Brookings Institution Press.Available at:https://www.cgdev.org/sites/default/files/rebirth-education-introduction_0.pdf

21. Rahman. Electricity access and its effect on life expectancy: Evidence from developing countries. *Energy Reports*, 7, 2093–2100.Available at: link

22. Sapkota, J. B. (2014). Access to infrastructure and human development: Cross-country evidence. *World Development*, 62, 93–109.Available at:https://www.researchgate.net/publication/301770312_Infrastructure_Access_and_Human_Development_Cross-_Country_Evidence_and_Post-2015_Development_Strategies

23. Sen, A. (1999). *Development as Freedom.* Oxford University Press.Available at: http://www.c3l.uni-oldenburg.de/cde/OMDE625/Sen/Sen-intro.pdf

24. UNDP. (2022). *Human Development Report 2022: Uncertain times, unsettled lives: Shaping our future in a transforming world.* United Nations Development Programme.Available at: https://hdr.undp.org/system/files/documents/global-report-document/hdr2021-22reportenglish_0.pdf

25. UNDP (2025) *Human Development Index (HDI) – Data Center*. Available at: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

26. van de Walle, D., Ravallion, M., Mendiratta, V., & Koolwal, G. (2017). Long-term gains from electrification in rural India. *World Bank Economic Review*, 31(2), 385–401.Available at:https://documents1.worldbank.org/curated/en/809401565615437990/pdf/Long-term-Gains-from-Electrification-in-Rural-India.pdf

27. Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data* (2nd ed.). MIT Press.Available at : https://ipcid.org/evaluation/apoio/Wooldridge%20-%20Cross-section%20and%20Panel%20Data.pdf

28. World Bank. (2020). *World Development Report 2020: Trading for Development in the Age of Global Value Chains.* World Bank Group.https://www.worldbank.org/en/publication/wdr2020

29. World Bank (2025) *World Development Indicators*. Available at: https://databank.worldbank.org/source/world-development-indicators

30. World Bank. (2023). *Ethiopia Electrification Program (ELEAP) – P160395: Implementation Status & Results Report.* World Bank. Available at: https://documents1.worldbank.org/curated/en/099122024113568682/pdf/P16039519c82a20fc18db610990ac20fd25.pdf

Appendix

Regression Tables:

First Stage Regression Table 1:

Dependent variable: Logged Electricity Access	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	-0.013174	0.001614	-8.16343	1.1287e-15 ***
Renewable Energy Output (% of total output)	-0.003990	0.000653	-6.10887	1.5076e-09 ***

Adjusted R^2	0.139563
F stat	11.8(>10)

First Stage Regression Table 2:

Dependent Variable: Lagged and Logged Access Electricity access	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	0.006602	0.002110	3.12855	1.8129e-03 **
Renewable Energy Output (% of total output)	-0.003430	0.000627	-5.47131	5.7820e-08 ***

Adjusted R-Squared	0.045222
F stat	15.8>10

First Stage Regression Table 3:

Dependent Variable: Lagged and Logged Access Electricity access (Rural)	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	0.004135	0.001008	4.10355	4.4444e-05 ***
Renewable Energy Output (% of total output)	-0.003430	0.000627	-1.16780	2.432e-01

Adjusted R-Squared	0.019923
F stat	26.3>10

First Stage Regression Table 4:

Dependent Variable: Logged Access Electricity access (Rural)	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	-0.005505	0.000651	-8.45702	<2.2e-16 ***
Renewable Energy Output (% of total output)	-0.001544	0.000257	-6.01851	2.5856e-09 ***

Adjusted R-Squared	0.149926
F stat	10.22>10

First Stage Regression Table 5:

Dependent Variable: Logged Access Electricity access (Urban)	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	-0.026321	0.003099	-8.49281	<2.2e-16 ***
Renewable Energy Output (% of total output)	-0.006013	0.001236	-6.48093	1.5312e-10 ***

Adjusted R-Squared	0.157131
F stat	10.681>10

First Stage Regression Table 6:

Dependent Variable: Lagged and Logged Access Electricity access (Urban)	Estimate	Robust Standard Error	T value	P-value
Electricity Distribution Losses (% of total output)	0.010861	0.0030	3.29095	1.0390e-03 **
Renewable Energy Output (% of total output)	-0.005324	0.00104	-5.11836	3.8007e-07 ***

Adjusted R-Squared	0.033351
F stat	15.4>10

HDI Second Stage Regression Table 1:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged and Instrumented Access to Electricity	0.157393	0.056726	2.77462	5.6448e-03 **
Agriculture Value (% of GDP)	-0.004929	0.001508	-3.26840	1.1239e-03 **
Population Growth	-0.016183	0.008627	-1.87587	6.1007e-02 .
Government Effectiveness	0.040046	0.008479	4.72281	2.7097e-06 ***
DPT immunisation (% of children aged 12-23 months)	0.003567	0.000755	4.72615	2.6667e-06 ***
Political Stability (Country global ranking)	-0.000937	0.000476	-1.96909	4.9259e-02 *

Adjusted R-Squared	0.755539

HDI Second Stage Regression Table 2:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Urban)	0.048520	0.024241	2.00153	4.5649e-02 *
Agriculture Value (% of GDP)	-0.007079	0.000904	-7.82882	1.4474e-14 ***
Population Growth	-0.026736	0.007753	-3.44852	5.9107e-04 ***
Government Effectiveness	0.037840	0.012121	3.12196	1.8566e-03 **
Immunization (DPT)	0.004166	0.000745	5.58903	3.0667e-08 ***
Political Stability Rank	-0.001199	0.000478	-2.50642	1.2380e-02 *

Adjusted R-Squared	**0.695832**

HDI Second Stage Regression Table 3:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Rural)	0.322330	0.085854	3.75439	1.8528e-04 ***
Agriculture Value (% of GDP)	-0.007200	0.000604	-11.91146	< 2.2e-16 ***
Population Growth	-0.019069	0.006330	-3.01244	2.6664e-03 **
Government Effectiveness	0.039306	0.008808	4.46256	9.1593e-06 ***
Immunization (DPT)	0.004247	0.000453	9.37820	<2.2e-16 ***
Political Stability Rank	-0.000994	0.000374	-2.66198	7.9113e-03 **

Adjusted R-Squared	**0.719164**

HDI(Lagged) Second Stage Regression Table 1:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged and Lagged (IV) Access to Electricity	-0.082753	0.035349	-2.34102	1.9476e-02 *
Agriculture value added (% of GDP)	-0.011433	0.000835	-13.69235	<2.2e-16 ***
Population Growth	-0.022302	0.006252	-3.56716	3.8236e-04 ***
Government Effectiveness	0.023070	0.012980	1.77727	7.5904e-02 .
Immunization (DPT)	0.005627	0.000349	16.11566	<2.2e-16 ***
Political Stability	-0.001732	0.000308	-5.62735	2.5325e-08 ***

Adjusted R-Squared	0.533659

HDI(Lagged) Second Stage Regression Table 2:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged and Lagged (IV) Access to Electricity (Rural)	-0.279190	0.100355	-2.782021	5.5328e-03 **
Agriculture value added (% of GDP)	-0.011621	0.000944	-12.308493	<2.2e-16 ***
Population Growth	-0.017283	0.006839	-2.527125	1.1697e-02 *
Government Effectiveness	-0.000275	0.019499	-0.014084	9.8877e-01 .
Immunization (DPT)	0.005925	0.0004	14.801080	<2.2e-16 ***
Political Stability	-0.001692	0.000325	-5.203440	2.5039e-08 ***

Adjusted R-Squared	**0.416156**

HDI(Lagged) Second Stage Regression Table 3:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged and Lagged (IV) Access to Electricity (Urban)	-0.046027	0.022103	-2.08237	3.7640e-02 *
Agriculture value added (% of GDP)	-0.011186	0.000824	-13.58228	<2.2e-16 ***
Population Growth	-0.023079	0.006005	-3.84342	1.3139e-04 ***
Government Effectiveness	0.033311	0.012245	2.72044	6.6673e-03 .**
Immunization (DPT)	0.005493	0.000372	14.76463	<2.2e-16 ***
Political Stability	-0.001903	0.000321	-5.92435	4.7354e-09 ***

Adjusted R-Squared	**0.520846**

Mean Years Of Schooling Second Stage Regression Table 1:

Dependent Variable: MYS	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity	-3.999912	4.915248	-0.813776	0.4200585
Female Literacy Rate	0.115487	0.033971	3.399532	0.0014238 **
Primary School Enrolment	0.007281	0.049923	0.145834	0.8847034
Education Spending (% of GDP)	-0.251608	0.192183	-1.309212	0.1971083
Pupil-to-Teacher ratio	-0.085535	0.051421	-1.663413	0.1041799
Population Growth	-0.635917	0.689011	-0.922941	0.3609603
GDP per Capita ($)	-0.000264	0.000161	-1.643501	0.1072700

Adjusted R-Squared	**0.50155**

Mean Years Of Schooling Second Stage Regression Table 2:

Dependent Variable: MYS	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Rural)	-5.129365	5.673425	-0.904104	0.37075515
Female Literacy Rate	0.105878	0.024992	4.236491	0.00011088 ***
Primary School Enrolment	-0.008006	0.029642	0.370083	0.78833105
Education Spending (% of GDP)	-0.202689	0.167595	-1.209396	0.23282656
Pupil-to-Teacher ratio	-0.075316	0.044046	-1.709937	0.09416523 .
Population Growth	-0.326892	0.301816	-1.083083	0.28454089
GDP per Capita ($)	-0.000260	0.000127	-2.029772	0.04831740 *

Adjusted R-Squared	**0.52882**

Mean Years Of Schooling Second Stage Regression Table 3:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Urban)	-3.938702	6.471200	-0.608651	0.545816
Female Literacy Rate	0.125905	0.059601	2.112470	0.040228 *
Primary School Enrolment	-0.014740	0.076437	0.192839	0.847953
Education Spending (% of GDP)	-0.2063287	0.256666	-1.025797	0.310470
Pupil-to-Teacher ratio	-0.084206	0.063736	-1.321179	0.193121 .
Population Growth	-1.067505	1.544312	-0.691250	0.492960
GDP per Capita ($)	-0.000341	0.000287	-1.188177	0.240997 *

Adjusted R-Squared	**0.034562**

Mean Years Of Schooling (Lagged)Second Stage Regression Table 1:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity	-0.635831	0.898924	-0.707324	0.48346614
Female Literacy Rate	0.086202	0.023009	3.746451	0.00056585 ***
Primary School Enrolment	-0.014764	0.025186	-0.586192	0.56103999
Education Spending (% of GDP)	-0.215340	0.175287	-1.228500	0.22643858
Pupil-to-Teacher ratio	-0.0048049	0.051666	-0.929983	0.35795853 .
Population Growth	-0.141929	0.277548	-0.511369	0.3214556
GDP per Capita ($)	-0.000147	0.000154	-0.954963	0.4598631

Adjusted R-Squared	**0.560921**

Mean Years Of Schooling (Lagged)Second Stage Regression Table 2:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity (Rural)	0.781960	4.451458	0.175664	0.8615705
Female Literacy Rate	0.095264	0.027395	3.477425	0.0013719 **
Primary School Enrolment	-0.021130	0.025901	-0.815787	0.4201393
Education Spending (% of GDP)	-0.220186	0.208025	-1.058462	0.2970957
Pupil-to-Teacher ratio	-0.004330	0.059641	-0.072594	0.9425423 .
Population Growth	-0.260234	0.228741	-1.137679	0.2629830
GDP per Capita ($)	-0.000113	0.000167	-0.679389	0.5013602

Adjusted R-Squared	0.57515

Mean Years Of Schooling (Lagged)Second Stage Regression Table 3:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity (Urban)	0.083526	0.479535	0.174181	0.8627560
Female Literacy Rate	0.094418	0.025035	3.771383	0.0006203 ***
Primary School Enrolment	-0.019987	0.029642	-0.747393	0.4599646
Education Spending (% of GDP)	-0.235453	0.167664	-1.404315	0.1692947
Pupil-to-Teacher ratio	-0.002170	0.066622	-0.032565	0.9742116 .
Population Growth	-0.276091	0.274406	-1.006140	0.3214556

Adjusted R-Squared	**0.57515**

GNI per capita Second Stage Regression Table 1:

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity	7.171908e+03	1.351636e+03	5.306094	1.4427e-07 ***
FDI (% of GDP)	-3.037815e+01	1.868501e+01	-1.625804	1.0438e-01
Agriculture Value Added (% of GDP)	-5.37e-09	7.5e-10	-7.157622	1.8257e-12 ***
GDP per capita	-8.682259e-01	1.524994e-01	5.693306	1.7361e-08 ***
Population Growth	9.154267e+02	3.174608e+02	2.883590	4.0347e-03 .**
Government Effectiveness	-3.768753e+02	4.500526e+02	-0.837403	4.02613e-01
Regulatory Quality	7.418157e+02	3.612650e+02	2.053394	4.0352e-02 *

Adjusted R-Squared	**0.50155**

GNI per capita Second Stage Regression Table 2:

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Rural)	1.257704e+04	1.733151e+03	7.256747	9.2101e-13 ***
FDI (% of GDP)	-1.134740e+01	1.189967e+01	-0.953589	3.4057e-01
Agriculture Value Added (% of GDP)	-4.96e-09	4.63e-10	-10.714455	<2.2e-16 ***
GDP per capita	1.284224e+00	6.737041e-02	19.062133	<2.2e-16 ***
Population Growth	5.257769e+02	1.676153e+02	3.136808	1.7690e-03 .**
Government Effectiveness	-6.495259e+01	3.066447e+02	-0.211817	8.3230e-01
Regulatory Quality	7.216197e+02	2.690715e+02	2.681888	7.4682e-03 **

Adjusted R-Squared	0.682527

GNI per capita Second Stage Regression Table 3:

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Urban)	3.247820e+03	5.101299e+02	6.366653	3.2373e-10 ***
FDI (% of GDP)	8.886046e+00	2.159434e+01	0.411499	6.8082e-01
Agriculture Value Added (% of GDP)	-5.18e-09	5.97e-10	-8.674528	<2.2e-16 ***
GDP per capita	1.09925e+00	9.464878e-02	11.614084	<2.2e-16 ***
Population Growth	6.794574e+02	2.142124e+02	3.171886	1.5717e-03 .**
Government Effectiveness	-7.819981e+02	4.618071e+02	-1.693344	9.0776e-02 .
Regulatory Quality	6.938858e+02	3.167123e+02	2.190903	2.8744e-02 **

Adjusted R-Squared	**0.627004**

GNI per capita (Lagged) Second Stage Regression Table 1:

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity	3.278994e+03	4.92272e+02	6.84225	1.6232e-11 ***
FDI (% of GDP)	-3.355136e+01	1.24532e+01	-2.6419	7.2143e-03 **
Agriculture Value Added (% of GDP)	4.06e-09	1.32e-09	2.85825	4.3782e-03 **
GDP per capita	1.744802e-00	3.933146e-02	44.36149	<2.2e-16 ***
Population Growth	-8.813576e+02	1.134570e+02	-7.76820	2.6269e-14 .***
Government Effectiveness	9.856308e+02	3.025262e+02	3.25803	1.1725e-03 **
Regulatory Quality	-9.671721e+02	2.470821e+02	-3.91438	9.8910e-05 ***

Adjusted R-Squared	**0.698989**

GNI per capita (Lagged) Second Stage Regression Table 2:

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity (Rural)	1.545507e+04	3.198781e+03	4.83155	1.6526e-06 ***
FDI (% of GDP)	-4.963569e+01	2.316008e+01	-2.14316	3.2431e-02 **
Agriculture Value Added (% of GDP)	2.13e-09	5.69e-09	3.74938	1.9133e-04 **
GDP per capita	2.018998e+00	9.824606e-02	20.55042	<2.2e-16 ***
Population Growth	-1.158596e+02	1.984253e+02	-5.83895	7.9131e-09 .***
Government Effectiveness	1.804630e+03	1.984253e+02	3.02850	2.5446e-03 **
Regulatory Quality	-1.940277e+03	5.665119e+02	-3.42495	6.4937e-04 ***

Adjusted R-Squared	**-0.022897**

GNI per capita (Lagged) Second Stage Regression Table 3:

Dependent Variable: GNIPC	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity (Urban)	2.073415e+03	2.885369e+02	7.18596	1.6923e-12 ***
FDI (% of GDP)	-3.209714e+01	1.303763e+01	-2.46188	1.4058e-02 *
Agriculture Value Added (% of GDP)	1.79e-09	1.02e-09	1.75221	8.0169e-02 .
GDP per capita	1.782794e+00	4.039015e-02	44.13933	<2.2e-16 ***
Population Growth	-8.838123e+02	1.234104e+02	-7.16157	1.9983e-12 .***
Government Effectiveness	1.036945e+03	2.963775e+02	3.49873	4.9664e-04 ***
Regulatory Quality	-1.202214e+03	2.638265e+02	-4.55685	6.4937e-06 ***

Adjusted R-Squared	**0.673597**

Life Expectancy Second Stage Regression Table 1:

Dependent Variable: Life Expectancy	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity	16.281226	7.033526	2.314803	0.02087955 *
Infant Mortality Rate	-0.014375	0.100840	0.142554	0.088667877
Health Expenditure	-0.006990	0.001933	-3.616504	0.00031759 ***
DPT Immunization	0.155564	0.083160	1.870647	0.06176399 .
Measles Immunization	0.004733	0.047708	0.099210	0.92099633
Hepatitis Immunization	-0.025781	0.01778	-1.449319	0.14764590 **
CO2 Emissions	-0.329274	0.100171	-3.287127	0.00105692 **
Adolescent Birth Rate	0.022293	0.043020	0.518215	0.60445359

Adjusted R-Squared	**0.2985**

Life Expectancy Second Stage Regression Table 2:

Dependent Variable: Life Expectancy	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Rural)	5.488747	7.382263	0.743505	0.45739754
Infant Mortality Rate	-0.174285	0.046739	-3.728912	0.00020606 ***
Health Expenditure	-0.003278	0.001135	-2.814578	0.00500576 **
DPT Immunization	-0.016565	0.051447	0.321987	0.74754762
Measles Immunization	0.002753	0.043466	0.063336	0.94951486 .
Hepatitis Immunization	-0.024622	0.015475	-1.591091	0.11198961
CO2 Emissions	-0.161589	0.064227	-2.515900	0.01207033 *
Adolescent Birth Rate	-0.061076	0.021324	-2.864259	0.00429082 **

Adjusted R-Squared	**0.604493**

Life Expectancy Second Stage Regression Table 3:

Dependent Variable: Life Expectancy	Estimate	Robust Standard Error	T value	P-value
Logged (IV) Access to Electricity (Urban)	5.690453	2.636661	2.158204	0.03121684 *
Infant Mortality Rate	-0.064463	0.070499	-0.914378	0.36080137
Health Expenditure	-0.005633	0.001522	-3.700084	0.00023069 ***
DPT Immunization	0.061717	0.054250	1.137649	0.25561690
Measles Immunization	0.016676	0.047114	0.353946	0.72347505 .
Hepatitis Immunization	-0.002758	0.018950	-0.145564	0.88430338
CO2 Emissions	-0.255414	0.071939	-3.550420	0.00040770 ***
Adolescent Birth Rate	-0.012042	0.032234	-0.373599	0.70880421

Adjusted R-Squared	**0.5015**

Life Expectancy(Lagged) Second Stage Regression Table 1:

Dependent Variable: Logged LE	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity	-4.670602	1.107721	-4.216407	2.972e-05 ***
Infant Mortality Rate	-0.192742	0.028424	-6.781050	2.4808e-11 ***
Health Expenditure	-0.003593	0.001266	-2.837801	4.6698e-03 **
DPT Immunization	-0.14844	0.059985	-0.247464	0.80462 .
Measles Immunization	0.0055633	0.061359	0.906680	0.36488
Hepatitis Immunization	-0.025781	0.034544	-1.628474	0.10386 **
CO2 Emissions	-0.329274	0.087389	-1.144534	0.25278 **
Adolescent Birth Rate	0.022293	0.009358	-6.482445	1.6708e-10 ***

Adjusted R-Squared	**0.228861**

Life Expectancy (Lagged) Second Stage Regression Table 2:

Dependent Variable: Life Expectancy	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity (Rural)	-9.960424	2.677017	-3.720717	2.1454e-04 ***
Infant Mortality Rate	-0.166055	0.027609	-6.014533	2.9022e-09 ***
Health Expenditure	-0.003278	0.001190	-2.754757	6.0257e-03 **
DPT Immunization	-0.045007	0.059200	-0.760252	4.4736e-01
Measles Immunization	0.106846	0.062255	1.716253	8.6557e-02 .
Hepatitis Immunization	-0.029891	0.024352	-1.227443	2.2007e-01
CO2 Emissions	-0.274427	0.081780	-3.355663	8.3437e-04 ***
Adolescent Birth Rate	-0.068408	0.009426	-7.257243	1.0494e-12 ***

Adjusted R-Squared	**0.269784**

Life Expectancy (Lagged) Second Stage Regression Table 3:

Dependent Variable: Life Expectancy	Estimate	Robust Standard Error	T value	P-value
Lagged and Logged (IV) Access to Electricity (Urban)	-3.711014	0.867293	-4.278846	2.1462e-05 ***
Infant Mortality Rate	-0.175983	0.030211	-5.825164	8.7774e-09 ***
Health Expenditure	-0.003346	0.001287	-2.599341	9.5414e-03 **
DPT Immunization	-0.049501	0.069111	-0.716254	4.7408e-01
Measles Immunization	0.025578	0.067681	0.377925	7.0560e-01.
Hepatitis Immunization	-0.008250	0.028528	-0.289185	7.7253e-01
CO2 Emissions	0.053417	0.113321	0.471378	6.3752e-01
Adolescent Birth Rate	-0.069342	0.010578	-6.555272	1.0931e-10 ***

Adjusted R-Squared	**0.063745**

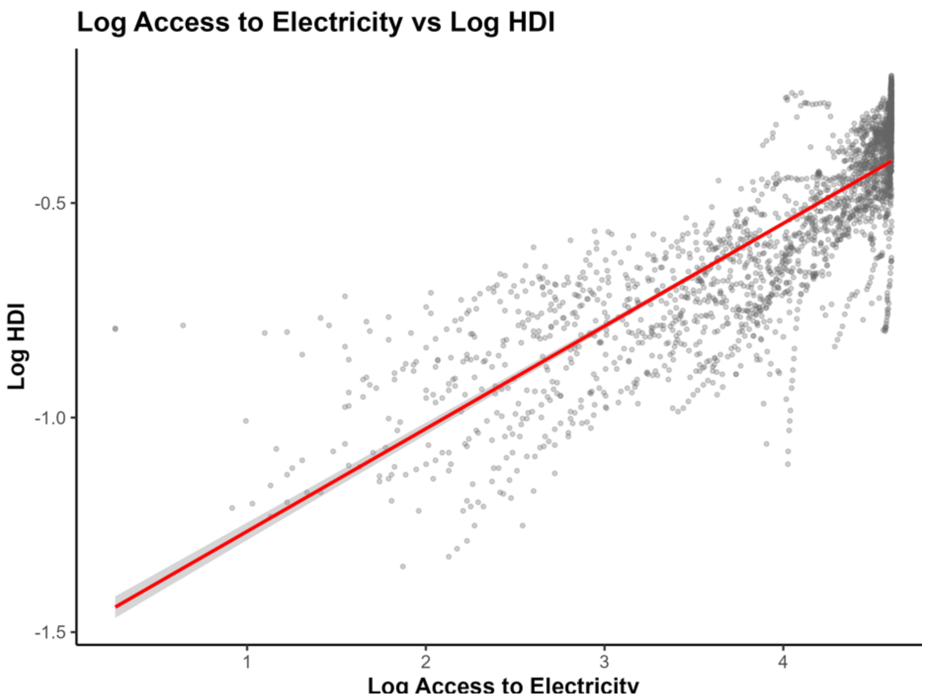
Baseline OLS Regression:

Dependent Variable: Logged HDI	Estimate	Robust Standard Error	T value	P-value
Logged Access to Electricity	0.208167	0.008540	24.37535	< 2.2e-16 ***
Agriculture value added (% of GDP)	-0.003657	0.000390	-9.38114	<2.2e-16 ***
Population Growth	-0.008364	0.003209	-2.60678	9.2958e-03 **
Government Effectiveness	0.035991	0.006726	5.35063	1.1208e-07 .***
Immunization (DPT)	0.002943	0.000284	10.37826	<2.2e-16 ***
Political Stability	-0.000595	0.000210	-2.83763	4.6505e-03 **

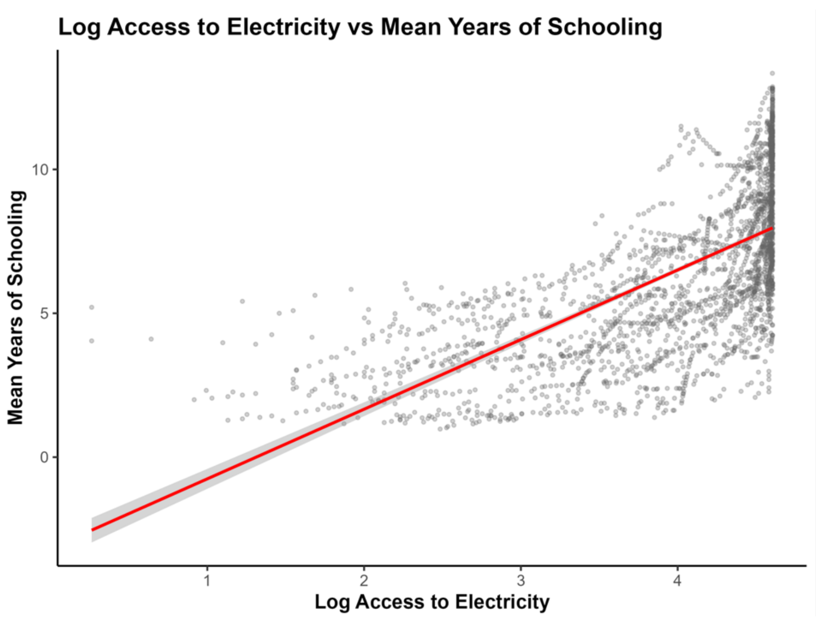
Adjusted R-Squared	**0.764866**

Graphical Relationships

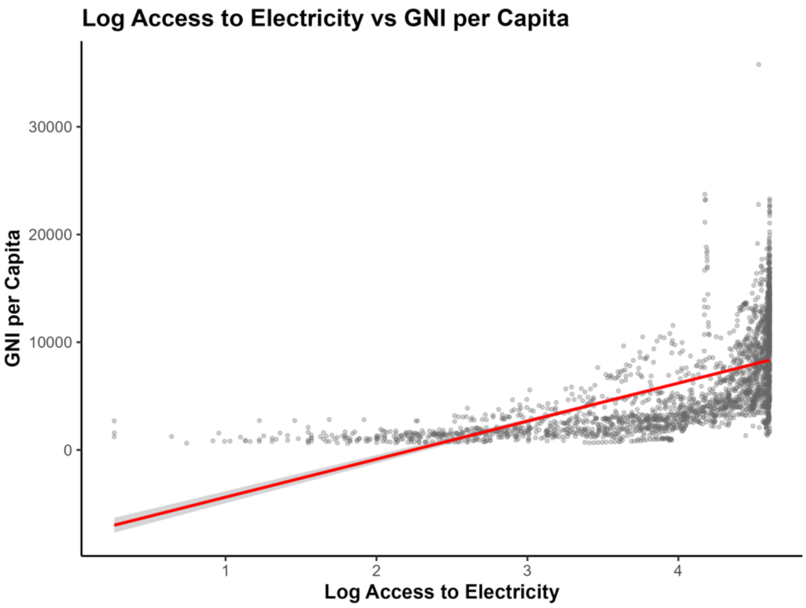
HDI and Electricity Access Correlation:



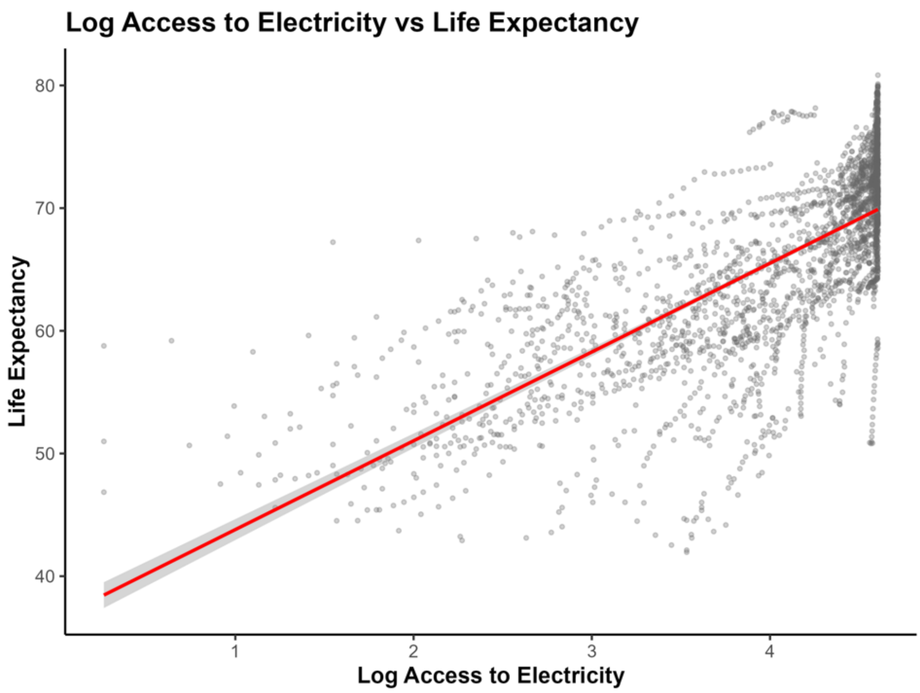
Mean Years of Schooling and Electricity Access Correlation:



GNI per capita and Electricity Access Correlation:



Life Expectancy and Electricity Access Correlation:



Robustness Checks

HDI Robustness Check:

	HDI Baseline	HDI excl. agri_gdp_percent	HDI excl. pop_growth	HDI excl. gov_effectiveness_est	HDI excl. immun_dpt	HDI excl. pol_stability_rank
fit_log_access_electricity	0.157**	0.229***	0.196***	0.219***	0.246***	0.193***
	(0.057)	(0.032)	(0.053)	(0.053)	(0.047)	(0.044)
Num.Obs.	892	908	892	892	892	892
R2	0.761	0.753	0.767	0.764	0.746	0.766
R2 Adj.	0.756	0.748	0.762	0.760	0.740	0.761
R2 Within	0.746	0.740	0.753	0.750	0.730	0.752
R2 Within Adj.	0.745	0.739	0.751	0.749	0.729	0.751
AIC	−1477.9	−1481.3	−1501.6	−1493.8	−1425.0	−1499.5
BIC	−1382.0	−1389.9	−1410.5	−1402.7	−1334.0	−1408.4
RMSE	0.10	0.10	0.10	0.10	0.11	0.10
Std.Errors	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust
FE: year	X	X	X	X	X	X

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Mean Years of Schooling Robustness Check:

	MYS Baseline	MYS excl. female_literacy	MYS excl. net_enroll_primary	MYS excl. edu_spending_percent_gdp	MYS excl. pupil_teacher_ratio_sec	MYS excl. pop_growth	MYS excl. gdp_pc_const_usd
fit_log_access_electricity	−4.000	−2.940	−0.786	−1.775	2.836	−12.682	−6.496
	(4.915)	(3.072)	(2.039)	(1.718)	(1.763)	(36.332)	(8.291)
Num.Obs.	67	268	83	95	124	67	67
R2	0.615	0.242	0.730	0.649	0.643	−0.603	0.401
R2 Adj.	0.435	0.181	0.643	0.554	0.573	−1.300	0.140
R2 Within	0.504	0.228	0.653	0.546	0.597	−1.063	0.229
R2 Within Adj.	0.427	0.210	0.620	0.509	0.574	−1.332	0.128
AIC	289.9	1292.5	327.3	377.0	500.5	383.5	317.5
BIC	338.4	1367.9	378.1	430.6	559.8	429.8	363.8
RMSE	1.52	2.49	1.35	1.41	1.54	3.09	1.89
Std.Errors	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust
FE: year	X	X	X	X	X	X	X

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

GNI per Capita Robustness Check:

	GNIPC Baseline	GNIPC excl. fdi_percent_gdp	GNIPC excl. agri_value_usd	GNIPC excl. gdp_pc_const_usd	GNIPC excl. pop_growth	GNIPC excl. gov_effectiveness_est	GNIPC excl. reg_quality_est
fit_log_access_electricity	7171.908***	5691.517***	6525.801***	9214.343***	6339.214***	6832.003***	6703.997***
	(1351.636)	(938.492)	(1208.682)	(1312.631)	(1000.475)	(1042.022)	(1143.420)
Num.Obs.	840	878	855	840	840	840	840
R2	0.513	0.613	0.580	0.135	0.575	0.556	0.568
R2 Adj.	0.502	0.604	0.570	0.115	0.565	0.545	0.558
R2 Within	0.489	0.592	0.557	0.091	0.553	0.533	0.547
R2 Within Adj.	0.485	0.590	0.553	0.085	0.550	0.530	0.543
AIC	15793.3	16307.7	15938.5	16274.6	15678.4	15715.1	15690.7
BIC	15892.7	16403.3	16033.5	16369.2	15773.1	15809.8	15785.3
RMSE	2855.00	2553.27	2639.76	3806.61	2669.48	2728.48	2689.02
Std.Errors	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust
FE: year	X	X	X	X	X	X	X

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Life Expectancy Robustness Check:

	LE Baseline	LE excl. infant_mortality	LE excl. health_exp_pc_ppp	LE excl. immun_dpt	LE excl. immun_measles	LE excl. immun_hepb3	LE excl. co2_prod	LE excl. abr
fit_log_access_electricity	16.281*	13.941*	5.936	17.168*	16.021*	23.625**	6.922	6.665+
	(7.034)	(6.024)	(4.334)	(6.704)	(7.023)	(8.745)	(4.805)	(3.969)
Num.Obs.	812	812	833	812	812	972	812	812
R2	0.318	0.417	0.587	0.262	0.330	−0.133	0.592	0.577
R2 Adj.	0.298	0.401	0.576	0.242	0.312	−0.158	0.581	0.566
R2 Within	0.312	0.412	0.582	0.255	0.324	−0.183	0.589	0.573
R2 Within Adj.	0.305	0.407	0.578	0.249	0.318	−0.192	0.585	0.570
AIC	5155.6	5025.7	4954.9	5217.5	5139.1	6869.6	4735.7	4765.1
BIC	5263.7	5129.1	5058.9	5320.8	5242.5	6976.9	4839.1	4868.5
RMSE	5.63	5.20	4.61	5.85	5.58	8.10	4.35	4.43
Std.Errors	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticity-robust	Heteroskedasticit robust
FE: year	X	X	X	X	X	X	X	X

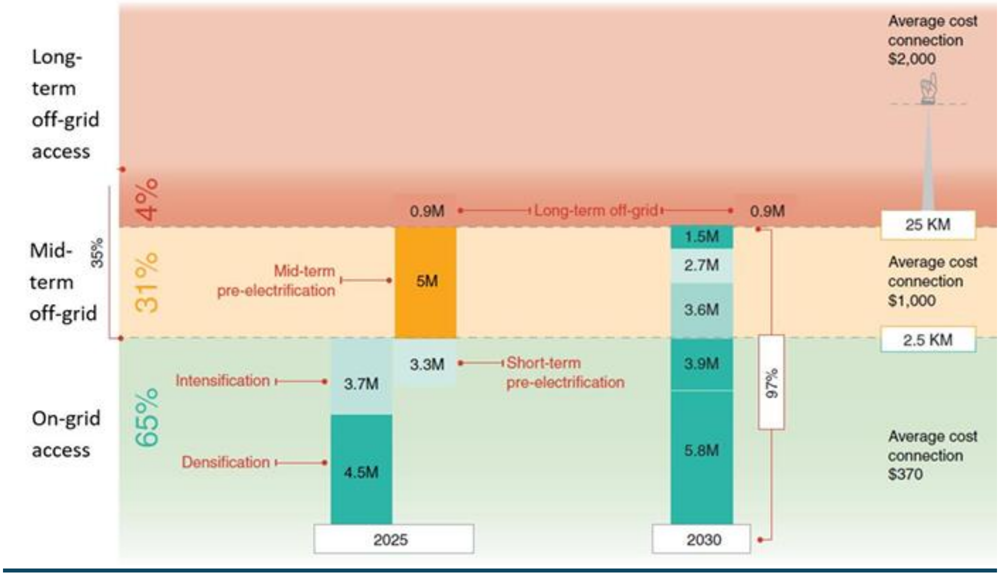
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Main Regression Robustness Checks:

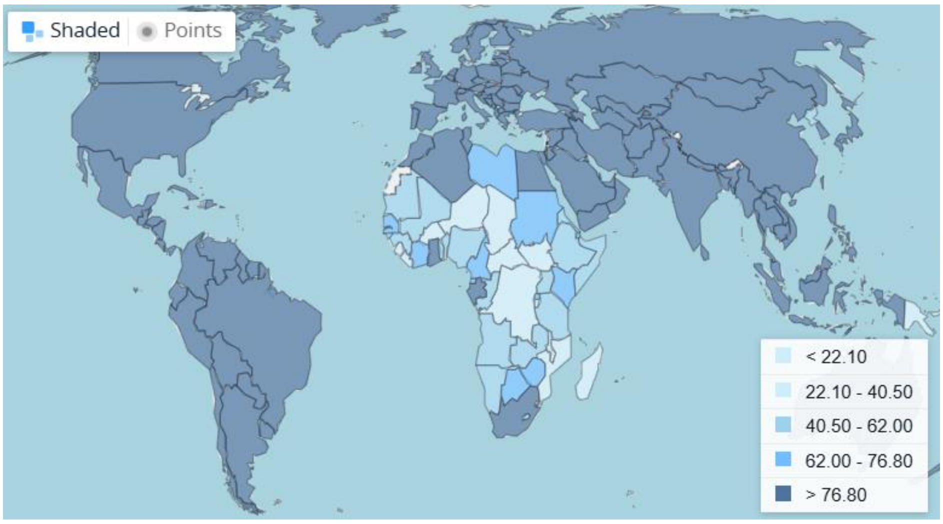
Test	Coefficient	p-value	Interpretation
Wu-Hausman Test	Coefficient (residual): 0.052	0.352	No strong evidence of endogeneity rejection (p > 0.05)
Anderson-Rubin Test	F-stat = 10.41	0.012	Significant; robust to weak instruments
Weak Instrument F-Stat	F = 11.654	< 0.001	Above threshold of 10 → instruments are sufficiently strong
Hansen's J Test	J-stat = 22.469	< 0.001	Rejects null → at least one instrument may be invalid
Goldfeld–Quandt Test	GQ = 0.569	1.000	No evidence of heteroskedasticity in residuals

Research Figures:

Research Figure 1:

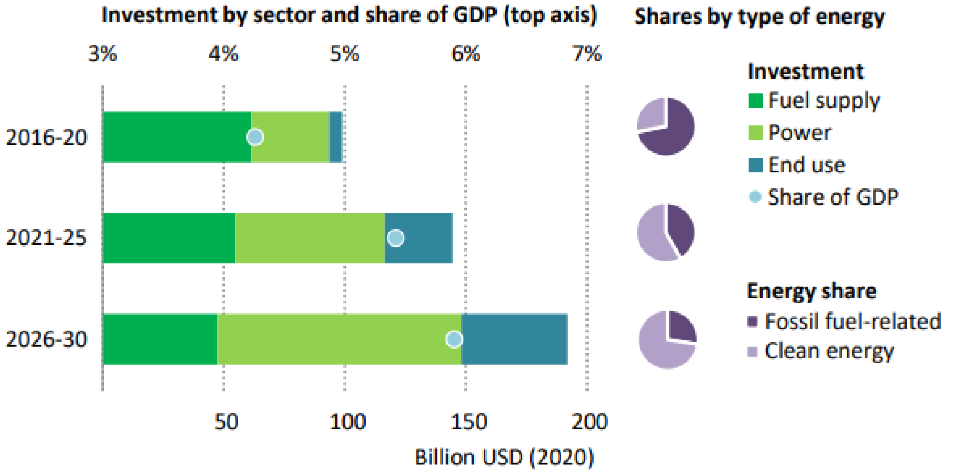


Research Figure 2:



Research Figure 3:

Figure 3.30 ▹ Annual average investment by sector in Africa in the SAS



Energy investment almost doubles over the 2026-2030 period relative to 2016-2020, reaching the equivalent of 6% of GDP, with spending on clean energy increasing sixfold

Summary Statistics:

Summary Table 1.

	country	cc	year	access_clean_cooking	access_electricity
count	2599	2599	2599	2599	2466
unique	113	113	n/a	n/a	n/a
freq	23	23	n/a	n/a	n/a
mean	n/a	n/a	2011	42.02241247	66.25965126
std	n/a	n/a	6.634526065	35.88118414	32.21785777
min	n/a	n/a	2000	0	1.3
25%	n/a	n/a	2005	6.1	37.8
50%	n/a	n/a	2011	35.8	76.45
75%	n/a	n/a	2017	79.8	97.7
max	n/a	n/a	2022	100	100

Summary Table 2.

	access_electricity_urban	access_electricity_rural	net_enroll_primary	agri_gdp_percent	agri_value_usd
count	2302	2434	1208	2360	2297
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	58.08268462	83.37263763	86.3373495	17.35997738	18774066130
std	37.23561882	21.11919394	14.71572577	10.63649892	90153815839
min	0.5	3.5	26.8954	0.800262	5900000
25%	19.5	72.6	81.35155	8.7304775	820000000
50%	68.05	93.8	92.1085	15.70615	2300000000
75%	96.2	99.5	96.845075	24.182825	7200000000
max	100	100	100	79.0424	1.2E+12

Summary Table 3.

	agri_value_lcu	health_exp_pc_ppp	elec_losses_percent	agri_employment_percent	fdi_percent_gdp
count	2316	2307	1002	2369	2196
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	2.91404E+13	339.9663671	18.30475237	40.47106778	3.831470215
std	1.64663E+14	349.6394267	11.72301743	20.09130259	6.550877834
min	12000000	10.4187	2.66956	1.17735	-37.1727
25%	6275000000	103.744	11.02885	24.722	0.9435985
50%	1.1E+11	208.895	15.37605	38.5271	2.51358
75%	1.525E+12	469.5505	21.951275	54.6	5.039075
max	1.6E+15	3176.12	88.0239	91.9297	103.337

Summary Table 4.

	gdp_pc_const_usd	gdp_pc_growth	gov_effectiveness_est	gov_effectiveness_sources	gov_effectiveness_rank
count	2437	2435	2352	2352	2352
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	2811.561982	2.453984283	-0.629008994	7.090136054	31.61199283
std	2340.178732	5.568142678	0.581662986	2.92446312	19.38472423
min	233.032	-38.5382	-2.44023	1	0
25%	1008.23	0.3367625	-1.0071575	5	15.1582
50%	2086.08	2.59218	-0.6435505	8	30.2571
75%	4030.2	4.696175	-0.215815	9	46.6667
max	17365.3	77.0896	0.872711	12	80.3279

Summary Table 5.

	edu_spending_percent_gdp	immun_dpt	immun_hepb3	immun_measles	female_literacy
count	1693	2482	2172	2482	582
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	4.248825666	82.21152297	83.05985267	81.19379533	72.1393646
std	2.171596907	16.41297388	16.66720093	16.66186692	24.70403836
min	0.348517	0	0	16	9
25%	2.77645	75	76	71	55
50%	3.79476	87	89	86	80.03285
75%	5.31744	95	95	95	92.95
max	15.377	99	99	99	100

Summary Table 6.

	infant_mortality	pm25_exposure	pol_stability_sources	pol_stability_rank	pop_growth
count	2484	2268	2366	2366	2484
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	39.44005636	31.41280023	5.477599324	35.4630112	1.680431324
std	25.10671549	16.25980163	1.904297217	23.57240447	1.319258154
min	4.1	5.23845	1	0	-4.13566
25%	18.9	20.27345	4	16.9903	0.91949225
50%	33	26.53305	6	32.381	1.68235
75%	55.7	40.2396	7	49.52265	2.5636625
max	138.3	107.145	10	99.0291	9.53921

	pupil_teacher_ratio_sec	reg_quality_est	gov_effectiveness_sources.1	reg_quality_rank	abr
count	984	2353	2353	2353	2599
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	21.90196739	[illegible]	7.314067148	31.29911077	74.41133566
std	8.968638034	0.628174325	2.559671238	18.84067429	[illegible]
min	5.31356	-2.54473	1	0	0.876
25%	15.315	-1.01475	5	15.2381	38.969
50%	20.51765	-0.578913	8	30.4762	68.766
75%	27.10065	-0.225915	9	45.933	101.9825
max	80.0523	1.05342	14	82.8571	205.385

Summary Table 7.

Summary Table 8.

	co2_prod	coef_ineq	diff_hdi_phdi	eys	eys_f
count	2599	1142	1990	2547	2506
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	1.62304632	27.64192491	3.392924915	10.95980909	10.80513
std	2.219475088	9.649325384	2.811068033	2.554911101	2.972846
min	0.019351581	6.859257	0.303030303	2.712899945	2.16437
25%	0.300933571	19.72644167	1.409279205	9.271498438	8.769833
50%	0.927078272	29.23577112	2.578201369	11.19850826	11.14368
75%	2.028681756	35.52049375	4.34040239	12.74223401	12.91962
max	16.5698813	47.121947	20.29177719	17.52378082	19.03713

Summary Table 9.

	eys_m	gdi	gdi_group	gii	gii_rank
count	2506	2086	105	1948	97
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	11.10191	0.906849	3.104762	0.491757	112.4948
std	2.254559	0.077823	1.518627	0.137553	34.95477
min	3.292099	0.456	1	0.116	34
25%	9.704058	0.864	2	0.401	89
50%	11.35575	0.923	3	0.506	115
75%	12.62265	0.961	5	0.599	142
max	16.46576	1.054	5	0.838	166

Summary Table 10.

	gni_pc_f	gni_pc_m	gnipc	hdi	hdi_f
count	2132	2132	2576	2506	2086
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	4296.002	8404.467	6110.17	0.590432	0.569539
std	3332.878	6062.693	4530.85	0.123887	0.129607
min	149.9717	660.6028	608.6782	0.26	0.201504
25%	1898.767	3454.623	2501.278	0.49	0.466421
50%	3167.501	6761.11	4682.222	0.6015	0.575994
75%	6067.5	12353.7	9188.649	0.698	0.677161
max	26504.52	45454.04	35782.91	0.816	0.814952

Summary Table 11.

	hdi_m	ihdi	ineq_edu	ineq_inc	ineq_le
count	2086	1142	1260	1282	1469
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	0.62314	0.446626	26.8402	34.15234	20.25904
std	0.110411	0.140679	14.09172	12.48336	10.0321
min	0.307677	0.184	1.77101	3.587569	3.978745
25%	0.538728	0.32625	15.00384	24.06125	11.55366
50%	0.632152	0.427	27.53963	33.37667	18.91902
75%	0.714107	0.57675	39.84142	43.42511	27.71684
max	0.817139	0.74	50.83121	67.58846	48.61643

Summary Table 12.

	le	le_f	le_m	lfpr_f	lfpr_m
count	2599	2599	2599	2128	2128
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	65.35248	67.75321	63.03396	49.6667	72.11024
std	7.835764	8.408559	7.407326	18.90989	10.47902
min	41.957	42.487	40.689	5.61	29.63
25%	60.074	61.835	58.264	37.29	65.8325
50%	66.437	69.079	63.945	50.82	73.495
75%	71.437	74.4775	68.5415	63.505	79.5725
max	80.839	83.929	80.065	94.4	98.58

Summary Table 13.

	loss	mf	mmr	mys	mys_f
count	1142	2040	2530	2511	2501
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	28.29216	6.373278	281.6235	6.467878	5.924849
std	9.846912	4.309675	284.7095	2.88427	3.184632
min	6.910569	0.0001	2.879425	0.97693	0.37451
25%	20.12256	3.228475	62.37705	4.164627	3.2598
50%	30.20008	5.13365	167.0087	6.27025	5.586644
75%	36.0567	8.2371	443.005	8.646399	8.524793
max	48.45938	30.8951	1682.449	13.34078	13.36542

Summary Table 14.

	mys_m	phdi	pop_total	pr_f	pr_m
count	2501	1990	2599	2570	2570
unique	n/a	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a	n/a
mean	7.057308	0.562084	45.65415	16.90019	83.09981
std	2.627387	0.11579	173.9355	11.17706	11.17706
min	1.235022	0.259	0.009609	0.01	42.45283
25%	5.053568	0.472	2.570504	8.695652	76.69999
50%	6.982294	0.572	9.781997	14.93289	85.06711
75%	8.81783	0.662	26.20696	23.30001	91.30435
max	13.31106	0.771	1425.893	57.54717	99.99

Summary Table 15.

	rankdiff_hdi_phdi	se_f	se_m	renewable_output
count	89	2244	2244	1812
unique	n/a	n/a	n/a	n/a
freq	n/a	n/a	n/a	n/a
mean	4.752808989	38.51549297	46.49853	37.66728125
std	8.399514189	27.95782732	25.54523	35.70655877
min	-23	0.941760004	3.23734	0
25%	1	14.67633487	26.3006	3.002415
50%	3	31.58333311	41.79758	28.89085
75%	10	55.80210548	63.57153	67.409525
max	24	100	100	100