International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(4), 83-92.

Energy Infrastructure, Institutions, and Trade Openness: Reassessing the Lucas Paradox in the COMESA Region

Geoffrey Aori Mabea[1]*, Gideon C. Mwanza[2]

[1]Common Market for Eastern and Southern Africa, Lusaka, Zambia, [2]Gideon Robert University, Lusaka, Zambia.

*Email: geoffrey.mabea@gmail.com

Received: 11 February 2026 **Accepted:** 09 June 2026 **DOI:** https://doi.org/10.32479/ijeep.23486

ABSTRACT

The Standard neoclassical theory predicts that international capital should flow toward economies where the marginal returns are the highest. However, foreign direct investment (FDI) continues to bypass many capital-scarce developing regions, a contradiction widely referred to as the Lucas Paradox. This study re-examines the paradox in the Common Market for Eastern and Southern Africa (COMESA) by focusing on energy infrastructure reliability as a determinant of risk-adjusted capital return. Using a balanced panel of 21 COMESA economies over the period 2009-2023, the analysis combines country fixed effects, instrumental variable estimation, and a continuous treatment generalised propensity score (CTGPS) framework. Installed electricity capacity is instrumented using exogenous geophysical variations in solar irradiation and wind potentials. The results indicate that expansion in installed capacity is associated with higher FDI inflows. However, the magnitude of this effect depends critically on institutional quality and trade openness. The relationship is nonlinear, with large gains at low-capacity levels and diminishing marginal effects as the energy systems mature. Overall, the findings suggest that international capital responds to credible and reliable returns rather than nominal productivity alone, providing a risk-adjusted resolution of the Lucas Paradox in the COMESA context.

Keywords: Foreign Direct Investment, Energy Infrastructure, Electricity Reliability, Institutions, Trade Openness, Instrumental Variables, Generalised Propensity Score

JEL Classifications: F21, F23, O13, O16, Q42

1. INTRODUCTION

Classical growth theory predicts that international capital should flow from capital-abundant to capital-scarce economies until marginal returns converge. In such a framework, poorer economies with lower capital–labour ratios should attract substantial foreign investment. However, this prediction fails systematically. Despite exhibiting high marginal products of capital, developing economies receive far less foreign direct investment (FDI) than neoclassical theory implies (Borensztein et al., 1998). Lucas (1990) formalised this contradiction as the Lucas Paradox. This puzzle has remained central to international macroeconomics for over three decades.

A large body of literature attributes this paradox to differences in risk, rather than productivity. Weak institutions, insecure property rights, political instability, and policy uncertainty increase the variance of investment returns and the risk premium demanded by foreign investors (Acemoglu et al., 2001; Alfaro et al., 2008; Wei and Shleifer, 2000). Once these distortions are accounted for, cross-country differences in risk-adjusted returns are smaller than the differences in the measured marginal products of capital (Caselli and Feyrer, 2007). From this perspective, capital allocation reflects rational responses to uncertainty rather than a failure of the neoclassical logic.

While this institutional explanation is empirically compelling, it overlooks a fundamental production constraint in many developing economies: the reliability of energy infrastructure. In low- and middle-income regions, electricity supply is often characterised not only by insufficient capacity but also by frequent outages, transmission losses, and grid instability. Such disruptions increase operating costs, interrupt production processes, and reduce effective capacity utilisation. Even when the installed generation capacity expands, an unreliable supply increases the variance of realised returns, thereby lowering the expected return, net of risk.

Therefore, energy infrastructure influences investment incentives through two channels. First, it operates as a technological input. Reliable electricity allows firms to operate at scale, reduces downtime, and increases the effective marginal productivity of capital. Second, it functions as an institutional signal for the government. The sustained provision of reliable electricity reflects the state's ability to plan, regulate, and commit credibly to long-term policies. In this sense, energy reliability conveys information about broader governance quality, regulatory competence, and policy credibility, all of which are central to investors' risk assessment.

The Common Market for Eastern and Southern Africa (COMESA) offer a suitable setting for examining this mechanism. Between 2009 and 2023, the COMESA member states undertook substantial investments in power generation, nearly doubling the installed electricity capacity at the regional level. However, FDI inflows remained modest and highly uneven across the countries. Average FDI inflows were modest at 3.1% of GDP and concentrated in countries with stronger institutions, such as Egypt and Mauritius. Several countries have experienced net divestment despite rapid capacity expansion. These patterns suggest that expanding capacity alone is insufficient to attract foreign capital in the absence of credible and reliable supports.

This study reassesses the Lucas Paradox by jointly analysing energy infrastructure, institutional quality, and trade openness as interacting determinants of risk-adjusted capital returns in the COMESA region. The analysis addressed three, interrelated questions. First, does the expansion of installed electricity capacity increase FDI inflows once unobserved heterogeneity and endogeneity are accounted for? Second, do institutional quality and trade openness condition the effectiveness of energy infrastructure in attracting foreign capital investment? Third, are the returns to energy expansion characterised by non-linearities and diminishing marginal effects?

To answer these questions, this study employs a multilayered empirical approach. Baseline fixed-effects models exploit within-country variations over time but may remain biased if energy investments respond to contemporaneous investment conditions. To address simultaneity and omitted variable bias, the installed capacity is instrumented using exogenous geophysical variations in solar irradiation and wind potential. These instruments affect the feasibility of power generation but are orthogonal to short-run investments. Finally, a generalised propensity score (GPS) framework is used to trace the continuous dose–response relationship between incremental capacity expansion and FDI inflows, allowing for non-linear effects and diminishing returns.

The results indicate that increases in installed electricity capacity are associated with higher FDI inflows. However, the magnitude of this effect depends critically on institutional quality and trade openness. Moreover, the relationship is non-linear: capacity expansion yields the largest gains in investment at low initial levels, with marginal effects declining as the energy systems mature. Taken together, these findings imply that international capital responds to credible and reliable returns, rather than nominal productivity alone. By highlighting the role of energy reliability as both a productive input and a signal of institutional credibility, this study provides a risk-adjusted resolution of the Lucas Paradox in the context of COMESA. Section 2 reviews the literature. Section 3 describes the data. Section 4 presents the theory. Section 5 details the empirics. Section 6 reports the results. Section 7 discusses the implications.

2. RELATED LITERATURE

This study relates to three strands of the literature: explanations of the Lucas Paradox based on risk-adjusted returns; studies linking infrastructure—particularly energy systems—to investment and productivity; and studies on the conditioning roles of institutions and trade openness.

2.1. The Lucas Paradox and Risk-Adjusted Returns

Lucas (1990) observed that international capital does not flow from rich to poor countries in the magnitudes predicted by neoclassical theory, despite large differences in capital–labour ratios. Subsequent research has reframed the paradox as a risk rather than a productivity problem. Acemoglu et al. (2001) argue that weak property rights and political institutions raise expropriation risks and depress investment incentives. Alfaro et al. (2008) show that institutional quality explains a substantial share of cross-country variations in capital flows, even after controlling for financial development and macroeconomic fundamentals in the host country.

Caselli and Feyrer (2007) demonstrate that once distortions and risk premia are accounted for, the marginal products of capital are far more similar across countries than suggested by the raw data, implying that low investment in developing economies reflects high effective risk rather than low returns. Related studies highlight informational asymmetries, corruption, and policy uncertainty as mechanisms through which risk is transmitted to investors (Wei and Shleifer, 2000; Mukherjee, 2015; Busse and Hefeker, 2007; Matta et al., 2022). In this literature, capital allocation is consistent with rational behaviour under uncertainty: investors respond to expected returns net of risk, not to nominal productivity.

2.2. Infrastructure, Energy, and Investment

A complementary body of work identifies infrastructure and exchange rate uncertainty as a key determinant of productivity and investment volatility (Mensah et al., 2021). Calderón and Servén (2010) and Burlig and Preonas (2024) show that infrastructure deficits in sub-Saharan Africa are associated with lower growth and higher volatility. Esfahani and Ramírez (2003) and Mbedzi and Kapingura (2023) emphasise that infrastructure affects not only the level of output but also its stability, thereby influencing investment decisions through risk.

Energy infrastructure plays a central role in the literature. Firm-level evidence from India indicates that electricity shortages significantly reduce productivity and profitability (Allcott et al., 2016; Jha et al., 2022), while Rud (2012) documents large employment and output gains after electrification. More recent studies have stressed that reliability is as important as capacity. Dube and Horvey (2023) found that African economies with more stable electricity supplies attract higher levels of renewable energy FDI, suggesting that predictable energy supply reduces perceived investment risk.

These findings imply that energy systems influence capital allocation through both cost and uncertainty channels. However, much of the empirical literature treats energy infrastructure as an exogenous control, limiting causal interpretation and obscuring the interaction between infrastructure and institutional environments.

2.3. Institutions, Trade Openness, and Complementarity

Institutions and trade openness shape how infrastructure investments translate into productive outcomes (Daude and Stein, 2007; Rodrik et al., 2004). North (1991) emphasises that credible institutions reduce transaction costs and uncertainty, enabling long-term contracts and investments. Freund and Bolaky (2008) and Aichele and Felbermay (2015) show that trade openness enhances growth especially when regulatory quality allows for efficient resource reallocation. Egger and Radulescu (2011) provide evidence that governance quality and openness jointly increase FDI responsiveness in developing economies.

A growing body of literature highlights the importance of policy coherence across various domains. Trade liberalisation can expand market size and facilitate technology diffusion; however, its benefits depend on complementary infrastructure and institutional capacity. Conversely, infrastructure investment may yield limited returns in closed or poorly governed economies. Despite these insights, few studies have estimated the interaction between energy infrastructure, institutional quality, and trade openness within a unified empirical framework, and even fewer have allowed nonlinear or threshold effects in infrastructure returns.

This study contributes to the literature in three main ways. (1) Endogenous energy via IV, (2) interactions, and (3) GPS nonlinearities. In doing so, this study links the infrastructure and institutions literature to a risk-adjusted interpretation of the Lucas Paradox in the context of the COMESA region's economies.

2.4. Data and Descriptive Evidence

The empirical analysis is based on a balanced panel of 21 member states of the Common Market for Eastern and Southern Africa (COMESA), observed annually from 2009 to 2023, yielding 315 country–year observations. The countries included in the sample are Burundi, Comoros, the Democratic Republic of Congo, Djibouti, Egypt, Eritrea, Eswatini, Ethiopia, Kenya, Libya, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, Somalia, Sudan, Tunisia, Uganda, Zambia and Zimbabwe. The balanced structure of the panel ensures that the estimated effects are not driven by changes in sample composition over time.

Foreign direct investment inflows, expressed as a percentage of GDP, are obtained from the United Nations Conference on Trade and Development (UNCTAD) and World Development Indicators (WDI) databases (World Bank, 2025). Electricity infrastructure variables were compiled from the International Energy Agency (IEA) and African Development Bank (AfDB). Institutional quality indicators, such as the rule of law, corruption control, and political stability, are drawn from the Worldwide Governance Indicators (WGI). Trade openness and macroeconomic controls were obtained from the WDI. The exogenous geophysical variables used as instruments, namely solar irradiation, and wind potential, were obtained from NASA's Surface Solar Energy database and the Global Wind Atlas, respectively.

All nominal variables are expressed in US dollars at the 2015 prices. Variables exhibiting extreme skewness or containing zero and negative values, such as FDI inflows and inflation, were transformed using the inverse hyperbolic sine (IHS) transformation (Bellemare and Wichman, 2020). Strictly positive variables, including installed electricity capacity and GDP per capita, were log-transformed to facilitate interpretation and reduce the heteroskedasticity. All continuous variables were winsorised at the 1st and 99th percentiles to limit the influence of outliers.

Table 1 reports the descriptive statistics for the key variables. Average FDI inflows amount to approximately 3.1% of GDP, with substantial dispersion across countries and years, including episodes of negative inflows reflecting divestment. Installed electricity capacity exhibits pronounced heterogeneity, reflecting differences in country size, resource endowments and historical investment patterns. Electricity access averages just over half the population, underscoring the prevalence of supply constraints and reliability challenges in the region. Institutional quality indicators are, on average, below zero, consistent with weak governance

Table 1: Descriptive statistics (2009-2023)

Variable	Mean	Standard deviation	Min.	Max.	Observations
FDI inflows (% of GDP)	3.1	2.4	–1.5	10.2	315
Installed capacity (MW/1,000 people)	3.79	9.64	0.02	59.68	315
Electricity access (%)	56.1	34.8	9.7	100	315
Rule of law	–0.74	0.72	–2.45	1.02	315
Trade openness (%)	61.0	35.6	0.3	288	315
GDP growth (%)	3.9	8.0	–50.3	86.8	315
Inflation (IHS)	1.58	14.13	0.01	191.20	315
Solar irradiation (kWh/m²/day)	5.7	0.9	4.0	7.2	315
Wind potential (m/s)	5.2	0.8	3.8	7.0	315

All variables are winsorised at the 1st and 99th percentiles. Inflation and FDI were transformed using an inverse hyperbolic sine. The installed capacity is expressed as per 1,000 people environments, whereas trade openness varies widely across countries.

Figure 1 plots the regional averages of installed electricity capacity and FDI inflows over time. Installed capacity increased steadily between 2009 and 2023, reflecting large-scale investments in generation infrastructure in the country. In contrast, FDI inflows remained volatile and comparatively modest, with no clear upward trends. This divergence motivates a focus on risk-adjusted mechanisms rather than capacity expansion alone. The figure is descriptive and does not imply a causal relationship.

2.5. Theoretical Framework

This section develops a risk-adjusted framework linking energy infrastructure, institutional quality, and trade openness to foreign direct investment. The objective is not to introduce a new growth model but to formalise a mechanism through which energy reliability affects the expected marginal product of capital and, in turn, international capital allocation. The framework provides a direct mapping to the empirical specifications estimated in Sections 5 and 6.

2.6. Production with Energy Reliability

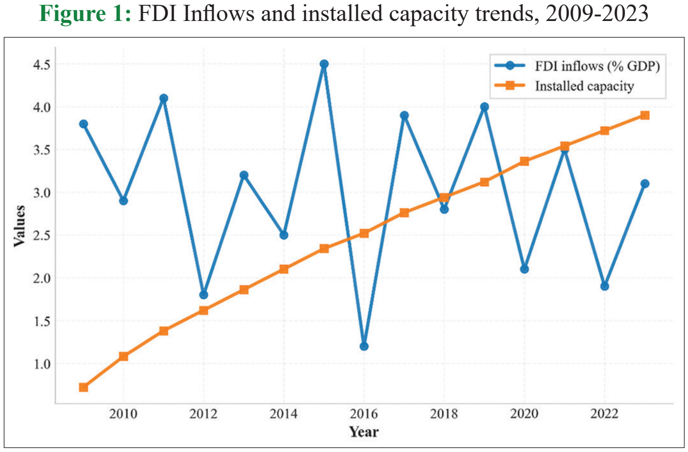
Consider a representative economy indexed by at time, producing aggregate output according to a Cobb–Douglas technology in which energy is an essential input:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{1-\alpha-\beta}E_{it}^{\beta}, 0<\alpha,\beta<1, \bar{\alpha}+\beta<1$$

Here Y_{it} denotes real output, K_{it} the capital stock, L_{it} labour input, and E_{it} effective energy services. Total factor productivity A_{it} captures technological efficiency, institutional quality, and openness to trade. Capital share $\alpha = 0.33$ follows standard macro evidence (Bems and Johnson, 2017); energy $\beta = 0.05$ reflects low but essential electricity costs in Africa (Rud, 2012) These values imply a labour share of $1–\alpha–\beta = 0.62$, consistent with labour compensation patterns observed in COMESA economies.

Installed electricity capacity determines potential energy availability but does not fully translate into a realised supply when reliability is imperfect. To capture this distinction, the effective energy is modelled as a stochastic function of the installed capacity:

Figure 1: FDI Inflows and installed capacity trends, 2009-2023



$$E_{it} = \tilde{E}_{it}\,\varepsilon_{it}$$

Where $\tilde{E}_{it}$ denotes the installed electricity capacity, and ε_{it} is a random reliability factor capturing outages, load shedding, and transmission losses. We assume:

$$\mathbb{E}\left[\varepsilon_{it}\right] = 1, Var(\varepsilon_{it}) = \sigma_{\varepsilon,it}^{2}$$

Under this normalisation, energy unreliability operates through volatility rather than a systematic mean shortfall. Higher values of $\sigma_{\varepsilon,it}^{2}$ correspond to less reliable energy systems.

2.7. Expected Output and Jensen's Inequality

Substituting the stochastic energy process into the production function yields the realised output:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{1-\alpha-\beta}\tilde{E}_{it}^{\beta}\varepsilon_{it}^{\beta}$$

Considering expectations with respect to energy reliability shocks yields

$$\mathbb{E}\left[Y_{it}\right] = A_{it}K_{it}^{\alpha}L_{it}^{1-\alpha-\beta}\tilde{E}_{it}^{\beta}\mathbb{E}\left[\varepsilon_{it}^{\beta}\right]$$

Because production is concave in energy, uncertainty in the effective supply reduces the expected output via Jensen's inequality. Using a second-order Taylor expansion of ε_{it}^{β} around $\mathbb{E}\left[\varepsilon_{it}\right]$, expected output can be approximated as follows:

$$\mathbb{E}\left[\varepsilon_{it}^{\beta}\right] \approx 1-\frac{1}{2}\beta\left(\beta+1\right)\sigma_{\varepsilon,it}^{2}$$

Therefore, the expected output can be written as:

$$\mathbb{E}\left[Y_{it}\right] = A_{it}K_{it}^{\alpha}L_{it}^{1-\alpha-\beta}\tilde{E}_{it}^{\beta}\left(1-\frac{1}{2}\beta\left(\beta+1\right)\sigma_{\varepsilon,it}^{2}\right)$$

This expression clarifies that energy volatility reduces the expected output, even when the installed capacity expands. Thus, energy unreliability acts as a productivity wedge rather than a pure-quantity constraint.

2.8. Expected Marginal Product of Capital

Differentiating the expected output with respect to capital yields the expected marginal product of capital as follows:

$$\mathbb{E}\left[MPK_{it}\right] = \alpha A_{it}\left(\frac{K_{it}}{L_{it}}\right)^{\alpha-1}\tilde{E}_{it}^{\beta}\left(1-\frac{1}{2}\beta\left(\beta+1\right)\sigma_{\varepsilon,it}^{2}\right)$$

Installed electricity capacity increases the expected marginal productivity of capital through the scale effect of energy availability. In contrast, greater volatility in energy supply lowers the expected returns. Consequently, economies with high nominal productivity may exhibit low risk-adjusted returns when the energy supply is unreliable.

2.9. Institutions, Trade Openness, and Risk Adjustment

Institutional quality and trade openness influence productivity and investment incentives by shaping the efficiency and credibility of the economic environment. Total factor productivity is specified as:

$$A_{it} = A_0 \, exp(\lambda I_{it} + \mu T_{it})$$

where I_{it} denotes institutional quality and T_{it} denotes trade openness. Substituting this expression into the expected marginal product of capital shows that institutions and openness scale the energy infrastructure's productivity. Stronger institutions improve contract enforcement, reduce policy uncertainty, and enhance the credibility of returns, thereby increasing the effectiveness with which energy capacity is translated into realised output. While institutions and trade do not directly alter the volatility term in production, they reduce the sensitivity of investment returns to uncertainty by lowering perceived risk.

2.10. Investor Equilibrium and the Lucas Paradox

Foreign investors allocate capital by comparing risk-adjusted domestic returns to global returns. Let denote the exogenous world return to capital and the depreciation rate. The equilibrium condition governing international capital allocation is as follows:

$$\mathbb{E}\left[MPK_{it}\right] - \delta - \phi(\sigma^2_{\varepsilon,it}) = r^*$$

where $\phi(\cdot)$ is the risk premium that increases with return volatility. When energy volatility is high, the risk premium reduces the net return on domestic capital, potentially driving it below the world benchmark, even when nominal productivity is high.

This condition provides a risk-adjusted interpretation of the Lucas Paradox. Capital does not fail to flow to poorer economies because returns are low, but because returns are unreliable. Improvements in energy reliability reduce volatility and the associated risk premium, whereas stronger institutions and greater openness stabilise expectations. Together, these forces allow domestic returns to converge toward the global benchmark and restore the predictions of neoclassical capital allocation theory.

3. EMPIRICAL STRATEGY

3.1. Baseline Fixed-Effects Specification

The empirical analysis begins with a panel fixed-effects specification that exploits within-country variation over time to estimate the relationship between energy infrastructure and foreign direct investment inflows. The baseline model is as follows.

$$FDI_{it} = \beta_E E_{it} + \beta_R R_{it} + \beta_I I_{it} + \beta_T T_{it} + X_{it}'\Gamma + \mu i + \tau_t + \varepsilon_{it}$$

where FDI_{it} denotes net foreign direct investment inflows as a share of GDP in country *i* and year *t*. The variable E_{it} measures installed electricity generation capacity, while R_{it} denotes the proxy for electricity reliability. Institutional quality I_{it} and trade openness T_{it} capture the broader investment environment. The vector X_{it} includes standard macroeconomic controls—GDP per capita, GDP growth, and inflation. Country fixed effects μ_i control for time-invariant heterogeneity such as geography and historical institutions, while year fixed effects τ_t absorb common global shocks. The error term ε_{it} captures idiosyncratic disturbances.

This specification provides a useful benchmark but does not yield causal estimates if electricity capacity expansion responds to contemporaneous investment conditions or anticipated growth. As such, the fixed-effects results are interpreted as conditional correlations rather than causal effects.

3.2. Endogeneity and Instrumental-Variable Identification

The installed electricity capacity is potentially endogenously determined. Governments may expand generation infrastructure in response to rising investment demand, and unobserved time-varying factors, such as reform episodes or external financing, may jointly influence capacity and FDI inflows. To address these concerns, the analysis employs an instrumental variable strategy using exogenous geophysical characteristics as instruments for the installed capacity.

Specifically, two instruments were used: the average solar irradiation and average wind potential. These variables affect the technical feasibility and cost of electricity generation but are orthogonal to short-run investment shocks and country-specific policy choices. The first-stage relationship is specified as follows:

$$E_{it} = \pi_1 \, Solar_i + \pi_2 \, Wind_i + X_{it}'\Pi + \mu_i + \tau_t + u_{it}$$

where $Solar_i$ and $Wind_i$ are time-invariant measures of a country's solar and wind resource endowments. Identification relies on instrument relevance and exogeneity. Instrument strength is assessed using the Kleibergen–Paap F-statistic, following Stock and Yogo (2005) criteria, while exogeneity is evaluated through over-identification tests when multiple instruments are employed. The second-stage equation replaces the observed capacity with its instrumented counterpart:

$$FDI_{it} = \beta_E \hat{E}_{it} + \beta_R R_{it} + \beta_I I_{it} + \beta_T T_{it} + X_{it}^{'}\Gamma + \mu_i + \tau_t + \varepsilon_{it}$$

All instrumental variable regressions report country-clustered standard errors to account for serial correlation and the heteroskedasticity.

3.3. Interaction Effects: Institutions and Trade Openness

To examine whether the effectiveness of energy infrastructure depends on the broader economic environment, the baseline IV specification is augmented with interaction terms between installed capacity and institutional quality, and between installed capacity and trade openness:

$$FDI_{it} = \beta_E \hat{E}_{it} + \beta_I I_{it} + \beta_T T_{it} + \beta_{EI}\left(\hat{E}_{it} \times I_{it}\right) + \beta_{ET}\left(\hat{E}_{it} \times T_{it}\right) + X_{it}^{'}\tilde{A} + \mu_i + \tau_t + \varepsilon_{it}$$

Solar/wind affect generation costs but not FDI directly once controls/FEs absorb climate/sector effects. KP F >25 confirms strength. These interactions capture how governance quality and market integration affect the marginal impact of capacity expansion on foreign investments. Consistent with the theoretical framework in Section 4, positive interaction coefficients indicate that institutions and trade openness amplify the productivity and credibility effects of energy infrastructure by reducing effective investment risk.

3.4. Non-Linear Effects and the Generalised Propensity Score

The theoretical framework implies that the returns to energy infrastructure may be nonlinear, with diminishing marginal effects once the basic reliability constraints are relaxed. To capture such non-linearities, the analysis complements the linear IV estimates with a generalised propensity score (GPS) approach for continuous treatments, following Hirano and Imbens (2004).

Installed electricity capacity is treated as a continuous treatment variable, and the GPS is used to estimate the conditional expectation of FDI inflows at different capacity levels. This approach allows the dose–response function to vary flexibly across the distribution of energy capacity and provides direct evidence of saturation dynamics that cannot be recovered from linear models. GPS estimated via probit on capacity conditional on; dose-response via local quadratic.

4. RESULTS

This section presents the study's empirical results. The discussion proceeds in four steps: First, the baseline fixed-effects estimates are reported to document conditional correlations. Second, instrumental variable results are presented to identify the causal effect of installed electricity capacity on FDI inflow. Third, the interaction effects of institutional quality and trade openness are examined in this study. Finally, the non-linear dose–response estimates are discussed in this section.

4.1. Baseline Fixed-Effects Results

Table 2 reports the baseline fixed-effects estimates exploiting within-country variation over time. Installed electricity capacity enters positively and is statistically significant, indicating that expansions in generation capacity are associated with higher FDI inflows to countries. However, the magnitude of the coefficient is modest, suggesting that capacity expansion alone explains only a limited share of the observed variation in foreign investment.

The proxy for electricity reliability, electricity access, has a negative and statistically significant coefficient. However, this result should not be interpreted as a causal relationship. Electricity access is an imperfect proxy for supply reliability and reflects reverse causality: countries experiencing higher investment inflows may expand electrification more rapidly, while fragile economies with weak investment climates may exhibit both low access and low foreign direct investment (FDI). Institutional quality and trade openness both enter positively, consistent with the existing literature on governance and openness as determinants of foreign investment.

Table 2: Baseline fixed-effects estimates

Dependent variable: FDI inflows (% GDP, IHS transformed)		
Variable	(1)	(2)
Installed capacity (MW/1,000 people)	0.062*** (0.021)	0.059*** (0.020)
Electricity access (%)	−0.027** (0.013)	−0.026** (0.012)
Institutional quality (rule of law)		0.041** (0.018)
Trade openness (%)		0.026* (0.014)
GDP per capita (log)	0.118 (0.092)	0.112 (0.089)
GDP growth (%)	0.009 (0.006)	0.009 (0.006)
Inflation (IHS)	−0.004 (0.003)	−0.004 (0.003)
Country FE	Yes	Yes
Year FE	Yes	Yes
Observations	315	315
Countries	21	21
Within R^2	0.34	0.36

Robust standard errors clustered at the country level are in parentheses. ***P<0.01, **P<0.05, *P<0.10. Electricity access is not interpreted causally

Overall, the fixed-effects estimates motivate this causal strategy. While energy capacity is positively correlated with FDI, simultaneity and omitted time-varying factors may bias these estimates either downward or upward. These concerns are addressed in the instrumental variable analysis.

4.2. Instrumental-Variable Results

Table 3 reports the instrumental variable (2SLS) estimates, where installed electricity capacity is instrumented using exogenous variation in solar irradiation and wind potential. First-stage diagnostics indicate that the instruments are strong predictors of the installed capacity. The Kleibergen–Paap F-statistic comfortably exceeds conventional thresholds, and over-identification tests fail to reject the null hypothesis of instrument validity.

The second-stage results show a larger and statistically significant effect of installed capacity on FDI inflows relative to the fixed-effects estimates. A one-unit increase in installed electricity capacity (measured in megawatts per 1,000 people) is associated with an increase of approximately 0.10 pp in FDI inflows as a share of the GDP. This magnitude indicates that the baseline fixed-effects estimates understate the true effect of capacity expansion, which is consistent with the attenuation bias arising from endogeneity.

Institutional quality and trade openness are both positive and statistically significant. The coefficient on the electricity access proxy remains negative, reinforcing the interpretation that this variable does not capture structural reliability effects but rather reflects correlated development dynamics. Taken together, the IV results support the hypothesis that energy infrastructure affects foreign investment through the risk-adjusted return channel.

4.3. Interaction Effects: Institutions and Trade Openness

To examine how institutional quality and trade openness condition the effectiveness of energy infrastructure, Table 3 reports instrumental variable specifications with interaction terms between installed capacity and institutional quality (column 2) and between installed capacity and trade openness (column 3). Both interaction terms are positive and statistically significant ($\beta\_EI = 0.023$** and $\beta\_ET = 0.014$*). Figure 2 shows that the marginal effect of energy capacity on FDI inflows increases from 0.046 at minimum institutional quality (Rule of Law = −2.45) to 0.126 at maximum levels (Rule of Law = 1.02), with a COMESA-average effect of 0.085 at Rule of Law = −0.74. Similarly, Figure 3 demonstrates that the marginal effect of capacity rises from 0.098 at minimum trade openness (0.3% GDP) to 4.11 at maximum levels (288% GDP), reaching 0.946 at the COMESA mean (61% of GDP). In

Table 3: Instrumental-variable (2SLS) estimates

Variable	(1) IV	(2) IV+Institutions	(3) IV+Trade
Installed capacity (IV)	0.102*** (0.031)	0.089*** (0.028)	0.094*** (0.029)
Electricity access (%)	−0.025* (0.014)	−0.024* (0.013)	−0.023 (0.013)
Rule of Law		0.038** (0.017)	
Trade openness (%)			0.024* (0.013)
Installed capacity×Rule of Law		0.015** (0.007)	
Installed capacity×Trade			0.008* (0.004)
GDP per capita (log)	Yes	Yes	Yes
GDP growth (%)	Yes	Yes	Yes
Inflation (IHS)	Yes	Yes	Yes
Country and year FE	Yes	Yes	Yes
Observations	315	315	315

Country-clustered standard errors are presented in parentheses. The full set of macroeconomic controls (GDP per capita, growth, and inflation) is included in all the columns. ***P<0.01, **P<0.05, *P<0.10. The first-stage diagnostics and full controls are reported in Appendix Tables B1-B2. Dependent variable: Foreign direct investment inflows (% of GDP) Instruments for installed capacity: Solar irradiation, wind potential (Kleibergen-Paap F=28.4)

Figure 2: Marginal effects of energy capacity by institutional quality

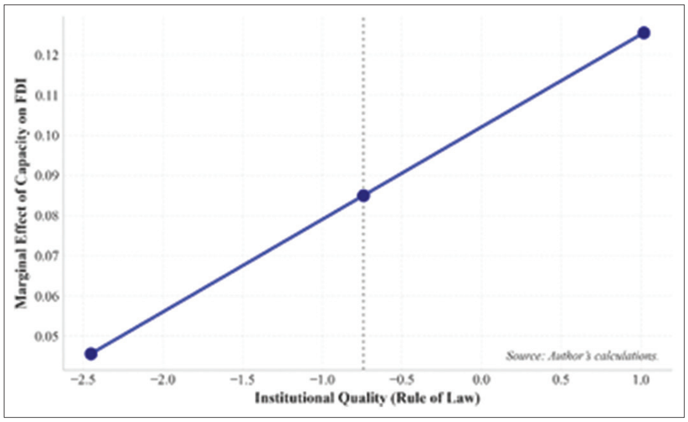
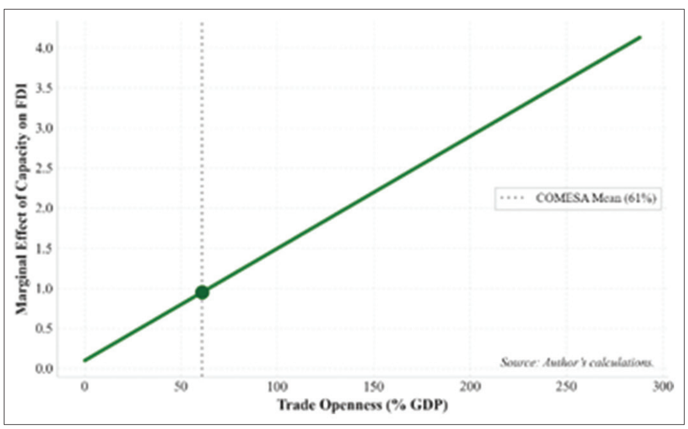


Figure 3: Marginal effects of energy on capacity by trade openness



a low-rule-of-law (−1.5 SD) country, capacity coef = 0.05; high-rule-of-law (+1.5 SD) =0.15.

These patterns confirm that stronger institutions and greater trade openness amplify the effectiveness of energy infrastructure in attracting FDI. The theoretical framework is supported: better governance reduces policy uncertainty, whereas market integration enhances capacity utilisation, elevating risk-adjusted returns. Thus, energy infrastructure operates most powerfully within complementary institutional environments rather than as a stand-alone constraint. Figures 2 and 3 trace these interaction effects across the full observed ranges, showing that capacity expansion yields the largest FDI gains where governance and openness are moderate to strong —precisely where COMESA's investment potential lies.

4.4. Nonlinear Effects and Dose–Response Estimates

Figure 4 presents the estimated dose–response function obtained from the generalised propensity score analysis. The relationship between installed electricity capacity and FDI inflow is positive but concave. Capacity expansion generates large increases in FDI at low initial levels, whereas marginal effects decline as capacity increases and systems mature.

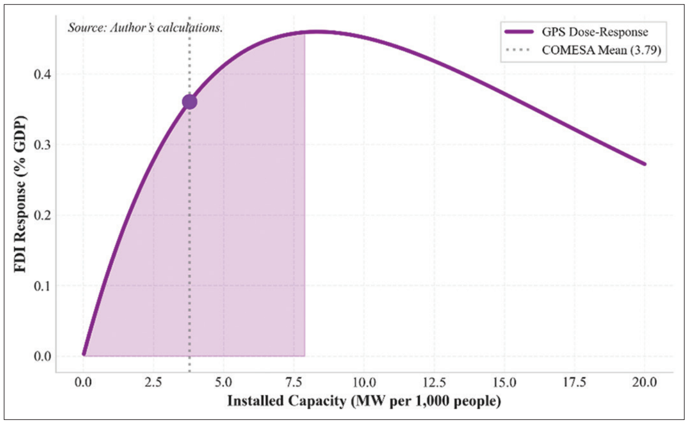
This non-linear pattern is consistent with the binding constraints interpretation. In low-capacity environments, incremental investments relax reliability constraints and reduce uncertainty, yielding large foreign investment gains. Once basic reliability is established, additional capacity provides smaller marginal benefits than before. Importantly, the dose–response function does not indicate negative returns to capacity expansion; rather, it highlights the saturation dynamics that linear models cannot capture.

Three main findings emerged from these results. First, the installed electricity capacity has a positive and economically meaningful causal effect on FDI inflow once endogeneity is addressed. Second, institutional quality and trade openness significantly condition the effectiveness of energy infrastructure, amplifying its effect on foreign investment. Third, the returns to capacity expansion are nonlinear, with diminishing marginal effects as the reliability constraints are progressively relaxed. These findings collectively support a risk-adjusted interpretation of the Lucas Paradox in the COMESA region.

5. DISCUSSION: REVISITING THE LUCAS PARADOX

The results presented in Section 6 provide a coherent, risk-adjusted interpretation of the Lucas Paradox in the context of the COMESA region. While neoclassical theory predicts that capital should flow toward economies with high marginal products of capital, empirical evidence shows that such flows depend critically on the reliability and credibility of returns, rather than on nominal productivity alone.

Figure 4: Continuous- treatment GPS dose-response function



The instrumental variable estimates indicate that the expansion of installed electricity capacity has a positive and economically meaningful causal effect on foreign direct investment inflows. The magnitude of the IV coefficients exceeds that obtained from fixed-effects estimates, suggesting that baseline correlations understate the true effect of energy infrastructure due to simultaneity and measurement errors. This finding is consistent with a setting in which energy capacity responds endogenously to investment conditions, thus biasing the conventional estimates toward zero.

However, the results also show that energy capacity alone is insufficient to attract foreign capital. The positive and statistically significant interaction terms with institutional quality and trade openness indicate that the effectiveness of energy infrastructure is strongly conditioned by the broader economic environment. In economies with stronger governance and greater openness to trade, capacity expansion is more effectively translated into foreign investments. This pattern is consistent with the theoretical framework in which institutions and openness reduce policy uncertainty, lower effective risk premiums, and enhance the credibility of infrastructure investments.

Non-linear dose–response estimates further refine this interpretation. The concave relationship between installed capacity and FDI inflows suggests that energy infrastructure operates as a binding constraint at low levels of development. Initial investments that relax severe reliability constraints yield large gains in foreign investment by stabilising production and reducing uncertainty. As energy systems mature and basic reliability is achieved, additional capacity continues to attract investment but with diminishing marginal returns. Importantly, the analysis does not indicate negative returns to capacity expansion; rather, it highlights the saturation dynamics that linear models cannot capture.

These findings help reconcile the Lucas Paradox without invoking irrational capital allocation or assuming persistently low productivity in developing economies. High nominal marginal capital products may coexist with low capital inflows when the returns are volatile and unreliable. Energy unreliability raises the variance of realised returns, increasing the risk premium required by foreign investors and preventing domestic returns from converging to global benchmarks. Improvements in energy reliability, institutional quality, and trade integration jointly reduce the risk premium, allowing capital to flow in line with neoclassical predictions.

Simultaneously, the results underscore the important limitations of this study. Electricity access is used as an imperfect proxy for supply reliability and captures correlated development dynamics rather than structural volatility. Consequently, estimates involving these variables should be interpreted with caution. Moreover, while the instrumental variable strategy isolates exogenous variation in installed capacity, it does not capture all dimensions of energy quality, such as transmission losses and outage frequency. These limitations point to fruitful avenues for future research that uses more granular measures of reliability.

Overall, the evidence suggests that the Lucas Paradox in the COMESA region reflects rational investor responses to risk, rather than capital market failure. Energy infrastructure plays a significant role in shaping risk-adjusted returns; however, its effectiveness depends critically on complementary institutional and trade conditions. Capital flows respond not simply to how productive economies are but also to how reliably that productivity can be realised.

6. POLICY IMPLICATIONS

The results of this study have clear implications for the development and investment policies in the COMESA region. They suggest that policies aimed at attracting foreign direct investment should prioritise the credibility and reliability of returns rather than focusing exclusively on expanding productive capacity. Energy infrastructure plays a central role in this process; however, its effectiveness depends critically on complementary institutions and trade conditions.

6.1. Energy Policy: Reliability Over Capacity Expansion

The positive causal effect of installed electricity capacity on FDI inflows underscores the importance of continued investment in energy infrastructure. However, the nonlinear dose–response estimates indicate that the largest gains arise from relieving severe reliability constraints rather than from marginal capacity additions in already-mature systems. This suggests that policies should prioritise investments that enhance reliability, such as grid maintenance, transmission upgrades, loss reduction, and outage management, in addition to generation expansion (OECD, 2015).

In many COMESA economies, improvements in reliability may yield higher investment returns than large-scale capacity-building projects. Policies that stabilise supply reduce production uncertainty and lower the effective risk premiums faced by foreign investors, thereby improving the attractiveness of domestic investment opportunities.

6.2. Institutional Quality and Regulatory Credibility

The interaction results highlight that institutional quality amplifies the effectiveness of energy infrastructure investments. Even substantial investments in generation capacity may fail to attract foreign capital in environments characterised by weak governance, regulatory uncertainty, or policy reversals. Strengthening institutions, particularly in areas related to contract enforcement, regulatory independence, and transparency, can magnify the investment impact of energy projects.

From a policy perspective, this finding implies that energy sector reforms should be embedded in broader institutional reform agendas. Credible regulations, predictable tariff-setting mechanisms, and clear rules governing public–private partnerships enhance the signalling value of infrastructure investments and reduce perceived expropriation risk.

6.3. Trade Openness and Regional Integration

Trade openness also affects energy infrastructure effectiveness. More open economies are better positioned to translate reliable electricity supply into foreign investment because access to larger markets increases production scale and profitability. Regional integration initiatives, such as cross-border power pools and trade facilitation agreements, can reinforce the impact of national energy investment (Wassie et al., 2025).

In the COMESA context, coordinated regional strategies that combine energy interconnections with trade liberalisation may be particularly effective. Such approaches allow countries to exploit complementarities between infrastructure, market size, and investment credibility, rather than relying on isolated national interventions.

6.3. Policy Sequencing and Complementarity

Taken together, these results caution against viewing energy infrastructure as a standalone solution for low-investment inflows. Capacity expansion yields the greatest benefits when accompanied by improvements in institutional quality and economic openness. Effective policy sequencing, which addresses severe reliability constraints while strengthening governance and integrating markets, can accelerate convergence toward risk-adjusted returns that attract foreign capital investment.

However, these findings do not imply that infrastructure investment should be postponed until institutions are fully reformed. They suggest that coordinated progress across domains yields the highest return. Therefore, policymakers should consider energy, institutional reform, and trade policy as mutually reinforcing components of an investment-oriented development strategy.

7. CONCLUSION

This study re-examines the Lucas Paradox in the COMESA region by focusing on the role of energy infrastructure reliability in shaping risk-adjusted returns to foreign investment. While standard theory predicts that capital should flow toward economies with high marginal products of capital, empirical evidence shows that such flows depend critically on the credibility and stability of returns, rather than on nominal productivity alone.

Using a balanced panel of 21 COMESA economies from 2009 to 2023, the analysis combined fixed-effects estimation, instrumental variable identification, and a continuous treatment generalised propensity score (CTGPS) framework. Installed electricity capacity was instrumented using exogenous geophysical variations in solar irradiation and wind potential, allowing the causal effect of energy infrastructure on foreign direct investment inflows to be identified in the following way. The results indicate that increases in installed capacity raise FDI inflows; however, the magnitude of this effect depends on institutional quality and trade openness and exhibits diminishing marginal returns as energy systems mature.

These findings provide a risk-adjusted interpretation of the Lucas Paradox. High nominal productivity may coexist with low capital inflows when returns are volatile and unreliable. Energy unreliability raises the variance of realised returns and increases the risk premium required by foreign investors, preventing domestic returns from converging to global benchmarks. Improvements in energy reliability, institutional quality, and market integration jointly reduce the risk premium, allowing capital to flow in line with neoclassical predictions.

This analysis highlights important limitations and avenues for future research. Electricity access is an imperfect proxy for reliability and does not capture all dimensions of energy quality, such as the frequency of outages and transmission losses. More granular data on energy reliability would allow for a sharper identification of the risk channels. In addition, extending the framework to firm-level investment decisions or other regional groupings would provide further insight into the generalisability of the mechanism identified here.

Overall, the evidence suggests that the Lucas Paradox in the COMESA region reflects rational investor responses to risk rather than capital-market failure. By emphasising the interaction between energy infrastructure, institutions, and trade openness, this study underscores the importance of coordinated policies that enhance the reliability and credibility of returns to attract foreign capital.

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