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A Systems Model for Deploying Renewable Energy Microgrids in Low-Income Communities of Sub-Saharan Africa

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Abstract

Access to reliable and affordable electricity remains a persistent challenge in low-income communities across Sub-Saharan Africa, where centralized grid systems have consistently failed to meet growing and dispersed demand. This paper presents a systems model for deploying renewable energy microgrids as a sustainable and context-sensitive solution to address energy poverty in such communities. The model integrates technical, economic, and social subsystems into a unified framework that emphasizes community participation, financial innovation, institutional alignment, and long-term adaptability. It identifies the core components of microgrids, including generation, storage, distribution, control systems, and community engagement, and outlines how systems thinking can be used to model dynamic interactions, feedback loops, and risk factors. The architecture of the model is designed to simulate real-world energy environments by connecting input-output dynamics across multiple stakeholders and operational domains. Implementation strategies highlight the importance of participatory planning, cooperative ownership structures, blended financing, and continuous monitoring and feedback. The study concludes by offering policy recommendations and practical implications for governments, NGOs, and development partners, while also proposing future research directions in localized modeling, stakeholder dynamics, and sustainability metrics. This holistic and adaptable systems model serves as a strategic tool for advancing equitable and resilient energy access across Sub-Saharan Africa.

Keywords: Renewable Energy Microgrids, Energy Access, Systems Thinking, Community Participation, Sustainable Electrification, Sub-Saharan Africa

1. Introduction

1.1. Background

Sub-Saharan Africa is home to over 600 million people without access to electricity, with a disproportionate concentration of this population in rural and low-income urban communities [1]. Despite decades of investment in large-scale power infrastructure, centralized electricity grids have consistently failed to meet the needs of marginalized populations due to geographical dispersion, high connection costs, unreliable supply, and weak institutional frameworks [2, 3]. In many rural areas, extending the national grid is economically unfeasible due to low population density and limited demand profiles. The result is a persistent state of energy poverty that restricts access to health services, education, clean water, and economic opportunities [4].

The failure of traditional grid expansion models stems not only from infrastructural deficits but also from systemic limitations, including regulatory bottlenecks, dependence on fossil fuels, and insufficient capacity for maintenance [5]. These centralized systems are capital-intensive, slow to deploy, and vulnerable to both climate-related disruptions and political instability. In addition, they often ignore the social contexts and localized energy needs of remote communities, leading to poor adoption and sustainability outcomes [6].

Emerging distributed energy technologies such as solar-based microgrids offer a promising alternative for electrifying low-income areas, but their implementation is fraught with challenges. These include fragmented policies, lack of community engagement, limited financial models, and inconsistent technical standards [7, 8]. The deployment of microgrids in such environments requires more than just technical solutions; it demands a comprehensive understanding of the socio-economic, environmental, and institutional dynamics that influence energy access.

A problem of this complexity requires a systems-based approach that integrates multiple variables and stakeholders in a coherent, strategic framework [9].

1.2. Rationale for Systems Approach

A systems approach is necessary because the challenge of energy access in low-income communities is not a singular technical issue but a multifaceted and interdependent problem. Deploying renewable energy microgrids involves an intricate web of relationships, between technology providers, local governments, financing institutions, end-users, and natural resource constraints [10]. A systems-thinking perspective enables researchers and practitioners to map out these interconnections and identify leverage points for effective intervention. Unlike linear planning models, systems approaches account for feedback loops, delays, trade-offs, and emergent behaviors that are often overlooked in conventional project designs [11, 12].

Moreover, energy systems in developing regions are embedded within larger socio-technical systems that evolve over time. A renewable energy solution that performs well in one locality may fail in another due to differences in community structure, governance, land tenure, or cultural acceptance [13]. Systems modeling provides a structured method to simulate how various components, technical reliability, policy frameworks, financing, and human behavior, interact and influence overall performance. It also facilitates anticipatory planning by revealing potential bottlenecks and enabling adaptive strategies that can evolve as conditions change [14].

The relevance of systems thinking becomes especially critical when considering long-term sustainability. Energy interventions that do not align with local needs, institutional capacities, and environmental constraints often collapse once donor support ends [15]. By focusing on holistic integration, resilience, and participatory design, a systems approach ensures that renewable energy microgrids can deliver consistent benefits over time. This paradigm shift from isolated project-based thinking to interconnected systems modeling is essential for solving the energy access crisis in Sub-Saharan Africa.

1.3. Objectives of the Study

This study aims to develop a systems-based model that can guide the deployment of renewable energy microgrids in low-income communities across Sub-Saharan Africa. The central objective is to design an adaptable and integrated framework that links technical components with financial, institutional, and social dimensions of energy delivery. The model is intended to support decision-makers, practitioners, and community stakeholders in planning, implementing, and sustaining microgrid systems that are context-sensitive and scalable. Rather than offering prescriptive solutions, the model seeks to provide a decision-support tool that allows for customization based on local realities and resource availability.

A core aim is to enhance sustainability, which encompasses technical durability, financial viability, and environmental stewardship. The model emphasizes the selection of renewable technologies that align with local climatic conditions and resource endowments while minimizing maintenance and operational costs. Sustainability also involves empowering communities to manage their energy systems through capacity building, governance structures, and inclusive ownership models.

Another key objective is to promote accessibility. This includes reducing financial and institutional barriers to entry, such as high capital costs, lack of credit access, and bureaucratic complexity. The model explores strategies for affordable tariffs, micro-financing, and public-private partnerships that can make energy services attainable for the most vulnerable. Finally, the model prioritizes resilience, understood as the capacity of the microgrid system to adapt to shocks, maintain performance under stress, and evolve with changing community needs. By achieving these objectives, the study aims to contribute to a transformative shift in how energy poverty is addressed across the region.

2. Conceptual Framework

2.1. Key Components of a Renewable Energy Microgrid

A renewable energy microgrid is an integrated energy system that provides localized electricity generation, distribution, and management, often in areas not served by centralized grid infrastructure [1, 16]. Its core components include generation sources, energy storage units, distribution networks, control systems, and community engagement mechanisms. Together, these elements form a cohesive and self-sufficient energy ecosystem tailored to the specific demands of the host community [17, 18].

Generation typically relies on renewable sources such as solar photovoltaic (PV) panels, wind turbines, or small-scale hydro, with solar being the most prevalent in Sub-Saharan Africa due to abundant sunlight [19, 20]. These sources convert natural energy into usable electricity with minimal environmental impact. Energy storage, commonly in the form of lithium-ion or lead-acid batteries, is essential for balancing supply and demand, especially during periods of intermittency when sunlight or wind is unavailable. Without adequate storage, reliability and load management become significant issues [21].

Distribution infrastructure ensures that electricity reaches end-users efficiently and safely. This includes wiring, transformers, and protective devices that regulate voltage and prevent outages. At the core of system operation are control systems, which monitor energy flows, optimize performance, and enable remote or automated management [22]. Finally, successful deployment depends on active community participation. Community engagement facilitates local buy-in, promotes ownership, and builds capacity for operation and maintenance. Without it, microgrids often struggle with underutilization, vandalism, or financial non-viability. All these elements must work in harmony to ensure long-term sustainability and scalability [23, 24].

2.2. Systems Thinking in Energy Planning

Systems thinking is an analytical approach that emphasizes the interdependence of components within a system and how their interactions affect overall outcomes. In the context of energy planning, this approach shifts the focus from isolated interventions to holistic designs that reflect the complexity of real-world environments. Rather than treating energy access as a purely engineering problem, systems thinking incorporates social, financial, institutional, and environmental dimensions into the planning and design process [25, 26].

One of the key contributions of systems thinking is its ability to model feedback loops. In a microgrid context, this might involve understanding how tariff structures influence consumer behavior, how energy demand affects system performance, or how community ownership models affect maintenance outcomes. These loops are critical because they reveal unintended consequences and emergent patterns that static planning tools often overlook. For instance, reducing electricity prices to improve affordability may lead to overconsumption and system strain if not balanced with load management strategies [27].

Furthermore, systems thinking allows for scenario analysis and adaptive planning. It enables decision-makers to simulate various "what-if" conditions, such as policy changes or technology failures, and to develop contingency strategies [28]. By visualizing the entire system, including energy sources, user behavior, regulatory inputs, and financing flows, stakeholders are better positioned to design resilient and responsive energy solutions. This methodology is especially vital in low-income settings, where resources are limited and vulnerabilities are high. It ensures that interventions are not only technically sound but socially relevant and economically viable over time [29, 30].

2.3. Enabling Conditions for Deployment

The success of renewable energy microgrids in Sub-Saharan Africa depends heavily on the presence of enabling conditions that support deployment, scaling, and sustainability. These conditions include coherent policy frameworks, accessible financial mechanisms, and robust institutional arrangements. Without these foundational supports, even the most well-designed systems can fail to achieve impact or endure over time [31, 32].

Policy alignment is essential for guiding investment, regulating technical standards, and ensuring that microgrid projects complement national energy goals. Supportive policies may include streamlined licensing procedures, feed-in tariffs, and incentives for renewable energy developers. Governments must also address land use regulations, grid interconnection rules, and consumer protection laws to reduce the legal uncertainties that often deter private investment. Crucially, policy must reflect the decentralized nature of microgrids, rather than applying grid-based assumptions to off-grid contexts [33].

Financial mechanisms are another cornerstone. Microgrid deployment involves significant upfront capital costs, which many communities and local entrepreneurs cannot afford. Innovative financing solutions such as results-based funding, concessional loans, blended finance, and pay-as-you-go models can help bridge this gap. Access to credit and investment de-risking tools also enhances the bankability of microgrid projects, attracting more private sector participation [34, 35].

Institutional frameworks provide the governance structures necessary for oversight, coordination, and service delivery. These may involve collaboration between energy ministries, local governments, rural electrification agencies, and non-state actors. Capacity building within institutions is vital to ensure that technical standards are enforced, community needs are met, and accountability is maintained. When these enabling conditions are in place, microgrids are far more likely to deliver reliable, inclusive, and sustainable energy services [36].

3. Model Architecture

3.1. Structural Design and Element Relationships

The systems model is structured around the integration of three primary subsystems: technical, economic, and social. These subsystems interact continuously to influence the design, deployment, and sustainability of renewable energy microgrids. The technical subsystem includes generation, storage, distribution, and control technologies, each represented as nodes within the model. Their operation is governed by physical parameters such as capacity, reliability, and energy efficiency. These nodes are dynamically linked to economic and social factors to reflect real-world complexity.

The economic subsystem encompasses cost structures, financing mechanisms, and revenue models. For instance, capital expenditure and operational costs influence tariff settings, which in turn affect affordability and long-term viability. This subsystem also captures investment flows and risk-sharing arrangements between public and private actors. It is designed to evaluate both short-term financial feasibility and long-term economic sustainability.

The social subsystem accounts for community engagement, governance, local ownership, and behavioral patterns. It emphasizes the role of trust, participation, and institutional support in shaping demand, maintenance, and compliance. The model uses system mapping to show how these subsystems influence each other, e.g., how community acceptance affects technical adoption, or how financial accessibility drives user uptake. By explicitly modeling these relationships, the system provides a multi-dimensional view that supports more informed and inclusive decision-making.

3.2. Input-Output Dynamics

The model operates through defined input-output dynamics that represent the flows of energy, information, capital, and decisions across system components. Inputs to the model include environmental resources (e.g., solar irradiance), technical specifications (e.g., panel efficiency), financial inputs (e.g., investment capital), and community-level data (e.g., population size, income levels). These inputs are fed into a systems map and processed through algorithmic or logic-based rules that simulate interactions and generate outputs.

Energy flows begin with renewable generation, are stored or transmitted through distribution infrastructure, and ultimately reach end-users. These flows are tracked and optimized using embedded control logic, which adjusts generation levels, load balancing, and battery dispatch based on real-time demand. Feedback from usage data informs system performance metrics, such as efficiency, outages, and energy losses, which can then trigger adaptive control responses.

Information flows are equally critical. Monitoring systems relay data on performance, faults, and usage patterns to operators, while communication channels allow users to report issues or receive updates. Decision-making flows are modeled through governance structures, local energy committees, cooperatives, or regulatory bodies, which process information and make collective choices about tariffs, maintenance schedules, or upgrades. Outputs from the system include performance reports, economic forecasts, and policy insights, all of which help stakeholders refine their strategies. The closed-loop nature of these input-output pathways allows the system to self-correct, learn, and evolve over time, enabling more responsive and efficient microgrid management.

3.3. Risk and Resilience Pathways

The model incorporates risk and resilience as integral components, recognizing that microgrids deployed in low-income and off-grid regions face a wide range of uncertainties. These may include resource intermittency, equipment failure, financial shortfalls, institutional breakdowns, or social resistance. The model identifies these risks as both internal and external variables and assigns them to specific nodes and links within the system, enabling targeted mitigation strategies.

Resilience pathways are embedded in the model through adaptive feedback loops, redundancy in system design, and contingency planning protocols. For example, technical resilience is enhanced by integrating modular components, such as scalable PV arrays and decentralized control units, which can be isolated and repaired without system-wide disruption. Economic resilience is supported through diversified revenue streams, such as combining energy sales with productive use applications like irrigation or refrigeration, which reduce dependence on a single user base and increase financial robustness.

Social resilience is addressed by incorporating participatory governance, training, and capacity-building programs that empower local stakeholders to manage and adapt the system. In response to external shocks like policy changes or extreme weather events, the model simulates different stress scenarios and evaluates system responses using resilience metrics such as recovery time, system stability, and service continuity. By embedding these pathways, the model not only anticipates risks but also builds the adaptive capacity of the system to thrive under uncertainty. This proactive design orientation is essential for ensuring that microgrids remain functional, relevant, and impactful in highly dynamic environments.

4. Implementation Strategy

4.1. Community-Centric Planning

At the core of any sustainable microgrid deployment is community-centric planning, which prioritizes the voices, needs, and agency of local residents. This approach begins with participatory planning processes that actively involve community members in system design, site selection, and decision-making. Engaging users from the outset enhances local ownership and fosters a sense of accountability, which is critical for long-term sustainability. When communities participate in identifying priorities and trade-offs, such as balancing affordability with reliability, they are more likely to accept and support the project.

Local ownership structures, such as energy cooperatives or community trusts, further anchor the system within the social and economic fabric of the area. These entities not only manage revenue collection and maintenance but also reinvest profits into social services or system expansion. Ownership models that are inclusive and transparent reduce the risk of elite capture and foster equitable access to electricity across income groups, genders, and social classes [37].

Capacity building is the final pillar of this strategy. Training programs must be developed to equip community members with technical, managerial, and governance skills. These programs should target both youth and adults, emphasizing practical competencies such as system troubleshooting, bookkeeping, and conflict resolution. When communities are empowered with the knowledge and authority to manage their own energy systems, microgrids become more than infrastructure, they become catalysts for local development and resilience [38, 39].

4.2. Financial and Institutional Mechanisms

Deploying microgrids in resource-constrained environments demands innovative financial strategies and strong institutional arrangements. One effective strategy is blended financing, which combines concessional public funds with private capital to lower investment risk and improve project bankability. Public funds may take the form of grants, subsidies, or guarantees, while private financing can come from social impact investors, microfinance institutions, or local enterprises. Blended models de-risk early-stage development and attract commercial capital that might otherwise avoid such high-risk markets.

Cooperative business models also offer a viable alternative for ensuring financial sustainability. In these arrangements, users are not just consumers but co-owners of the energy system. They contribute to operational costs and have voting rights in management decisions. Revenues from tariffs are reinvested into system maintenance or distributed as dividends, ensuring both financial accountability and shared benefit. Cooperatives can also leverage collective bargaining to secure better prices for equipment and services, reducing costs across the value chain [40, 41].

On the institutional side, partnerships between local governments, NGOs, utility companies, and rural electrification agencies are essential for coordination and policy alignment. Institutional roles must be clearly defined to avoid duplication or jurisdictional conflict. These entities should collaborate on regulatory support, quality assurance, and long-term oversight. Technical assistance facilities, perhaps funded by development agencies, can help bridge capacity gaps in planning, procurement, and evaluation. The strength of financial and institutional frameworks directly influences the durability and scalability of microgrid initiatives [42].

4.3. Monitoring and Adaptive Feedback Loops

An effective implementation strategy must include systems for monitoring performance and integrating adaptive feedback. Monitoring ensures that the microgrid functions as intended, while adaptive feedback enables continuous improvement in response to changing conditions or emerging challenges. Together, they form a learning system that evolves with the needs and capacities of the community.

Performance monitoring should encompass technical, financial, and social indicators. Technical monitoring includes metrics such as uptime, energy losses, and battery health. Financial indicators track revenue collection, cost recovery, and profitability. Social metrics assess user satisfaction, equitable access, and community participation levels. These indicators must be gathered regularly using digital tools or manual methods, depending on the technological capacity of the area. The data collected becomes the foundation for informed decision-making and transparent governance [43, 44].

Feedback loops allow stakeholders to act on this information in a timely and effective manner. For example, if data shows a pattern of payment defaults, the community cooperative may decide to adjust tariff structures or implement flexible billing. If technical failures are detected, maintenance protocols can be revised. Institutional actors can also use monitoring results to revise policies or allocate support resources more efficiently. The model includes built-in mechanisms for reviewing this data at regular intervals, promoting a culture of evidence-based management. Ultimately, a well-functioning monitoring and feedback system enhances resilience by allowing microgrids to adapt to shocks, correct inefficiencies, and scale up best practices. It ensures that the system is not static but dynamic, learning from experience and improving over time to meet evolving community needs [45].

5. Conclusion

The systems model developed in this study offers a structured, multidisciplinary approach to tackling the energy access deficit in low-income areas. It responds to the inadequacies of centralized grid expansion by proposing a decentralized alternative that aligns with the socio-economic realities of Sub-Saharan Africa. The model identifies and interconnects critical components, including generation, storage, distribution, control, and community engagement, into a unified framework that mirrors the complexity of real-world energy ecosystems.

One of the central insights is the value of linking technical performance with social participation and financial sustainability. Rather than treating these domains as isolated, the model recognizes their mutual influence: for example, how community trust enhances maintenance, or how stable financing ensures reliable service delivery. It also integrates systems thinking principles that allow for feedback loops, adaptive learning, and resilience, making the model robust against operational and contextual uncertainties.

The architecture's strength lies in its balance between general applicability and contextual adaptability. It provides a blueprint that can be customized to specific communities while maintaining a consistent logic for planning, implementation, and evaluation. In doing so, it addresses the challenge of delivering clean, affordable, and reliable energy to those most in need, advancing both development and sustainability goals in the region.

The findings of this study carry significant implications for policymakers, non-governmental organizations, and development partners engaged in energy access initiatives. For governments, the systems model provides a framework for designing national and sub-national electrification strategies that prioritize decentralized solutions. It supports the development of enabling policies, such as regulatory simplification, tariff reform, and technical standards, that foster innovation while safeguarding consumer interests. Integration of the model into rural electrification programs can also promote equity and inclusiveness by systematically targeting underserved populations.

For NGOs and civil society actors, the model offers guidance on designing interventions that are community-driven and institutionally supported. It underscores the importance of participatory planning, local ownership, and continuous capacity building. Organizations can use the model to structure engagement processes, coordinate with stakeholders, and measure impact across multiple dimensions, technical, social, and financial. The emphasis on adaptive feedback loops aligns well with development practices that seek to remain responsive and accountable.

Development partners, including donors and international financial institutions, can leverage the model to inform investment decisions and funding mechanisms. The model's clear articulation of input-output dynamics and resilience pathways enables better risk assessment and project monitoring. It also facilitates alignment between financing instruments, such as grants, guarantees, and concessional loans, and on-the-ground implementation needs. By adopting a systems perspective, stakeholders across sectors can move toward more coherent, scalable, and sustainable electrification outcomes.

While this study lays a strong conceptual foundation, there remains significant room for further research and refinement. One priority area is the localization of systems models to specific regions or communities. Future studies could explore how variables such as climate conditions, cultural norms, and governance structures shape the design and operation of microgrids. Developing spatially differentiated models will enhance precision and relevance, particularly for countries with highly diverse socio-geographic contexts.

Another area for deeper exploration is stakeholder dynamics, including power relations, negotiation processes, and institutional trust. Understanding these dynamics is critical for predicting how community engagement efforts translate into long-term system sustainability. Research can also investigate the role of gender, youth participation, and marginalized groups in energy governance, ensuring that microgrid systems are truly inclusive. Finally, there is a need for robust sustainability metrics that go beyond traditional technical performance indicators. These should include long-term measures of environmental impact, financial health, and social well-being. Future research could contribute to the development of composite indices that capture these dimensions and guide ongoing evaluation. Incorporating advanced tools such as agent-based modeling or scenario simulation may also enhance the model’s capacity to handle complexity and uncertainty. These future efforts will be crucial in transforming the model from a planning tool into a living framework for sustainable energy transformation.

6. References

1. Avila N, Carvallo JP, Shaw B, Kammen DM. The energy challenge in sub-Saharan Africa: a guide for advocates and policy makers. Generating energy for sustainable and equitable development, Part 1. Oxfam Research Reports; 2017. p. 1-79.
2. Blimpo MP, Postepska A, Xu Y. Why is household electricity uptake low in Sub-Saharan Africa? World Dev. 2020;133:105002.
3. Kojima M, Zhou X, Han J, De Wit JF, Bacon R, Trimble CP. Who uses electricity in Sub-Saharan Africa? Findings from household surveys. World Bank Policy Research Working Paper, no. 7789. Washington, DC: World Bank; 2016.
4. Pachauri S, Brew-Hammond A, Byers E, Ekholm T, Fahl U, Grubler A, *et al*. Energy access for development. In: Global Energy Assessment - Toward a Sustainable Future. Cambridge: Cambridge University Press; 2012. p. 1401-58.
5. Narayan NS. Solar home systems for improving [dissertation/master's thesis]. [Location unknown]: [Publisher unknown]; [year unknown].
6. A.R. Energy. Clean and improved cooking in Sub-Saharan Africa. Washington, DC: World Bank Group;

2014.
7. Bhanja A, Das A, Bera R. Developing a framework for rural electrification in India-analysis of the prospects of micro-grid solutions. Int J Sustain Dev Plann. 2020;15(8):1341-50.
8. Handule H. Financing solar infrastructure in Somaliland: investigating the potential for communal and crowdfunded solutions [master's thesis]. Toronto (ON): Toronto Metropolitan University; [year unknown].
9. Gbabo EY, Okenwa OK, Chima PE. Constructing AI-enabled compliance automation models for real-time regulatory reporting in energy systems. [Publication details unavailable].
10. Walsh EA. Home ecology and challenges in the design of healthy home environments: possibilities for low-income home repair as a leverage point for environmental justice in gentrifying urban environments [dissertation]. [Location unknown]: [Publisher unknown]; 2015.
11. Tàbara JD, Storch HV, Frantzeskaki N, Cots F. Micro-solutions to global problems: understanding social processes to eradicate energy poverty and build climate-resilient livelihoods. Clim Change. 2020;160:711-25.
12. da Costa Junior J, Diehl JC, Secomandi F. Towards systems-oriented energy solutions: a multilevel analysis of a low-income energy efficiency program in Brazil. Sustainability. 2019;11(20):5799.
13. Barbarà Mir L. The water-energy-food nexus to tackle climate change in Morocco. [Publication details unavailable]; 2020.
14. Gbabo EY, Okenwa OK, Chima PE. Integrating CDM regulations into role-based compliance models for energy infrastructure projects. [Publication details unavailable].
15. Greet N. Building energy resiliency in the Asia Pacific–providing transition pathways for a more secure and sustainable future. In: Asia-Pacific security challenges: managing black swans and persistent threats. Cham: Springer; 2018. p. 165-95.
16. Mas'ud AA, Wirba AV, Muhammad-Sukki F, Mas'ud IA, Munir AB, Yunus NM. A review on the recent progress made on solar photovoltaic in selected countries of sub-Saharan Africa. Renew Sustain Energy Rev. 2016;62:441-52.
17. Basak P, Chowdhury S, nee Dey SH, Chowdhury S. A literature review on integration of distributed energy resources in the perspective of control, protection and stability of microgrid. Renew Sustain Energy Rev. 2012;16(8):5545-56.
18. Liu X, Su B. Microgrids—an integration of renewable energy technologies. In: 2008 China International Conference on Electricity Distribution; 2008 Dec 10-13; Guangzhou, China. IEEE; 2008. p. 1-7.
19. Bishoge OK, Kombe GG, Mvile BN. Renewable energy for sustainable development in sub-Saharan African countries: challenges and way forward. J Renew Sustain Energy. 2020;12(5):052901.
20. Kaunda CS, Kimambo CZ, Nielsen TK. Potential of small-scale hydropower for electricity generation in sub-Saharan Africa. Int Sch Res Notices. 2012;2012:132606.
21. Yan J, Zhai Y, Wijayatunga P, Mohamed AM, Campana PE. Renewable energy integration with mini/micro-grids. Appl Energy. 2017;201:241-4.
22. Mohammed Y, Mustafa M, Bashir N. Status of renewable energy consumption and developmental challenges in Sub-Sahara Africa. Renew Sustain Energy Rev. 2013;27:453-63.
23. Bhatti HJ, Danilovic M. Making the world more sustainable: enabling localized energy generation and distribution on decentralized smart grid systems. World J Eng Technol. 2018;6(2):350-82.
24. Adefarati T, Bansal R. Reliability and economic assessment of a microgrid power system with the integration of renewable energy resources. Appl Energy. 2017;206:911-33.
25. Sioshansi F. Smart grid: integrating renewable, distributed and efficient energy. Burlington (MA): Academic Press; 2011.
26. Lasseter R, Akhil A, Marnay C, Stephens J, Dagle J, Guttromson R, *et al*. Integration of distributed energy resources. The CERTS Microgrid Concept. Berkeley (CA): Lawrence Berkeley National Laboratory; 2002.
27. Sherman GR. Sharing local energy infrastructure: organizational models for implementing microgrids and district energy systems in urban commercial districts [master's thesis]. Cambridge (MA): Massachusetts Institute of Technology; 2012.
28. Wright G, Cairns G. Scenario thinking: practical approaches to the future. New York (NY): Palgrave; 2011.
29. Chermack TJ. Scenario planning in organizations: how to create, use, and assess scenarios. San Francisco (CA): Berrett-Koehler Publishers; 2011.
30. Maani K. Multi-stakeholder decision making for complex problems: a systems thinking approach with cases. Singapore: World Scientific; 2016.
31. Baurzhan S, Jenkins GP. Off-grid solar PV: is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? Renew Sustain Energy Rev. 2016;60:1405-18.
32. Charles RG, Davies ML, Douglas P, Hallin IL. Sustainable solar energy collection and storage for rural Sub-Saharan Africa. In: A comprehensive guide to solar energy systems. London: Elsevier; 2018. p. 81-107.
33. Symstad AJ, Fisichelli NA, Miller BW, Rowland E, Schuurman GW. Multiple methods for multiple futures: integrating qualitative scenario planning and quantitative simulation modeling for natural resource decision making. Clim Risk Manag. 2017;17:78-91.
34. Burke MJ, Stephens JC. Energy democracy: goals and policy instruments for sociotechnical transitions. Energy Res Soc Sci. 2017;33:35-48.
35. Rinaldi KS, Bunnen E, Rogers S. Residential grid-interactive efficient building technology and policy: harnessing the power of homes for a clean, affordable, resilient grid of the future. Arlington (VA): National Association of State Energy Officials (NASEO); 2019.
36. Ford R, Hardy J. Are we seeing clearly? The need for aligned vision and supporting strategies to deliver net-zero electricity systems. Energy Policy. 2020;147:111902.
37. Becker S, Kunze C, Vancea M. Community energy and social entrepreneurship: addressing purpose, organisation and embeddedness of renewable energy projects. J Clean Prod. 2017;147:25-36.
38. Van der Schoor T, Van Lente H, Scholtens B, Peine A. Challenging obduracy: how local communities transform the energy system. Energy Res Soc Sci.

2016;13:94-105.
39. Schreuer A, Weismeier-Sammer D. Energy cooperatives and local ownership in the field of renewable energy technologies: a literature review. Vienna: Research Institute for Co-operation and Co-operatives (RiCC); 2010.
40. Jeter DC, Thomas RS, Wells H. Democracy and dysfunction: rural electric cooperatives and the surprising persistence of the separation of ownership and control. Ala L Rev. 2018;70:361.
41. Slee B. Social innovation in community energy in Scotland: institutional form and sustainability outcomes. Glob Transit. 2020;2:157-66.
42. Wirth S. Communities matter: institutional preconditions for community renewable energy. Energy Policy. 2014;70:236-46.
43. Lennon B, Dunphy NP, Sanvicente E. Community acceptability and the energy transition: a citizens' perspective. Energy Sustain Soc. 2019;9(1):35.
44. Klein SJ, Coffey S. Building a sustainable energy future, one community at a time. Renew Sustain Energy Rev. 2016;60:867-80.
45. Caramizaru A, Uihlein A. Energy communities: an overview of energy and social innovation. Luxembourg: Publications Office of the European Union; 2020.