Techno-computing Journal 1(2) 18-25 (2025) **Research Paper**
https://doi.org/10.71170/tecoj.2025.1.2.18-25

Beyond the Grid: How Incentive Policies Can Bridge the Electricity Access Gap in Rural Nigeria

Abdullahi Yusuf Sada[1], Hamza Sabo Maccido [2*], Munir Husein [3]

[1] *Department of Electrical and Computer Engineering, Baze University Abuja, Nigeria*
[2] *Department of Electrical and Computer Engineering, Baze University Abuja, Nigeria*
[3] *Department of Electrical and Computer Engineering, Baze University Abuja, Nigeria*
**Corresponding Author Email: ashrafmaccido@gmail.com*

Abstract

Globally, Nigeria has the highest number of people without electricity access, with the majority living in rural areas. Traditional grid extension is not economically feasible for most rural communities, necessitating private investment in mini-grids and stand-alone systems. However, progress is slow due to high perceived investment risk, highlighting the critical need for government incentive policies. This paper investigates the impacts and effectiveness of such policies in Nigeria, revealing that financing productive use equipment proves decisively more effective in lowering costs for mini-grids and stand-alone systems than concessionary loans or capital subsidies. We identified three main incentives: (i) concessionary loans, (ii) capital subsidies, and (iii) financing for productive use equipment. Using a combination of geospatial and regulatory analyses, we evaluated the impact of these incentives on rural electrification across 22,696 rural population clusters.

Keywords: Electricity Access, Renewable Energy, Incentive Policies, Mini-grid, Nigeria

1. Introduction

Lack of access to electricity remains a significant challenge in Nigeria, with 87 million people lacking electricity, the highest number globally [1], [2]. This problem continues to persist despite several research pointing to the benefits of electricity access [3], [4], [5], [6], [7], [8]. These benefits are more profound in education. In Nigeria, both school attendance and healthcare services were improved after electricity access [9]. This finding is consistent in other countries. In Uganda, it was found that electricity access leads to an increased school enrollment rate [10]. Increased children's study time and overall academic performance were observed after gaining electricity access in Zambian communities [11]. Similarly, in Brazil, school attendance and enrolment rates were all improved after having electricity access [12].

The socioeconomic benefits of electricity access are prompting governments in developing countries to intensify their efforts to provide this service. However, limited government budgets are leading to the emergence of private investors as promising enablers of rural electrification through mini-grids and stand-alone systems (SASs) [13]. However, progress is hampered by a perceived high investment risk, discouraging many potential investors [14]. To mitigate the risk of investing in rural areas with low ability to pay, governments in developing countries are developing various incentive policies to encourage private investment. Despite these efforts, a clear understanding of the specific impacts and effectiveness of these diverse incentive policies in accelerating rural electrification remains elusive.

This paper examines the effects and effectiveness of incentive policies in promoting rural electrification in Nigeria. We identified three of these policies: concessionary loans, capital subsidies,

(Received 16 June 2025; revised 22 July 2025; accepted 28 July 2025; first published online 30 July 2025);
 Journal homepage https://technocomputing.org/index.php/tecoj

and financing productive-use equipment. Our study employs a geospatial and regulatory framework to assess and analyze the impact of these incentives on electrification across 22,696 unelectrified rural communities in Nigeria.

Our findings demonstrate that financing productive-use equipment proves to be the most effective in reducing the costs of mini-grid and stand-alone systems compared to both concessionary loans and capital subsidies. This study contributes to the ongoing conversation on rural electrification in sub-Saharan Africa by providing a quantitative evaluation of specific incentive policies, thereby advancing the understanding of effective mechanisms for accelerating rural electrification beyond general discussions of challenges. By highlighting the most impactful intervention among the explored incentive options, it offers valuable insights for policymakers and stakeholders working toward achieving universal electricity access in Africa.

2. Methodology

2.1 Model Overview

The off-PVGIS model that is used in this paper (schematized in Figure 1) was developed in our previous study [2] and is extensively discussed in Huld et al., 2017 [15]. The approaches described in [16] have been used to enhance and expand the basic model. This planning tool for large-scale electrification makes use of: 1) Geographical characteristics and population-density data (GHSL) for un-electrified clusters, 2) The clusters' estimated hourly annual electricity usage 3) Annual weather information with an hourly resolution, including sun radiation, wind speed, temperature, etc. 4) The financial and technical specifications of different electrification options. The model's goal is to identify the best electrification option for a cluster, which can be either grid extension, mini-grid, or SAS. The levelized cost of electricity (LCOE) for each electrification option is calculated to determine the most economical one. The best electrification option for that cluster is taken to be the one with the lowest LCOE.

Any combination of solar PV, wind turbines, small hydro, batteries, and diesel or gas-powered generators can be used to electrify a mini-grid in the model. But only solar PV backup with battery mini-grid is taken into account in this study. Additionally, only solar PV and battery systems are considered in the case of SASs. These systems are preferred by the business model over diesel generators for several reasons, including their typically greater environmental friendliness, reduced maintenance requirements, and greater economic viability. The average LCOE of the national grid, plus an additional LCOE for the transmission and distribution assets, makes up the grid extension LCOE.

2.2 Modeling Load Profile

One of the essential parts of our model is the profile of electricity consumption. Load profiles for each population cluster produced at a resolution of 100 m^2 are incorporated into the model. A bottom-up stochastic load profile simulation model called RAMP [17] is used to generate the load profiles. The methodology for load formulation and assignation to population clusters was built on the work of M-LED [18].

The exact number of load curves is computed using a collection of 100 residential user archetypes. Three different parameters are used to calculate the user archetypes: the user's latitude (five locations), climate zone (four zones), and socioeconomic conditions (five levels). The various users are distinguished by varying appliance ownership baskets and daily usage patterns based on the variance of such factors. After feeding in the acquired user personas regarding appliance ownership and use, RAMP produces 100 distinct load curves.

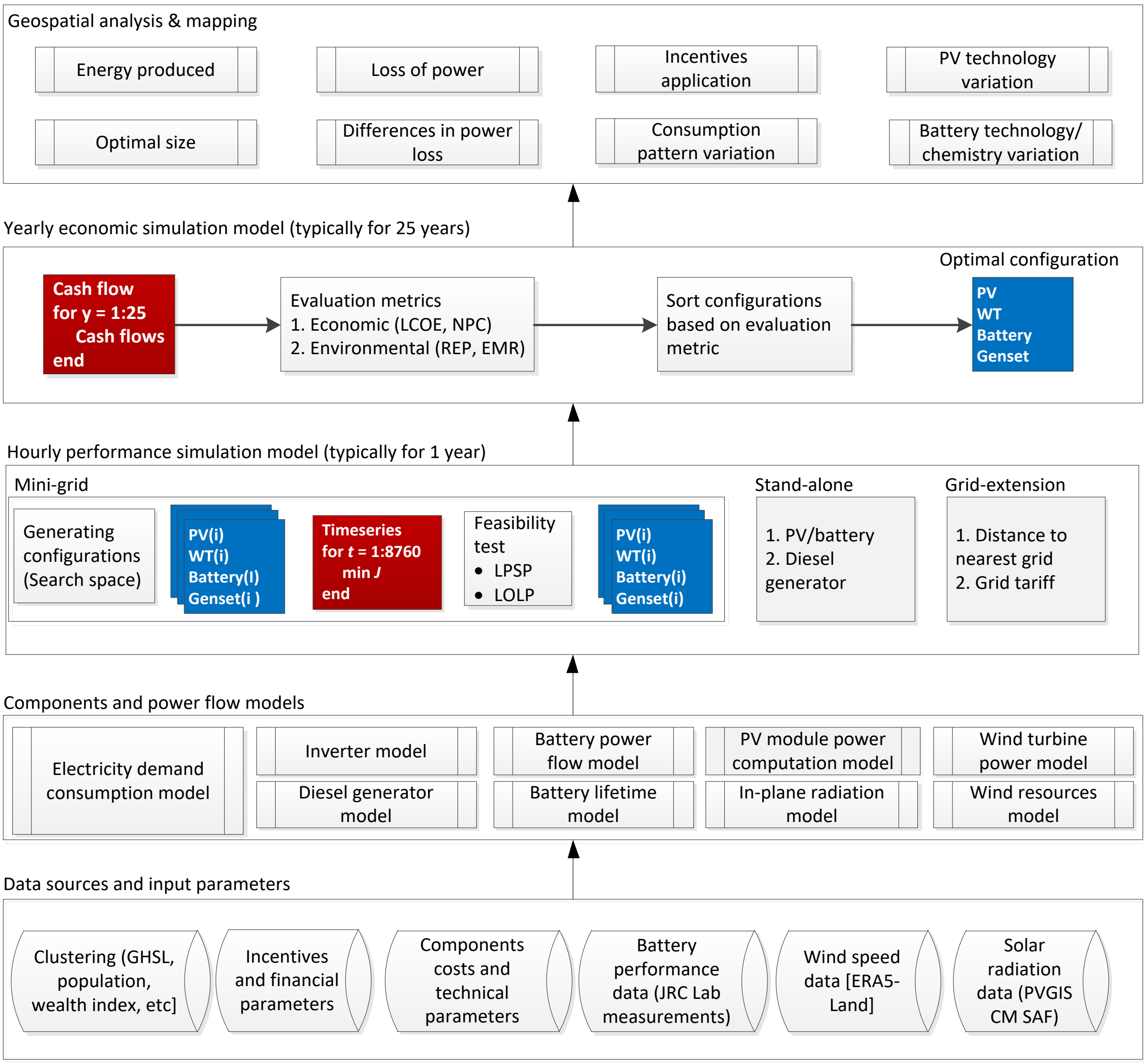

Figure 1: *Flowchart diagram of the structure of the model and data sources.*

3. Data and Materials

Our study uses data from a variety of sources, as indicated in Fig. 1. We use data to determine the load profile for each community (cluster), radiation data to determine the available weather resources for each community, technical and cost data of the various technologies considered in the study, and parameters of the incentive policies considered.

3.1 Weather Data

Data on solar radiation has been gathered using algorithms based on satellite images. The SARAH Climate Data Record (PVGIS-SARAH2), created by CM SAF, contains data spanning a temporal range from 2005 to 2020. The global horizontal and direct horizontal irradiances are included in the solar radiation data, which allows one to compute the irradiance on inclined planes—a typical arrangement for photovoltaic modules. The solar radiation data have an hourly temporal resolution and a spatial precision of three arc minutes, or approximately five kilometers. It should be noted that this resolution is finer than the 6-arc-minute precision employed for the computations in this work.

3.2 Technology and Cost Parameters

In this study, a monocrystalline solar PV module was assumed. In Nigeria, our survey indicates that the CAPEX for a solar system (without battery storage) can range from 600 to 1600 EUR/Wp. Based on this range, 830 EUR/kWp is assumed to be average. This value is chosen to reflect the significant global decline in PV module prices observed in recent years, driven by increased manufacturing capacity and supply chain efficiencies. While regional costs in Sub-Saharan Africa can sometimes be higher due to local market conditions and supply chain factors, this figure represents a realistic average for the module component within the broader system CAPEX considered in this study. The estimated cost of operation and maintenance (O&M), which primarily consists of cleaning and repairs for the modules, is assumed to be 5 EUR/kW/year. Table 1 provides a summary of the technical parameters in detail.

Table 1: *Parameters considered without incentive policies, range of values for each analyzed policy, and selected value*

Category	**Parameters and Values**		
	Parameter	***Value***	***Units***
Technology parameter	PV module efficiency	20.30	%
	Lifetime	25	years
	Max. power voltage/current	39.8/9.29	Vdc/Adc
	Battery depth of discharge	90	%
Cost parameter	PV module capital cost	830	EUR/kWp
	Battery capital cost	352	EUR/kWh

For batteries, there are several chemistries and technologies, each with unique technical specifications and features. This study assumes a lithium-ion battery. Table 1 provides a tabular summary of the battery's key specifications.

3.3 Incentive Parameters

Table 2 presents the range of incentive policy parameters in Nigeria. The base case parameters correspond to the scenario where no incentives are applied. This is not a realistic scenario, as there are many existing incentive policies; however, the scenario provides a basis for the current Nigerian market and can therefore serve as a reference for comparison.

Table 2: *Parameters considered without incentive policies, range of values per each analyzed policy, and selected value*

Policy	**Without incentives (Base case)**	**Value selected for each incentive**	**Range of existing policies**
Capital subsidy			
Rebate (EUR/household)	None	350	100 – 600
Concessionary loan			
Interest rate (%)	15.42	9	6 – 12
Loan term (years)	5	8	7 – 12
Loan percent (% of capital cost)	0	100	50 – 100
Financing equipment for productive use			
Cost of productive use equipment (% of capital cost)	None	30	20 – 50
Demand increases because of the productive use of equipment	None	2 kWh demand increase for every 200 EUR	Depending on the percentage of capital cost

4. Results and Discussion

The results of our investigation into how incentives affect Nigeria's best electrification option are presented in this section. Three incentive policies were assessed: capital subsidies, concessionary loans, and financing productive use equipment. For a total of 129 million individuals in 22,696 population clusters in Nigeria, the least-cost electrification option was determined (See Table 3). Note that there are four scenarios: the base case (no incentives), and the other three cases with different incentive policies.

Table 3: *Comparison of Electrification Options*

Category	Electrification options (%)		
	Grid extension	***Mini-grid***	***Stand-alone system***
Base case (without incentive)	66	27	7
Concessional loan	51	37	12
Capital subsidy	47	41	12
Productive use	42	43	15

In the base case, mini-grids and SASs are less appealing as investments since there are no incentives. Mini-grids and SASs make up 27% and 7% of the total, respectively, with grid expansion accounting for roughly 66%. In contrast to other Sub-Saharan African nations, villages in Nigeria have a comparatively higher population density and a shorter average distance from the national grid, which accounts for the relatively high percentage of grid extension. While this scenario may not precisely represent the current market reality due to the existence of various incentive policies, it serves as a valuable benchmark for evaluating the impact of the three incentive policies under consideration. The concessionary loan scenario employs a 9% discount rate, which is the same interest rate as most concessionary loans available for renewable energy projects in Nigeria, including the SUNREF facility and the Bank of Industry solar loan. The findings show that investing in mini-grids and SASs becomes more appealing in this scenario.

However, the percentage of SASs increases from 7% to 12%, a 5% rise, while the rate of mini-grids increases from 27% to 37%, a 10% rise. Low-interest loans effectively lower the LCOE of mini-grids and SAS, increasing their competitiveness with grid extension. We discovered that the share of mini-grids and SASs in the electrification options increases when we assume a capital subsidy of 600 EUR rebate per connection (household) for mini-grids and stand-alone systems in underserved and unserved communities, as is currently provided by the Nigerian Rural Electrification Agency. The most significant increase was observed in mini-grids, which rose from 27% in the baseline instance to 41%, while SAS increased from 7% to 12%. According to our analysis, capital subsidies and concessional loans have the same effect on SAS, raising its share to 12% in both cases. This isn't the case, though, with mini-grids, where capital subsidies work better to reduce the LCOE, increasing their contribution to 41% as opposed to 37% for concessional loans.

Due to the operation of the acquired equipment for productive purposes, there will be an increase in daytime demand (the equipment and power rating assumptions are included in the Appendix). This will present a favorable case for PV systems, as they produce more energy during the daytime. This will lead to a lower LCOE system, which, consequently, results in the increasing proportion of mini-grids and SASs from 27% to 43% and 7% to 15%, respectively. The three electrification alternatives under the baseline and three incentive policies are shown in Figure 2. Four areas (designated 1, 2, 3, and 4 on the map) were selected to illustrate how electrification options changed before and after different incentive policies were implemented for the clusters under various scenarios. The map demonstrates how incentive programs can change the baseline scenario's electrification option. Financing productive use equipment consistently outperforms other incentives due to a strong economic rationale rooted in demand-side benefits and improved project viability. Productive uses of electricity (PUE), such as powering agricultural processing, small businesses, or cold storage, typically consume more energy and often operate during daylight hours, aligning well with solar PV generation profiles.

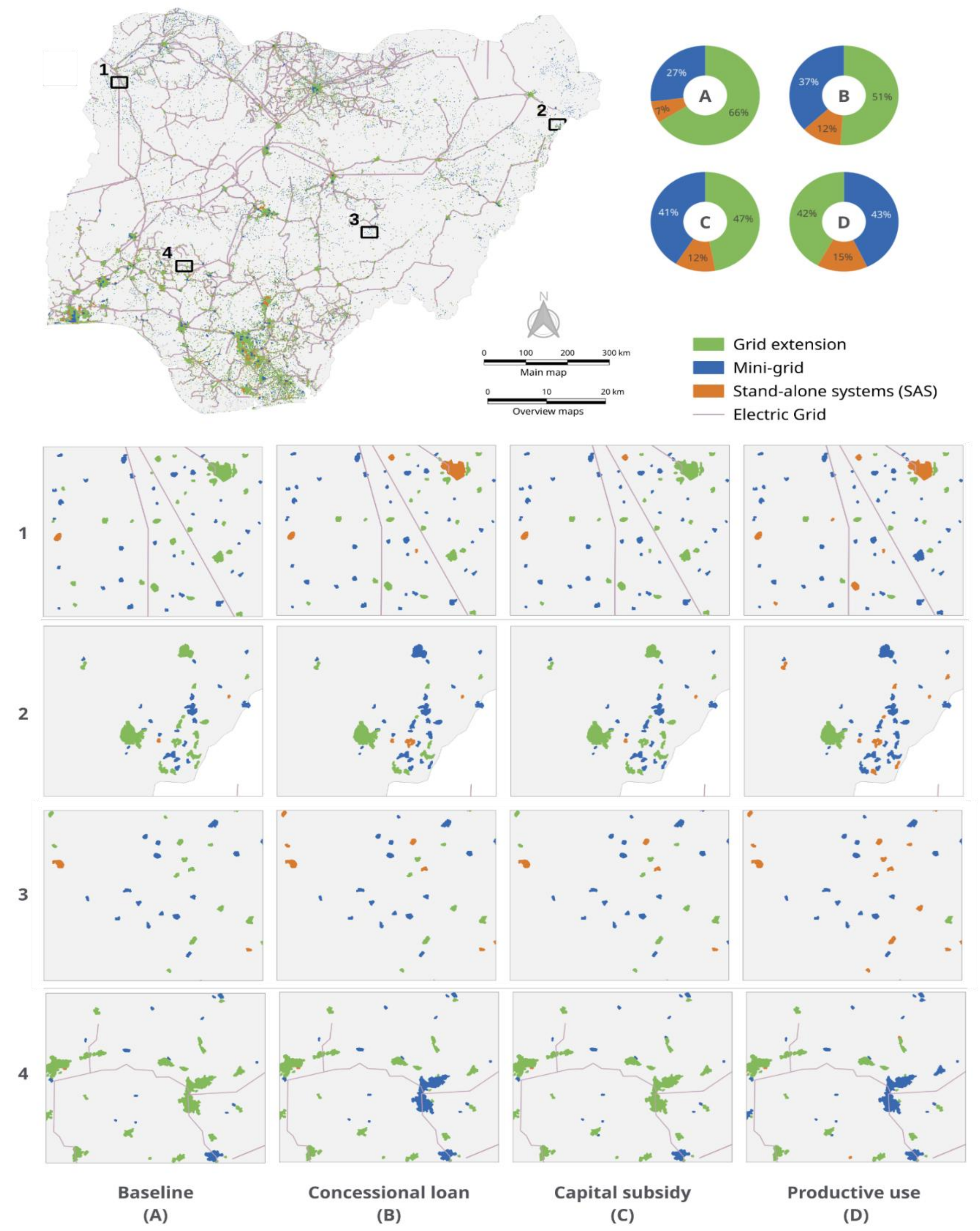

Figure 2: *Comparison of the electrification options under the baseline and the three incentive policies. **(A)** Baseline, **(B)** Concessional loan. **(C)** Capital subsidy **(D)** Financing productive use of equipment*

This increased and more consistent energy consumption directly translates into higher and more predictable revenue streams for mini-grid and stand-alone system operators. By acting as "anchor loads," PUE improves the system's load factor and overall utilization rate, making the energy infrastructure more efficient and cost-effective. This enhanced financial performance significantly reduces the risk of electrification projects, making them more attractive to private investors and improving their bankability compared to projects relying solely on residential consumption. Furthermore, PUE directly contributes to income generation and economic development within rural communities, creating a "virtuous cycle" where higher incomes lead to increased demand for electricity and a greater ability to pay for services, fostering long-term sustainability.

5. Conclusion

We examined in this study how three incentive schemes that are currently in place in Nigeria affect the best options for electrification—grid extension, mini-grids, and SASs—as well as the related economic factors. A total of 22,696 population clusters in Nigeria were investigated using the least-cost electrification model. The findings show that the electrification alternatives are impacted by incentive schemes to varying degrees. For most population clusters, grid extension is the best electrification option in the baseline case (66%), followed by mini-grid (27%), and SASs (only 7%). The results also show that financing equipment for productive use is the best policy to increase the proportion of mini-grids and SASs, which, consequently, will lead to more sustainable renewable energy electrification for rural areas.

This study has important policy implications. The results show that the effects of various incentive schemes on mini-grid and SAS deployments are not uniform. In particular, the findings suggest that capital subsidies may be more effective in reducing mini-grid costs in certain areas, whereas the opposite is true for SASs. For policymakers, the key actionable insights from this study include:

- Prioritize Productive Use Financing: Focus on policies that facilitate the financing of productive use equipment, as this approach has proven most effective in increasing the adoption and sustainability of mini-grids and stand-alone systems.
- Tailor Incentive Schemes: Recognize that the impact of incentives varies between mini-grids and stand-alone systems. Policies should be carefully designed to address the specific needs and economic characteristics of each electrification option.
- Leverage Data-Driven Policy Making: Utilize comprehensive geospatial and regulatory analyses, like those presented in this study, to inform policy decisions and ensure that interventions are well-targeted and effective for sustainable rural electrification.

It is essential to note the limitations of this study, particularly the assumption that only solar PV backup with battery mini-grids and solar PV and battery systems for SASs were considered. While these are prevalent technologies, future research could explore the impact of other renewable energy sources or hybrid systems to provide a more comprehensive understanding of electrification options.

Future research could also explore community-level behavioral factors that influence technology adoption, offering a more comprehensive understanding of successful rural electrification strategies. Therefore, research like this one should be the first resource used by policymakers to establish well-informed policies for sustainable rural electrification in Africa.

Competing Interests: The authors declare that they have no competing interests.

Data Availability Statement: The supported data associated with this researcher is available upon request from the corresponding author.

References

[1] S. Pachauri *et al.*, "Pathways to achieve universal household access to modern energy by 2030," *Environmental Research Letters*, vol. 8, no. 2, p. 8, 2013, doi: 10.1088/1748-9326/8/2/024015.

[2] M. Husein, M. Moner-Girona, G. Falchetta, N. Stevanato, F. Fahl, and S. Szabó, "The impacts of incentive policies on improving private investment for rural electrification in Nigeria – A geospatial study," *Heliyon*, vol. 10, no. 5, p. e27440, Mar. 2024, doi: 10.1016/J.HELIYON.2024.E27440.

[3] V. Akram, "Causality Between Access to Electricity and Education: Evidence From BRICS Countries," *Energy RESEARCH LETTERS*, vol. 3, no. 2, 2022, doi: 10.46557/001C.32597.

[4] C. Candelise, D. Saccone, and E. Vallino, "An empirical assessment of the effects of electricity access on food security," *World Dev*, vol. 141, p. 105390, 2021, doi: 10.1016/j.worlddev.2021.105390.

[5] A. L. Kooijman-van Dijk and J. Clancy, "Impacts of Electricity Access to Rural Enterprises in Bolivia, Tanzania and Vietnam," *Energy for Sustainable Development*, vol. 14, no. 1, pp. 14–21, 2010, doi: 10.1016/j.esd.2009.12.004.

[6] M. Kanagawa and T. Nakata, "Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries," *Energy Policy*, vol. 36, no. 6, pp. 2016–2029, 2008, doi: 10.1016/j.enpol.2008.01.041.

[7] A. G. Dagnachew, P. L. Lucas, A. F. Hof, and D. P. van Vuuren, "Trade-offs and synergies between universal electricity access and climate change mitigation in Sub-Saharan Africa," *Energy Policy*, vol. 114, no. December 2017, pp. 355–366, 2018, doi: 10.1016/j.enpol.2017.12.023.

[8] F. Riva, H. Ahlborg, E. Hartvigsson, S. Pachauri, and E. Colombo, "Electricity access and rural development: Review of complex socio-economic dynamics and causal diagrams for more appropriate energy modelling," *Energy for Sustainable Development*, vol. 43, pp. 203–223, 2018, doi: 10.1016/j.esd.2018.02.003.

[9] I. A. Olanrele, A. I. Lawal, S. O. Dahunsi, A. A. Babajide, and J. O. Iseolorunkanmi, "The impact of access to electricity on education and health sectors in Nigeria's rural communities," *Entrepreneurship and Sustainability Issues*, vol. 7, no. 4, pp. 3016–3035, Jun. 2020, doi: 10.9770/JESI.2020.7.4(30).

[10] B. Faisal, J. Kapeller, S. Vicent, and A. Ahmed, "Differential impacts of electricity access on educational outcomes: Evidence from Uganda," *The Electricity Journal*, vol. 37, no. 1, p. 107362, Jan. 2024, doi: 10.1016/J.TEJ.2023.107362.

[11] M. Gustavsson, "Educational benefits from solar technology-Access to solar electric services and changes in children's study routines, experiences from eastern province Zambia," *Energy Policy*, vol. 35, no. 2, pp. 1292–1299, 2007, doi: 10.1016/j.enpol.2006.03.019.

[12] D. Lopez-Cajiao, "Lightning the Future of Education in Brazil: The Impact of Rural Electrification on Educational Outcomes," *SSRN Electronic Journal*, Sep. 2018, doi: 10.2139/SSRN.3252166.

[13] International Energy Agency and The World Bank, "Sustainable Energy for All 2017—Progress toward Sustainable Energy," Washington, 2017.

[14] IRENA, "Policies and Regulations for Private Sector Renewable Energy Mini-grids," 2016. [Online]. Available: www.irena.org/publications

[15] T. Huld, M. Moner-Girona, and A. Kriston, "Geospatial Analysis of Photovoltaic Mini-Grid System Performance," *Energies (Basel)*, vol. 10, no. 2, p. 218, 2017, doi: 10.3390/en10020218.

[16] M. Husein and I. Y. Chung, "Optimal design and financial feasibility of a university campus microgrid considering renewable energy incentives," *Appl Energy*, vol. 225, no. May, pp. 273–289, 2018, doi: 10.1016/j.apenergy.2018.05.036.

[17] F. Lombardi, S. Balderrama, S. Quoilin, and E. Colombo, "Generating high-resolution multi-energy load profiles for remote areas with an open-source stochastic model," *Energy*, vol. 177, pp. 433–444, Jun. 2019, doi: 10.1016/J.ENERGY.2019.04.097.

[18] G. Falchetta, N. Stevanato, M. Moner-Girona, D. Mazzoni, E. Colombo, and M. Hafner, "The M-LED platform: Advancing electricity demand assessment for communities living in energy poverty," *Environmental Research Letters*, vol. 16, no. 7, 2021, doi: 10.1088/1748-9326/ac0cab.