

Financing the energy transition: International clean energy finance and renewable energy outcomes in Sub-Saharan Africa: A dynamic panel GMM analysis

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Abstract

This study explores the relationship between international investments in clean energy and energy infrastructure in Sub-Saharan Africa (SSA), a region with limited access to energy and energy-related financial services. The study uses a panel of 15 SSA countries from 2005 to 2021 and estimates a two-step system in the Generalized Method of Moments (GMM) framework. Renewable energy consumption (RECAP) is used as the proxy variable for the outcome. The results show that renewable energy consumption in the sample countries is persistent. International clean energy finance is positively related to renewable energy, but the relationship is not statistically significant. The results show that international clean energy finance is not enough to accelerate the energy transition. The level of financial development is positively related to renewable energy consumption, while GDP per capita and Carbon Emissions are negatively related. Improving the quality of institutions does not affect renewable energy consumption. The results suggest that international clean energy finance, in conjunction with other improvements to the country's financial system and access to energy, will improve the energy transition. This paper provides evidence to facilitate the improvement of international energy finance towards green energy transitions in Sub-Saharan Africa.

1. Introduction

Sub-Saharan Africa (SSA) is of critical concern as the world attempts to implement the required energy transformation to achieve the goals of the Paris Agreement (Leesya 2025; Obi et al. 2025; Amoah et al. 2025; Asongu et al. 2026). SSA is the most energy poor and most vulnerable region to climate change and has the least access to modern energy services of all the regions of the world. Combined with extreme financial constraint conditions, these strongly justify the case for large-scale energy transformation and the need to address energy poverty as well as provide energy services in a clean and sustainable manner (Schwerhoff & Sy, 2017; International Energy Agency, 2022; International Renewable Energy Agency, 2022; Asongu et al., 2026). The limited progress in the electrification of SSA (especially rural areas) as well as the lack of adequate enabling frameworks and adequate financial markets to support large-scale energy projects (Eberhard et al., 2017; Olabisi et al., 2025; Mazzucato & Semieniuk, 2018) provide strong justification for financing to facilitate the transformation of energy systems and renewable energy infrastructure.

In Sub-Saharan Africa (SSA), increasing investments in renewables would speed up several Sustainable Development goals including SDG 7 (the access to affordable clean energy). The increased use of renewables would also help achieve several other SDGs. Beyond the need for decarbonization, accelerating the deployment of renewables would help achieve several other development goals, including facilitating economic transformation, and improving energy, and health systems. For countries highly impacted by energy poverty, transforming energy systems with renewables would help achieve SDG 1 (poverty eradication) by providing access to energy for the vulnerable and hard to reach populations, faster than transforming energy systems with other sources (i.e. fossil fuels). (World Bank, 2022; Ehimen et al, 2023). Transforming the energy systems with renewables has developmental, and positive impact on the environment, and therefore, helps accomplish various Sustainable Development Goals including SDG 7 (Climate Policy Initiative, 2023; International Renewable Energy Agency, 2023). Compared to other regions, the countries in Sub-Saharan Africa have, historically, received less international financing (African Development Bank, 2022).

International funds dedicated to clean energy are another key element of the climate finance mix. Graham & Serdaru (2020) and Briera & Lefèvre (2024) identify several multilateral and bilateral funds, as well as facilities and partner-ship arrangements, working to reduce barriers to financing of renewable energy projects in the Global South. From an economic perspective, it makes sense to provide grant or concession financing for projects in the Global South. It is unlikely that the projects will be commercially viable. As Fazzari et al. (1988), Stiglitz & Weiss (1981), and Raikar & Adamson (2022) posit, financing may enable the structural changes in the production system needed for cleaner production and help integrate new technology. However, the outcomes of international clean energy financing are by no means certain. Results will be contingent upon the extent to which countries integrating the financing commitments restructure their economies to improve the sector.

While existing literature covers the intersection of finance and the development of renewable energy, several aspects remain unaddressed. Evidence shows financial development, availability of capital, policy commitment, and institutional quality affect outcomes of renewable energy development, regardless of the level of economic development of a country (Pfeiffer & Mulder, 2013; Taghizadeh-Hesary et al., 2022; Leesya, 2025; Obi et al., 2025; Amoah et al., 2025). Other studies show how clean energy transitions are financed through development finance, foreign investment, and other external investment instruments, such as climate finance, and green bonds (Doytch & Narayan, 2016; Mazzucato & Semieniuk, 2018; Li & Ayub., 2025). Still, the evidence-based research concerning Sub-Saharan Africa (SSA) is scattered. Much research focuses on a primary country, climate finance, energy transition, or international clean energy investment and renewable energy financing. A majority of studies do not account for endogeneity, persistence in investment behavior, country heterogeneity, and dynamic system modeling. Identifying and addressing these gaps is crucial for path dependent renewable energy investment, which is based on previous investment patterns.

Another gap is in the combined analysis of International Clean Energy Finance and other Domestic Conditions in examining Renewable Energy. International finance may combine with other Domestic Conditions, like Financial, Electricity system and Governance. The evidence in Sub-Saharan Africa is lacking. This study assumes a priori that International Finance and Renewable Energy combine with other Domestic Conditions.

This study examines the relationship between International Clean Energy Finance and Renewable Energy (RE) in Sub-Saharan Africa (SSA) and other covariates. The study covers the period 2005–2021. It includes 15 SSA countries. The study takes into account GDP per capita, financial development, electricity access, CO2 emissions, governance, and other variables. It accounts for the first order lag of the dependent variable.

Common understanding is larger International Financing increases the pace of the Energy Transition. However, empirical evidence supports this assertion only to some degree. This study assesses International Clean Energy Finance and its relationship with the Renewable Energy Transition (RET) in SSA. By providing evidence on International Clean Energy Finance and the Energy Transition in SSA, the study evaluates if International Financing is a moderating factor for the Energy Transition in SSA.

1.1 Status of SSA in renewable energy transition

Rising investment in renewables globally creates an opportunity for Sub-Saharan Africa (SSA). SSA has vast potential for renewable energy. However, it has the world's largest access deficit for modern energy services. Limited electricity infrastructure leads to high costs for each new connection, making it difficult to provide universal access to energy. About 600 million people, including 47% of the regional population, have no access to electricity. Of these, 95% live in rural areas.

Figure 1. International public financial flows to clean energy in SSA, 2010–2023.

Source: Author's reconstruction based on *Tracking SDG 7: The Energy Progress Report 2025*, Fig. 5.5; data from IRENA and OECD (2024).

Only a small share of the international financing available for sustainable development has been allocated to SSA. Additionally, significant renewable energy potential remains financially unattractive. By 2024, it will be important from an international perspective to develop SSA's energy sector. Most of the population in the region still lacks basic energy services. Limited SSA's urgent case for investment has been accompanied by a decline in international investments in renewable energy in the region. From 2019 to 2022, investments by the member states of the International Renewable Energy Agency (IRENA) in the region fell from an average of USD 5.3 billion to USD 3.6 billion. The level of investment in the region is inadequate and unrelated to the world's goals and targets for investment in renewable energy.

The investment gap in sub-Saharan Africa is one of the largest in the world. The International Energy Agency (IEA) reported that between 2000 and 2020, investments in renewable energy source (RES) worldwide amounted to USD 2.8 trillion, and in this period, the continent of Africa attracted less than 1.5% of these investments. However, more recently, there have been signs of improved international investments. Accelerating SDG7 goals reports that in 2022, international public financial flows to support access to renewable energy in sub-Saharan Africa increased to USD 5.6 billion. Although this is an improvement, it is insufficient to close the region's energy infrastructure gaps. The lack of access to renewable energy has transformed from not having the financial means to access energy, to not having the energy itself. The greater challenge is how to make affordable renewable energy available to the people of sub-Saharan Africa.

2. Theoretical framework and literature review

The study utilizes Ecological Modernization Theory (EMT) to analyze international clean energy finance and its relationship with renewable energy in Sub-Saharan Africa (SSA). EMT suggests that sustainable improvement in the environment and the economy can be achieved by combining improved technologies and policies to help prepare the economy and society for the introduction of better and cleaner production and industrial systems (World Commission on Environment and Development, 1987; Mol and Sonnenfeld, 2000). Within the field of energy, this theory suggests that improvement in the systems and infrastructure, together with the necessary finance and policies, can lead to the establishment of cleaner energy systems. International clean energy finance is the main variable of interest in the study, while the main objective of the study is to determine the factors that influence the consumption of renewable energy (RECAP). Variables such as gross domestic product (GDP) per capita, financial development, electricity access, carbon emissions, and institutional quality are some of the covariates included in the study.

The study investigates international financial flows for clean energy. It defines international clean energy finance as the multilateral and bilateral public financing flows for clean energy projects in developing countries, in addition to other public and private financing. Renewable energy projects are capital-intensive and require long-term financing, which is often unavailable due to a high level of risk.

According to various theories of investment (Jorgenson, 1963; Tobin, 1969; Fazzari et al., 1988), the cost and availability of financing, as well as expectations and organization of the investing entities, determine the level of investment. These factors are especially relevant for developing countries, where lack of information and functional capital markets result in a situation where concession or blended financing is the only means to facilitate investment in the energy sector. The crowding in of additional public and private financing is possible through international public finance for clean energy and related projects (Mazzucato and Semieniuk, 2018). Further, the authors affirm that international public finance facilitates and accelerates the reforms and institutional transformation necessary for the clean energy transition in developing countries (Graham and Serdaru, 2020; Briera and Lefèvre, 2024).

The empirical data do not always show that the use of external finance improves the adoption of renewable energy. Some studies show positive associations with the relaxation of financing constraints. Others show positive associations because of the role of financial institutions in building trust and confidence in the market. Still other studies show that positive associations between external finance and adoption of renewable energy are inconclusive because of fragmentation and volatility in the availability of finance, especially when financing is not congruent with domestic policies. For instance, Ostadzad & Ghafoorian Yavarpanah (2025) argue that the reason for the low level of adoption of renewable energy in some countries is primarily because of the availability of financing, and that the major barriers to the uptake of renewable energy are primarily institutional. In their study, they show that positive associations between finance and adoption of renewable energy are largely inconclusive. This study also aims at reducing this type of uncertainty in the literature. Thus, a statistically insignificant ICEF coefficient in the specified model of the study will imply that the researchers failed to determine positive associations between external finance and the adoption of renewable energy. This, however, does not mean that external finance is a necessary or sufficient condition for the positive association between the two variables for renewable-energy progress.

2.1. Conceptual model and hypotheses of the study

Given this context, the first conceptual expectation is that international clean energy finance should be positively associated with the renewable energy outcome by easing financing constraints and supporting clean-energy deployment in capital-scarce economies. Therefore, the study proposes the following

hypothesis:

H1. International clean energy finance is positively associated with the renewable energy outcome (RECAP) in Sub-Saharan Africa. (Fig. 2).

The second important construct is economic development, measured by GDP per capita. The study includes GDP per capita because high average income levels indicate economic capacity, infrastructural preparedness, and the overall material conditions that support clean energy systems, and the study explicitly states that, depending on the construction, energy transition, and development theories, a positive correlation is to be expected. There is broad literature support that higher income levels result in more investments in modern infrastructure, improve the economy, and drive the demand for modern energy services (Fankhauser and Jotzo, 2018). Within the EMT framework, economic growth can both initiate the necessary resources and provide the political motivation for environmental improvements. However, the gaps are concerning in lower- and middle-income economies. Economic growth can be a double-edged sword; it can support renewables when backed by strong institutions and advanced financial markets, but can also reinforce carbon-intensive energy systems when accompanied by conventional industrialization or fossil fuel infrastructure. Accordingly, the conceptual expectation remains positive, but the empirical sign is allowed to vary across specifications. GDP per capita is treated as a direct explanatory covariate in the estimated model, not as a moderator of the international clean energy finance effect.

Figure 1. Conceptual model of study

H2. GDP per capita is positively associated with the renewable energy outcome (RECAP) in Sub-Saharan Africa.

Financial development is a third core construct and is especially critical in this model. In this study, it is measured as domestic credit to the private sector as a percentage of GDP and is justified as a mechanism that diminishes borrowing costs, broadens the reach of financial tools, and enables local co-financing of renewable energy initiatives. This line of reasoning is certainly supported by financial development theory, which associates more profound and efficient financial systems with higher degrees of intermediation, lower transactional costs, and a better disposition of capital toward productive investments (Gurley and Shaw, 1955). In the case of renewable energy markets, the importance of financial development is perhaps even more significant, as such markets entail long-term debt, risk-sharing instruments, and a pool of institutional investors with a preference for investments with delayed return. Scholars recently documented in Standard Bank Africa that financial development stimulates the renewable energy transition (Amoah et al., 2025; Asongu et al., 2026). Taghizadeh-Hesary et al. (2022) noted that the development of green financing instruments could accelerate energy transition in developing economies. Generally, a developed financial system is crucial in determining whether the inflow of global investments is simply available or effectively utilized. This becomes important as the study merely states financial development to some extent to emphasize the local co-financing capacity through which international clean energy funds may operate.

Although there is less empirical debate for this measure than for GDP per capita, the expected effect remains context dependent because of differences in regulatory environments, market structures, and banking-system development. In Sub-Saharan Africa, where long-term project financing is constrained, financial development may facilitate domestic co-financing and the mobilization of capital for renewable energy. In the conceptual model, financial development is therefore specified as a direct explanatory covariate. Its empirical association is assessed in Section 4; no interaction term between financial development and international clean energy finance is estimated.

H3. Financial development is positively associated with the renewable energy outcome (RECAP) in Sub-Saharan Africa.

Access to electricity serves as the fourth major construct in the model and illustrates the developmental aspect of the energy transition. The study defines it as the % of the population with access to electricity. The study defends its inclusion by stating that low access often creates the need for off-grid and mini-grid renewable options, especially in the rural and underserved, therefore linking renewables to the improvement of energy poverty and lowering the SDG 7. The literature confirms the inclusion on both normative and empirical grounds. Renewables in SSA is not just an environmental technology, it is also an infrastructural approach to increasing energy access in the context of slow, and expensive centralized grid expansion (World Bank, 2022; Ehimen et al., 2023). The literature on energy access in low-income African contexts is unanimous in its assessment that dispersed renewables offer the potential to close last-mile electrification gaps, especially in the absence of strong public utilities and low demand density. From an EMT perspective, the improvement of access with clean technology is what developmental ecological modernization is about, where the environmental and social dimension of the modernization process reinforce each other (Fig. 3, Table 1).

The relationship between electricity access and renewable energy development is theoretically ambiguous. Low access can create demand for off-grid and mini-grid renewable options, whereas higher access can also reflect network expansion, market development, and infrastructure readiness that facilitate additional renewable deployment. The present study adopts the latter expectation and tests access to electricity as a direct explanatory covariate of RECAP. It is not specified as a moderator of international clean energy finance. Based on this conceptual logic, the study proposes the following hypothesis:

H4. Access to electricity is positively associated with the renewable energy outcome (RECAP) in Sub-Saharan Africa.

The model also includes carbon dioxide emissions per capita as an environmental-pressure control. Higher emissions may increase pressure for cleaner energy adoption, but in lower-income economies they may also reflect fossil-fuel-intensive industrialization and extractive activity. Because the theoretical direction is ambiguous, CO₂ emissions are retained as a control rather than a formal hypothesis; their empirical association is assessed in Section 4.

Figure 2. Theoretical foundation of the study

Table 1
hypotheses of the study

Theoretical framework based on the literature	Hypothesis	Variable / Construct	Role in the study	Expected relationship
Researching ecological modernization and energy-transition reasoning, investing in cleaner energy systems means investing in more sustainable production and infrastructures.	-	Renewable energy investment (REI / RECAP)	Dependent variable	Outcome to be explained
Ecological Modernization Theory; financing-constraints and investment logic. Outside climate/clean-energy financing should unshackle capital, lower the associated risks, and spur the rollout of renewables (Mazzucato and Semieniuk, 2018; Graham& Serdaru, 2020; Briera and Lefevre, 2024).	H1: International clean energy finance encourages the growth of renewable energy investment in Sub-Saharan Africa.	International clean energy funds (ICEF)	Main independent variable	Positive effect on REI
From the development and energy-transition viewpoints, the general perception is that an increase in income translates to larger fiscal and investment capacity. However, the empirical outcomes are not always so, especially when the income growth is associated with energy-locked systems (Fankhauser and Jotzo, 2018).	H2: GDP per capita encourages the growth of renewable energy investment in Sub-Saharan Africa	GDP per capita (GDPpc)	Explanatory control / domestic enabling condition	Expected positive effect on REI
The theory of financial development and the literature on financing renewable energy projects suggest that improved financial systems will lead to lower the costs of borrowing and better access to long-term capital, which can be used to finance renewable projects (Gurley and Shaw, 1955; Taghizadeh-Hesary et al., 2022; Mugume and Bulime, 2024).	H3: Financial development encourages the growth of renewable energy investment in Sub-Saharan Africa.	Financial development (FinDev)	Explanatory control / domestic enabling condition	Positive effect on REI
SDG 7 and literature on energy access highlight the strong connection that exists in low access rural and disadvantaged communities, where the expansion of electrification is associated with the deployment of renewables (World Bank, 2022; Ehimen et al., 2023).	H4: Availability of electricity encourages the growth of renewable energy investment in Sub-Saharan Africa.	Access to electricity (ACCE)	Explanatory control / developmental driver	Positive effect on REI
The literature on environmental transitions suggest that although emissions are seen to provide opportunities for cleaner energy adoption, and in some developing countries they may represent some forms of fossil dependent growth; the evidence is not consistent (Acheampong et al., 2021).	Expecting higher emissions to pressure the renewable transition, the relationship is still not well enough established to pose a formal hypothesis in the study.	CO2 emissions per capita (CO2)	Control / environmental pressure	Direction theoretically ambiguous; included as control
Ecological modernization stresses the importance of changes in the institutions, the credibility of regulatory frameworks, and governance capacity to bring about an environmental transition, although when it comes to governance, the wider effects are complementary, but are often uneven across the African continent.	Expecting the better institutional quality to support renewable energy investment, the current study considers this primarily as a contextual control rather than a central hypothesized driver.	Institutional quality (IQ)	Control / governance context	Direction theoretically positive, but empirically mixed
The willingness to invest is consistent with path dependence, where the infrastructure is seen to set the direction and act as an enabler, and the cumulative formation of capabilities with respect to energy transitions	Expecting prior investment to positively influence current renewable energy investment, the level of investment is primarily what is driving investment growth.	Lagged renewable energy investment [L.REI]	Dynamic control	Positive persistence effect expected

Finally, institutional quality indicates the governance aspect of the research. Although this component is not discussed much in the methodology chapter, its inclusion is important because renewable energy investments are determined by credible rules, administrative capability, and enforcement of contracts and policies, as well as consistency and protection of investors (North, 1990; Mol & Spaargaren, 2000; Jänicke, 2008; Wilson, 2022; IEA & AfDB, 2023; OECD, 2023, 2024; World Bank, 2024; Appiah-Otoo et al., 2025). EMT has always argued for the importance of institutional modernization for enabling environmental transition; cleaner technologies don't simply break into the market, but rather, they come through supportive institutional frameworks which deal with uncertainty and incentive alignment.

In practice, the existence of solid institutions correlates with investment attractiveness, efficient use of public financing, and policy coordination regarding needed infrastructure. Beyond the mentioned factors, the relative importance of institutions in SSA is likely to be heterogeneous and nonlinear, especially where formal governance assessment frameworks miss out on certain sector-specific governance arrangements, donor-led projects, or hybrid state-market systems (IEA & AfDB, 2023; OECD, 2023; IRENA, 2024; IMF, 2025).

In the empirical model, institutional quality is retained as a governance control because credible rules, administrative capacity, policy consistency, and investor protection may influence renewable energy outcomes. Its direct association with RECAP is assessed in Section 4. No interaction term between institutional quality and international clean energy finance is included; therefore the model does not test a moderating effect of governance on the finance relationship (Hašičič et al., 2015; Asongu & Odhiambo, 2021; Crescenzi & Harman, 2023; Dossou et al., 2023; Nawaz et al., 2023; Appiah-Otoo et al., 2025).

A key measurement limitation follows from the operationalization of the dependent variable: RECAP measures renewable energy consumption rather than direct renewable-energy investment expenditure. It is therefore interpreted throughout the empirical analysis as a renewable energy outcome and an indirect proxy for deployment or uptake, not as a direct financial measure of investment.

Prior research establishes that finance is relevant to renewable-energy deployment, but evidence on the relationship between international clean energy finance and renewable energy outcomes in Sub-Saharan Africa remains unsettled, particularly in comparative dynamic-panel studies that account for persistence and domestic structural covariates. Many studies focus on single countries, broader climate finance, renewable-energy consumption, emissions mitigation, or policy adoption. The present study contributes by examining the association between international clean energy finance and RECAP in 15 SSA countries from 2005–2021 while accounting for GDP per capita, financial development, electricity access, emissions, institutional quality, and lagged RECAP. Because RECAP is a consumption-based outcome and the model does not estimate interaction terms, the contribution is framed as evidence on conditional associations rather than direct investment effects or domestic moderation of external finance.

3. Methodology

This study employs a quantitative cross-country panel-data approach to examine the association between international clean energy finance and renewable energy outcomes in Sub-Saharan Africa (SSA). Panel analysis captures both cross-sectional and inter-temporal variation and allows the dynamic model to account for time-invariant country heterogeneity through its panel structure. Consistent with the study's theoretical framework, the empirical analysis evaluates whether international clean energy finance is statistically associated with RECAP after accounting for selected economic, financial, energy-access, environmental, and institutional covariates. The design is observational and the reported coefficients are not interpreted as causal effects.

The sample comprises 15 Sub-Saharan African countries selected on the basis of complete and consistent annual data availability for the study variables. The analysis covers 2005–2021, yielding 255 country-year observations before introducing the lagged dependent variable. The Appendix Stata outputs confirm 15 country groups. The period includes major international commitments to clean energy finance, including the 2015 Paris Agreement and the Sustainable Development Goals (SDGs).

This study uses a balanced panel of 15 countries over 2005–2021, yielding 255 country-year observations before introducing the lagged dependent variable. The main level-log system-GMM specification uses 240 observations after the one-period lag. Dynamic panel GMM is used to model persistence in RECAP and the dynamic-panel structure, while the treatment of the contemporaneous regressors in the reported Stata command is described explicitly below. Control variables include GDP per capita, financial development, access to electricity, institutional quality, and carbon emissions.

The variables are drawn from the World Development Indicators and other established secondary sources (World Bank, 2023). The dependent variable is renewable energy consumption (RECAP). Because RECAP does not measure project-finance commitments or investment expenditure, it is treated as a consumption-based renewable energy outcome that may indirectly reflect deployment and uptake, rather than as a direct measure of renewable-energy investment. The principal explanatory variable is international clean energy finance (ICEF), measured in constant US dollars and representing external clean-energy financial flows from multilateral development banks, bilateral donors, and other development partners. All empirical interpretations are therefore expressed in terms of the association between ICEF and RECAP.

To examine this association, the model includes several direct covariates. GDP per capita (GDPpc) captures differences in economic capacity and development. Financial development (FinDev), measured through domestic credit to the private sector, reflects the depth of domestic financial intermediation. Access to electricity (ACCE) captures the energy-access dimension of the transition. These variables enter as separate regressors and are not interacted with ICEF.

Per capita carbon dioxide emissions (CO2) capture environmental pressure and aspects of the prevailing energy structure, while institutional quality (IQ) represents the broader governance context. Together, these controls allow the analysis to estimate the ICEF–RECAP association conditional on selected domestic structural characteristics. They do not establish a causal transmission mechanism or moderation pathway.

The main dynamic panel specification corresponding to the reported level-log system-GMM output relates $\log(\text{RECAP})$ to its one-period lag, international clean energy finance, and the selected direct covariates as follows:

$$\log(\text{RECAP}_{it}) = \alpha + \rho \log(\text{RECAP}_{i,t-1}) + \beta_1 \log(\text{ICEF}_{it}) + \beta_2 \log(\text{GDPpc}_{it}) + \beta_3 \Delta \log(\text{ACCE}_{it}) + \beta_4 \Delta \log(\text{FinDev}_{it}) + \beta_5 \Delta \log(\text{CO2}_{it}) + \beta_6 \Delta \log(\text{IQ}_{it}) + \mu_i + \varepsilon_{it}$$

where i indexes countries, t indexes years, ρ captures persistence in RECAP, Δ denotes the first-difference operator for the transformed covariates, μ_i captures unobserved country-specific effects, and ε_{it} is the idiosyncratic error term. The reported `xtabond2` command does not include year-dummy regressors; accordingly, common time shocks are not separately controlled through year fixed effects in the reported specification.

The lagged dependent variable captures temporal persistence in RECAP. GDP per capita, financial development, electricity access, carbon emissions, and institutional quality enter as direct covariates. No interaction terms between ICEF and the domestic variables are included; consequently, the specification does not test moderation. Because the reported unit-root test classifies $\log(\text{RECAP})$ as non-stationary at level, an alternative system-GMM specification using $\Delta \log(\text{RECAP})$ is retained as a sensitivity analysis in Section 4.8. The corresponding first-difference unit-root result for financial development is not reported in the available Appendix output and should therefore not be assumed from the present tables.

The principal dynamic estimator is two-step system GMM. This estimator is useful for models containing a lagged dependent variable and can reduce dynamic-panel bias when its moment conditions are valid (Arellano & Bover, 1995; Blundell & Bond, 1998). In the reported `xtabond2` command, only

logRECAP is included in the GMM-style instrument set (lag 2, collapsed). logICEF, logGDPpc, dlogACCELE, dlogFINDEV, dlogCO2, and dlogIQ enter as standard IV-style instruments, so the specification treats these contemporaneous regressors as exogenous for the stated moment conditions rather than instrumenting them as endogenous or predetermined. Consequently, the model does not by itself resolve possible reverse causality or endogeneity of ICEF or the other contemporaneous covariates, and their coefficients are interpreted as conditional associations. A random-effects model is retained as a static baseline. The main level-log GMM output uses robust two-step standard errors, 9 instruments, and 15 country groups. Because the cross-sectional dimension is small and the reported main specification does not include year dummies, finite-sample inference and common time shocks remain important limitations.

The reported diagnostics focus on the checks available in the manuscript and Appendix: unit-root tests, variance inflation factors, the Hausman comparison of fixed and random effects, Arellano–Bond tests for serial correlation, and Sargan/Hansen tests of overidentifying restrictions. These diagnostics inform the plausibility of the specification but do not establish causal identification. In particular, non-rejection of the Hansen or Sargan tests is not proof that all instruments or exogeneity assumptions are valid, especially with only 15 country groups.

4. Results

4.1. Descriptive statistics

Table 2 presents the raw data for study variables. The mean value for the outcome variable RECAP is 68.63 with a standard deviation of 26.87. International clean energy finance (ICEF) exhibits higher variance. The mean is approximately 116 million US Dollars and the standard deviation is approximately 234 million US Dollars, with a range of 10 000 US Dollars to 1 720 000 000 US Dollars. Raw Stata output indicates 255 cases for each variable, which is consistent with 15 countries over a period of 17 years. It is important to consider the differences that occur over various countries and over time. These differences can influence the outcomes of renewable energy and other related variables such as finance, income, access to electricity, the financial system, carbon emissions and the quality of institutions. Dispersion of the data can not be used to draw conclusions related to access.

Table 2 Descriptive Statistics							
Statistic	RECAP	ICEF	GDPpc	ACCELE	FINDEV	CO2	IQ
Mean	68.63255	1.16e + 08	1535.986	41.01569	32.88627	3.288217	37.48039
Standard Deviation	26.86731	2.34e + 08	1683.866	27.56794	32.05793	3.128421	13.16337
Minimum	7.6	10000	158.2	3.7	1.5	.0794506	11.4
Maximum	94.7	1.72e + 09	8646.1	100	142.4	10.21678	72.5
Observations	255	255	255	255	255	255	255
Source: Authors' computation using Stata 15							

The Appendix presents descriptive statistics for the variables used in this study. Transformations on the variables are explained in this study's methodology. The focus of this study is on the relative changes of variables. This study uses the descriptive statistics to demonstrate sufficient variation in the variables for panel analysis. However, variation does not necessarily imply a behavioral relationship between International Clean Energy Finance (logICEF) and RECAP.

4.2 Stationarity and Unit Root Tests

Tables 3 and 4 report the results of stationarity tests on the variables used in this study. At level, the Stationarity Test results show that logGDPpc and logICEF are I(1), and therefore, not stationary. LogRECAP and the other control variables are I(0) and thus, stationary. However, it is important to note that there may be stochastic trends in these variables, especially if the variables are integrated of order one (I(1)), and estimating such variables in their levels may lead to incorrect conclusions.

Table 3 ADF Test Results at Level			
Variable	Test statistic / p-value		Decision
	ADF Statistic	P value	
logRECAP	3.5016	0.9998	Non- Stationary
logICEF	-4.3374	0.0000	Stationary
LogGDPpc	-6.0063	0.0000	Stationary
logFINDEV	0.8119	0.7916	Non- Stationary
logCO2	0.2804	0.6104	Non- Stationary
logIQ	1.4327	0.9240	Non- Stationary
Source: Authors' computation using Stata 15			

Table 4 displays the first-difference results, and the results show that dlogRECAP, dlogACCELE, dlogCO2, and dlogIQ are I(0) in their levels and first differences. Hence, transformations can be applied on the non-stationary series. logFINDEV is classified as non-stationary in Table 3, but Table 4 does not report the first-difference unit-root result. However, dlogFINDEV is taken as input in the regressions. In general practice, it is good to report all diagnostic results. Transformations and GMM approaches are applied considering the unit-root results. The GMM approach is further applied considering the lagged dependent variable and potential endogeneity

Table 4
ADF Results at First Difference

Variable	Test statistic / p-value	Decision
	ADF Statistic	
dlogRECAP	-7.3376	Stationary
dlogACCELE	-11.9895	Stationary
dlogCO2	-7.9820	Stationary
dlogIQ	-6.5300	Stationary
Source: Authors' computation using Stata 15		

4.3 Multicollinearity diagnostics

The values in Table 5 show that the variance of each of the regressors included in the regression is inflated between 1.02 to 1.09 times. The corresponding tolerances are in the range of 0.91 to 0.98. This shows that the regressors are not highly linearly related to each other and therefore multicollinearity is not a major concern.

Table 5
Variance Inflation Factor (VIF) diagnostics

Log GDPpc	VIF	1/VIF
	1.09	0.9146
logICEF	1.08	0.9301
dlogIQ	1.05	0.9513
dlogACCELE	1.04	0.9617
dlogFINDEV	1.04	0.9644
dlogCO2	1.02	0.9843
Source: Authors' computation using Stata 15		

From the GMM results and the diagnostic tests done, it can be confirmed that multicollinearity is not a concern; however, this does not guarantee that endogeneity and the overall specification of the model is correct.

4.4 Baseline and dynamic model estimation

The fixed- and random-effects models function as baselines. The results of the Hausman test are $\chi^2(6) = 8.55$, with $p = 0.2008$. Therefore, the random-effects model functions as the baseline. The Hausman test does not correct for the dependence of a variable on its own past values, often referred to as lag, nor does it account for possible endogeneity. The two-step systems GMM approach introduces correct dynamic specification for lag of the RECAP term. The estimated effects are considered to be truly causal and not just related to the variable of interest. This is the case only if the GMM approach is used to instrument the lag of the term of interest. If the GMM approach is not applied to instrument lag terms, the specification should not be considered to have resolved endogeneity of terms of interest, and the estimated effects should be considered to be related to the terms of interest, not causal.

The main two-step system-GMM estimation (Table 7) is based on 240 observations across 15 countries and nine instruments. The results show that the lagged dependent variable is strong and significant ($\beta = 0.8812$, $p < 0.001$), thus indicating that log(RECAP) is persisting. The diagnostics for this estimation indicate first order serial correlation of the residuals from the first difference ($p = 0.027$), and second order serial correlation of the residuals from the second difference ($p = 0.252$). The results from the Sargan and Hansen tests indicate that over-identifying restrictions of the instruments are not binding ($p = 0.615$ and $p = 0.726$, respectively). Considering that there are 15 country groups and nine instruments, this indicates that there is no problem of instrument excess. Evidence from the diagnostics of the over-identifying restrictions should be interpreted with caution, considering there are 15 country groups but only one degree of freedom from the tests.

Table 7
Two-step system GMM results (main level-log specification)

Variable	Coefficient	Robust SE	z	p-value	95% confidence interval
L.logRECAP	0.8811786	0.075071	11.74	< 0.001	[0.7340421, 1.028315]
logICEF	0.0352388	0.0341357	1.03	0.302	[-0.0316658, 0.1021435]
logGDPpc	-3.067683	1.822128	-1.68	0.092	[-6.638989, 0.5036217]
dlogACCELE	1.199704	0.5832905	2.06	0.040	[0.0564757, 2.342932]
dlogFINDEV	1.801259	1.009075	1.79	0.074	[-0.1764914, 3.77901]
dlogCO2	-2.202799	1.790354	-1.23	0.219	[-5.711828, 1.306231]
dlogIQ	-2.044627	2.141125	-0.95	0.340	[-6.241155, 2.151901]
Constant	28.44302	17.81186	1.60	0.110	[-6.467596, 63.35363]

Diagnostics: N = 240; countries = 15; instruments = 9; Wald $\chi^2(7) = 173,609.07$ ($p < 0.001$); AR(1) $p = 0.027$; AR(2) $p = 0.252$; Sargan $p = 0.615$; Hansen $p = 0.726$. Source: Authors' Stata 15 output (Appendix).

4.5 International clean energy finance and the renewable energy outcome (RECAP)

Positive international clean energy finance (ICEF) flows (the main explanatory variable) are expected to have a positive effect on the both the scale and scope of renewable energy capacity (RECap) in the system GMM framework. The main GMM framework estimates a positive effect of international clean energy finance (ICEF) flows on RECap ($\beta = 0.0352$), but the effect is not statistically significant ($p = 0.302$). Thus, the effect of ICEF flows on RECap in the framework is not supported by the data and therefore, we cannot accept H1 in the framework.

In the absence of statistical support for an ICEF-RECap relationship, we can conclude that, within the limitations of this study, there is not enough evidence to establish a relationship between the two. It is important to understand the limits of this study. Testing for a relationship between ICEF and RECap does not provide evidence for or against the sufficiency or inadequacy of international finance for renewable energy. To evaluate those conditions, other research may be necessary.

4.6 Economic growth, electricity access, and financial development

System-GMM outcomes reflect various patterns among country-specific controls. The coefficient for GDP per capita is negative ($\beta = -3.0677$) and almost significant at the 10% level ($p = 0.092$), and thus, does not support the hypothesis in 2, which expects a positive relationship. Access to electricity, on the other hand, supports the hypothesis in 4 of the main specification, as the coefficient is positive ($\beta = 1.1997$) and significant at the 5% level ($p = 0.040$). The coefficient for financial development is positive ($\beta = 1.8013$) and almost significant at the 10% level ($p = 0.074$), therefore, not strongly supportive of hypothesis 3. In the static Hausman comparison, the sign for GDP per capita changes based on the method of fixed ($\beta = -0.3884$) and random ($\beta = 0.1423$) effects. The coefficient for access to electricity and financial development, on the other hand, is positive in both cases. The main estimates of system-GMM should therefore be the basis of the overall inferences.

The system-GMM estimates indicate that among the three variables of the main specification, access to electricity has the strongest positive influence on RECAP, and the relationship with GDP per capita, in the system-GMM estimates, does not supportive of the hypothesis, and thus, is negative. Because the transformations of the regressors differ, comparisons of estimates should not indicate relative importance. The Hausman Test indicates that among the baselines, a system of random effects is to be preferred.

Table 6
Hausman specification test comparing fixed- and random-effects estimates

```
. hausman fe re, sigmamore
---- Coefficients ----
| (b) (B) (b-B) sqrt(diag(V_b-V_B))
| fe re Difference S.E.
-----+-----
logICEF | .0037603 .0073352 - .0035749 .0214262
logGDPpc | - .3883653 .1422907 - .530656 .5103578
dlogACCELE | 1.101196 1.086674 .0145221 .0884188
dlogFINDEV | 1.73308 1.062471 .6706084 .3048631
dlogC02 | - .7392993 -1.218763 .4794639 .4983731
dlogIQ | -2.526907 -2.317928 - .2089784 .372244
-----+-----
b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg
Test: Ho: difference in coefficients not systematic
chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 8.55
Prob>chi2 = 0.2008
```

Source: Stata output

4.7 Environmental and institutional controls

The main system-GMM model shows that the impacts of carbon emissions and the quality of institutions on RECAP are negative but statistically insignificant (carbon emissions: $\beta = -2.2028$, $p = 0.219$, 95% CI: [-5.7118, 1.3062]; quality of institutions: $\beta = -2.0446$, $p = 0.340$, 95% CI: [-6.2412, 2.1519]). Results from the fixed and random effects models show the same negative effects.

Results from the main specification suggest that carbon emissions and institutions do not have a direct impact on RECAP. The negative impacts of carbon emissions and institutions should not be interpreted as carbon emissions and/or weak institutions lead to impacts on renewable energy. The confidence intervals for both effects suggest there is no causal relationship. The results suggest that positive changes in electricity access and/or financial development do not change the impact of ICEF, and therefore do not have a moderating effect on ICEF.

Results from the system-GMM model suggest there is long-term persistence for RECAP. The model does not suggest that there is a direct relationship between ICEF and RECAP. Therefore, the hypothesis that ICEF is Positive for RECAP (H1) is not supported. The model shows that GDP per capita is negatively related to RECAP and is significant at the 10% level (opposite of the hypothesis). The model also shows that financial development is positively related to RECAP and is also significant at the 10% level (support for H3). Finally, the model also shows that the impact of electricity access is positive and significant at the 5% level (support for H4). The impacts of carbon emissions and the quality of institutions are not supported by the model. Finally, since there are no interaction terms in the model, it is not possible to interpret results in terms of country conditions.

4.8 Sensitivity to Dependent Variable Transformation

The Appendix describes an alternative two-step system-GMM estimation with dlogRECAP as the dependent variable. With respect to this specification, the lagged dependent variable is not significant ($\beta = 0.0775$, $p = 0.540$). ICEF is not significant and negative ($\beta = -0.0070$, $p = 0.873$). GDP per capita is not significant ($p = 0.312$), as well as the access to electricity ($p = 0.227$), financial development ($p = 0.188$), carbon emissions ($p = 0.336$), and country-level governance ($p = 0.136$). The second-order autoregressive (AR(2)) and Sargan and Hansen-type tests are satisfactory (AR(2), $p = 0.303$; Sargan $p = 0.180$; Hansen $p = 0.148$; 9 ICES for 15 country groups).

As this alternative specification focuses on the changes of RECAP, as opposed to its levels, it defines a different estimand. Therefore, the results obtained from the alternative model should be articulated with caution. It is worth mentioning that, with this alternative estimation, the results related to the persistence and the level of access to financial and electrical services remain.

The evidence from the main specification indicates a positive, though statistically insignificant, relationship between International Clean Energy Finance (ICEF) and RECAP. Therefore, the evidence does not construct a relationship between ICEF and RECAP for this sample. As the estimated model does not include any terms for interaction, it is not appropriate to state the evidence supports a relationship between ICEF and RECAP that is conditional on financial

development and electricity access and other domestic variables. These variables are included in the model as control variables. The evidence from the first difference sensitivity analysis also indicates the sign of the ICEF relationship is not fixed.

Financing constraints can negatively impact the bankability of projects, and therefore, the mobilization of project finance (Briera and Lefèvre 2024; Buchner et al. 2019; OECD 2022). If international public climate financing alleviates financing constraints, projects may become bankable and mobilize more project finance. However, this model does not test this theory. Therefore, it is neither demonstrated or denied that international public climate financing plays a critical role in achieving the Sustainable Development Goals.

A large lagged RECAP coefficient in the level-log specification suggests that, in the case of renewable energy, persistence is present in the series and that it is important to take into account the history of the series when modeling renewable energy.

From a path-dependence perspective, persistence in the level of renewable energy consumption may be due to the presence of renewable energy infrastructure and/or policy persistence, among others. The first-difference sensitivity model does not capture such a persistence. Thus, in the level-log specification, we can be cautious in interpreting such persistence, but it does not allow us to confirm that investment in renewable energy infrastructure leads to a decline in renewable energy consumption.

Similar interpretative caution is required for the level-log coefficient of Electricity Access. The presence of a positive coefficient for Electricity Access does not mean that, in the absence of Electricity Access, investments in renewable energy would be made first. In the level-log specification, a positive coefficient of Electricity Access may suggest that, in the presence of electricity system expansion, such an improvement may lead to an improvement in the renewable energy system.

The positive coefficient of Electricity Access may reflect an improvement in the electricity access system and an improvement in the renewable energy system, especially if both systems share the same type of infrastructure. In such a case, we may say that improvement in one system may lead to an improvement in the other. The first-difference model does not capture such a relationship, and it may be considered specification-sensitive.

Financial development is found to have a marginally positive effect at the 10% level. The result, however, is not statistically significant (p -value = 0.074). Given that a positive result is indicative of financial development improving the level of investment, the association is consistent with Financial Constraints Theory. Under this theory, the type of financial constraint, and the source of the constraint, affects an individual's or firm's ability and willingness to make long-term investments (Fazzari et al., 1988; Stiglitz and Weiss, 1981). The first difference sensitivity model does not recognize financial development as being statistically significant (p -value = 0.188). Therefore, as empirical evidence is lacking, the claim that financial development interacts with international clean energy finance to accelerate the adoption of clean energy in Sub-Saharan Africa (and elsewhere) should not be accepted.

Higher levels of GDP are negatively and marginally significantly associated with the level of renewable energy (p -value = 0.092). The coefficient is also negative in the random effect model of the investment function. Therefore, the theory is not supported by the available data. The result, however, should also be interpreted as specification sensitive.

This interpretation supports the literature in which the use of renewable energy sources is more influenced by the combined impact of a suitable legal framework and appropriate financing, as opposed to the level of income (Pfeiffer and Mulder, 2013; Olabisi et al., 2025).

Though the coefficients for carbon emissions and the quality of institutions are expected to have a negative impact on carbon emissions and are statistically insignificant in the baseline level-log GMM, they also remain statistically insignificant in the first difference. These results do not and should not be interpreted as if carbon emissions and quality of institutions do not have any impact or do not matter. The absence of a statistically significant impact of these variables in the case studies is due to the fact that the relative differences in the level of carbon emissions and the quality of institutions do not vary across the countries studied. To explore if the effect of international financing is modified by changes in the quality of domestic institutions, other formal approaches should be taken. Taken together, the main specification shows no statistically significant direct ICEF relationship, while electricity access is positively associated with RECAP and financial development provides weaker positive evidence. These are separate direct relationships. The present model does not establish that the effectiveness of international clean energy finance depends on domestic financial structure, electrification, or prior investment conditions.

More cautious interpretation, based on the authors' assessments of the data, suggests the financing coefficient is positively correlated with renewable energy investments, and is statistically indistinguishable from zero in the majority of cases. Use of a first difference approach in the econometrics model reverses sign on the financing coefficient. Therefore, in the absence of a more adequate research design, the authors advise against drawing broad conclusions about the role of national enabling conditions in regard to international finance and local renewable energy investments.

5.1 Limitations and Interpretation

The authors note the potential shortcomings of their study. The dependent variable represents the consumption (RECAP) of renewable energy rather than the investment. Consequently, the study should be viewed as assessing the outcomes of renewable energy rather than as an evaluation of renewable energy investment.

Second, the panel consists of only 15 country groups. In the command reportedly used in the main system, only lagged RECAP is instrumented in GMM. Therefore, the model treats ICEF and other contemporaneous variables as traditional IVs. In addition, the model does not incorporate year dummies and does not estimate any interaction terms. Hence, the model does not account for possible endogeneity of ICEF, common time-varying shocks, or relative country-specific differences. The authors also do not consider the first-difference test of $dlogFINDEV$ in their available appended tables and reports.

Third, the authors do not find significant associations for persistence and electric connectivity using the unit-root test with first-differences. They also do not find significant associations using the level of log of financial development. Therefore, future research should consider other possible sources of renewable energy development and test the effects of first-differences using more refined instruments of ICEF in the presence of year-specific effects.

6. Conclusion

The goal of the research is to study the impact of international financing of clean energy on renewable energy in Sub-Saharan Africa using the Renewable Energy and Clean Air Programme (RECAP) as a proxy for impact. In the preferred level-log system GMM estimator, international clean energy finance (ICEF) is positive but not significant. Access to electricity is positive, significant at the 5% level, financial development is positive and marginally significant at the 10% level, GDP per capita is negative and marginally significant at the 10% level, and carbon emissions and institutional quality are not significant. Given that the model does not include any interaction terms, it treats the simultaneous (or time-variant) variables as standard instruments of Ransom and Price (1983), and does not include country fixed-effects, these results are viewed as partial effects (or conditional associations).

It is worth mentioning that in the preferred specification international clean energy finance (ICEF) is not significantly associated with the RECAP proxy. The absence of a significant association should not be misinterpreted as international clean energy finance being ineffective to achieve renewable energy goals in Sub-Saharan Africa. Rather, the results represent a case where the coefficient is not significantly different from zero in the frame of the tractable model.

The main specification shows that access to electricity is positively and significantly related to RECAP, and financial development is also positively related to RECAP but not significantly so. The results of the analysis suggest that increased financial development and expansion of the energy infrastructure of a country may be related to improvement in renewable energy outputs of that country.

The lagged dependent variable in the main equation with level-log transformation of persistence is large and highly significant ($\beta = 0.8812$, $p < 0.001$), indicating the presence and or importance of RECAP. The lagged change in RECAP in the base-line difference specification is not significant ($p = 0.540$). Therefore, the level-log transformation of the persistence equation appears to be appropriate, while the dynamic equation is more sensitive to the functionality of the transformation of the outcome of interest.

The analyses show that international gender-inclusive clean energy finance is not a Salient or significant behavioral driver of the RECAP outcome in the main analysis. In contrast, other domestic and structural variables are of interest and importance. It would be premature to conclude international gender-inclusive clean energy finance is a complement to or moderator of other variables and/or a 'necessary' but 'not sufficient' condition, without other more encompassing analyses.

The evidence supports possible catalytic effects of external finance on renewable energy. However, the current analysis is unable to directly capture such effects. The evidence is more clearly outlined in other areas. After accounting for persistence and the other controls, the main estimate in the analysis does not demonstrate a significant relationship between ICEF and RECAP. Finally, many of the country-level results are comparatively more robust to the change in the dependent variable.

Because of these limitations, and in the absence of other evidence, firm policy prescriptions cannot be made. Increasing international clean energy finance is not, in and of itself, expected to increase the level of renewable energy capacity. The relationship between the availability of electricity and financial development, and the positive relationship in the main estimate, underscore the importance of other factors, in particular the extent of domestic electrification and financial development. The study does not determine whether finance, electrification, and development are, in fact, coordinated. Thus, policies to promote the integration of these factors, and to consider financing for electricity development and expansion of the domestic financial system, may be the most prudent.

Declarations

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Figures

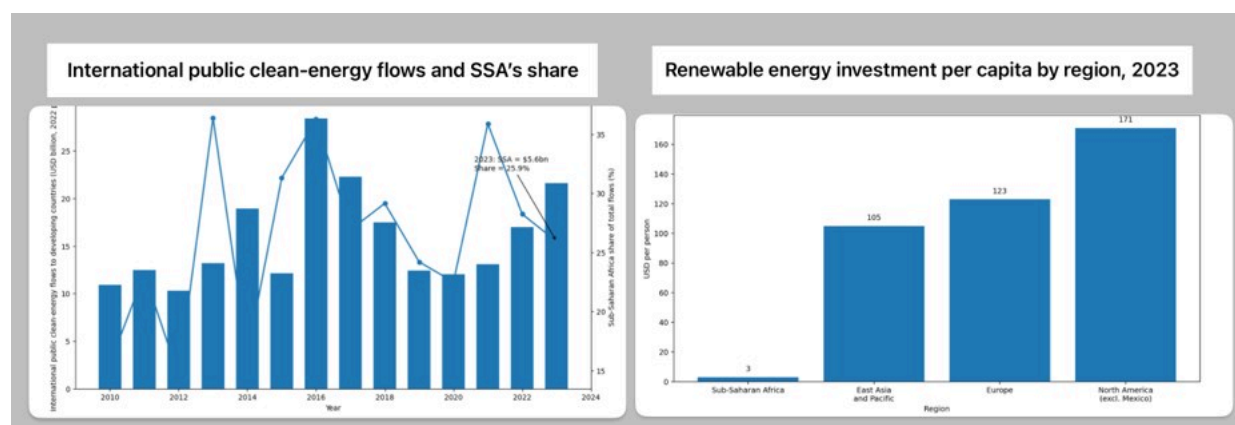


Figure 1

International public financial flows to clean energy in SSA, 2010–2023.

Supplementary Files

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