Degree Program in International Relations

Course of
Energy for Development and the Climate Constraint

Reframing Energy Communities: A Development-Centered Approach for Rural Sub-Saharan Africa

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Academic Year 2024/2025

Abstract: This work investigates the potential and limitations of energy communities (EC) as a model for increasing access to energy and fostering local economic development in Sub-Saharan Africa. By exploring existing practices from an organizational and economic perspective, this study aims at shedding light on how this model of energy management can be applied to access-oriented contexts. The regional focus on Sub-Saharan Africa is primarily motivated by its need for decentralized solutions for access to electricity in rural areas. Moreover, the relative immaturity of most energy systems in the region offers an opportunity to explore innovative models with fewer technical constraints. While many countries in the region are characterized by institutional and macroeconomic frameworks that might hinder long-lasting commitment from investors, some effective models of off-grid utilities regulation and operation have emerged, presenting room for replication. Although challenges such as low take-up rates in rural electrification projects persist, designs that foster both energy access – which is not limited to access to electricity - and local development are worth exploring. The first chapter of this work will provide a theoretical framework for energy communities in developing countries, while the second will contextualize their application in Sub-Saharan Africa by outlining the state of the art in access to electricity and clean cooking technologies. After a methodological section, the fourth chapter will conduct a case study analysis of two energy communities in rural areas of Zambia and Tanzania, especially investigating their economic and organizational structures. The last chapter will discuss the findings from a comparative perspective and in relation to the discourse on both EC and energy for development practice.

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List of abbreviations

ABPP - Africa Biogas Partnership Programme
ACRA - Italian NGO: Associazione di Cooperazione Rurale in Africa e America Latina
ACRA-CCS - Italian NGO: ACRA – Centro di Cooperazione per lo Sviluppo
ADB - Asian Development Bank
AfDB - African Development Bank
AFUR - African Forum for Utility Regulators
AGM - Absorbent Glass Mat (lead-acid battery type)
ASEAN - Association of Southeast Asian Nations
BGFA - Beyond the Grid Fund for Africa
BSEAA2 - Bioenergy for Sustainable Local Energy Services and Energy Access in Africa (Phase 2)
CAPEX - Capital Expenditure(s)
CAPP - Central African Power Pool
CCP - Chinese Communist Party
CEC - Citizen Energy Community
CEDP - Community Energy Development Programme (Malawi)
CEM - Community Energy Malawi
CO - Carbon Monoxide
CO2 - Carbon Dioxide
CSIS - Center for Strategic and International Studies
DRC - Democratic Republic of the Congo
DSM - Demand Side Management
E4D - Energy for Development (research group/project)
EAPP - Eastern Africa Power Pool
EC - Energy Community
ECA - Economic Commission for Africa
ECB - European Central Bank
ECOWAS - Economic Community of West African States
EMDEs - Emerging Market and Developing Economies
ERB - Energy Regulation Board (Zambia)
ESCO - Energy Service Company
ESCOs - Energy Service Companies
EU - European Union
EUR - Euro
EWURA - Energy and Water Utilities Regulatory Authority (Tanzania)
G20 - Group of Twenty
GDP - Gross Domestic Product
GNI - Gross National Income
GOGLA - Global Off-Grid Lighting Association
GridCo - Ghana Grid Company Limited
GSE – Gestore Servizi Energetici (Italy)
GW - Gigawatt
HV - High Voltage

ICE - Integrated Community Energy System
ICT - Information and Communications Technology
IEA - International Energy Agency
IEEE - Institute of Electrical and Electronics Engineers
IEJ - Institute for Economic Justice
IEJ-G20 - Institute for Economic Justice - G20
IFAD - International Fund for Agricultural Development
IGAD - Intergovernmental Authority on Development
ILEC - Integrated Local Energy Community
ILO - International Labour Organization
IMF - International Monetary Fund
IPP - Independent Power Project
KETRACO - Kenya Electricity Transmission Company
kW - kilowatt
kWh - kilowatt-hour
LCOE - Levelized Cost of Energy
LPG - Liquefied Petroleum Gas
LUMAMA – Lupande-Mawengi-Madunda (hydro mini-grid association, Ludewa, Tanzania)
LV - Low Voltage
MEGA - Mulanje Electricity Generation Agency
MENA - Middle East and North Africa
MV – Medium Voltage
MW - Megawatt
NEET - Not in Education, Employment, or Training
NGO - Non-Governmental Organization
OECD - Organisation for Economic Co-operation and Development
OOA - Organisationen til Oplysning om Atomkraft (Danish anti-nuclear movement)
OPEX - Operating Expenditure(s)
PAYG - Pay-As-You-Go
PM-KUSUM - Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (India)
PM10 - Particulate Matter ≤10 µm
PPA - Power Purchase Agreement
PPP – Public-Private Partnership
PV - Photovoltaic
REA - Rural Electrification Authority
REC - Renewable Energy Community
RED II - Renewable Energy Directive (EU) 2018/2001
RESCO - Renewable Energy Service Company
RREP - Rural Renewable Energy Project
RURA - Rwanda Utilities Regulatory Authority
SADC - Southern African Development Community
SAPP - Southern African Power Pool
SHS - Solar Home System
SME - Small and Medium-sized Enterprise
SOE - State-Owned Enterprise
SSA - Sub-Saharan Africa
TANESCO - Tanzania Electric Supply Company
TCN - Transmission Company of Nigeria
TEDAP - Tanzania Energy Development and Access Project

TSO - Transmission System Operator
UN - United Nations
UNDESA - United Nations Department of Economic and Social Affairs
UNDP - United Nations Development Programme
UNECA - United Nations Economic Commission for Africa
UNIDO - United Nations Industrial Development Organization
UNOPS - United Nations Office for Project Services
UOMA - Uganda Off-Grid Energy Market Accelerator
USD - United States Dollar
WAPP - West African Power Pool
WHO - World Health Organization
WTO - World Trade Organization
ZESCO - Zambia Electricity Supply Corporation

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Introduction

Scarce access to energy is a major challenge to development in Sub-Saharan Africa, which is the least electrified region in the world – with only 51% of the population having access to electricity - and registers the lowest rates of access to clean cooking technologies (23%). This issue is amplified in rural areas, where the high cost of infrastructure and difficult business conditions complicate grid expansion. Consequently, off-grid options such as mini-grids and stand-alone systems are gaining increasing attention from investors. However, low household expenditure often tests the financial sustainability of decentralized energy systems in rural areas of Sub-Saharan Africa. On the one hand, building affordable solutions for customers is key for increasing take-up and energy consumption, leading development actors to often subsidize tariffs or sustain operational costs. On the other hand, both development practice and national strategies of emerging economies increasingly aim at local empowerment and reduced dependency. Therefore, it is necessary to find solutions that fulfill the following requirements: affordability for customers, financial sustainability for operators, local operation and management allowing phasing out of external aid. Given that low GDP per-capita negatively impacts energy consumption, pairing access-oriented projects with growth-generating activities is instrumental for attaining such objectives in rural SSA. This thesis investigates whether and under which conditions energy communities have the potential to combine affordability with long-term sustainability, while acting as local development catalyzers. More explicitly, the main research question is the following:

"Which elements determine whether energy community projects can sustainably deliver access to energy in rural Sub-Saharan Africa?"

'Sustainably' refers to their ability to generate impact by consistently providing energy access in the long term more than to its environmental connotation: while the cases selected (and most of the literature reviewed) utilize renewable energy sources, an environmental impact assessment falls outside the scope of this work.

Energy communities are known in the EU as a recent regulatory category but have existed as a model of local empowerment and/or environmental activism for a long time: from agricultural cooperatives producing energy in post-WW1 central Europe to REC promoting affordable energy transitions in remote areas of the EU, this configuration has evolved with the spirit of the times. Though still failing to agree on a definition, the West-focused literature on EC is very abundant – while their implementation and potential for favoring energy access in developing countries is understudied. More specifically to Sub-Saharan Africa, the only existing piece of theoretical research

(Ambole et al., 2021) performs a literature review of off-grid utilities displaying the structure of an EC, classifying them by organizational model and level of democratic participation. Empirical studies either focus on single cases privileging social impact over economic analysis (e.g., Damien 2016, Muhoza et al. 2018, etc[1].) or qualitatively describe various projects within the context of wider energy for development work (Hara et al., 2024).

However, the question of whether and under which conditions energy communities offer sustainable models for access to energy in SSA is still unanswered. This work does not investigate to a great length the social dimensions of *prosumerism*, as it focuses instead on filling the research gap through an economic and organizational assessment of case studies in Eastern and Southern Africa. Findings will show that – contrary to the common understanding of an 'enabling policy framework' for EC in low-income contexts – the prolonged reliance on subsidies is detrimental to the system's long-term socioeconomic sustainability. On the contrary, cost-reflective tariff structures paired with technical reliability and economic growth advancement can produce comparatively economically efficient models and autonomously sustain OPEX. However, upfront costs are still too high compared to profits for EC to be proposed as commercial projects in rural SSA. Therefore, development-centered designs currently represent the most coherent and financially sustainable application.

Additionally, this work contributes to a clearer understanding of what an energy community is and how it works based on its organizational model, adapting the theoretical concept of EC to the energy for development field. While energy communities in Europe are conceived as indissolubly linked to electrification, they have stronger potential: this work proposes their implementation as instruments for increasing access to clean cooking and fostering local development as well.

The first chapter investigates the conceptual and practical evolution of energy communities through the analysis of academic frameworks and case studies in Europe, the Americas, and Asia, identifying how organizational and economic models interact with different institutional and business environments. Moreover, it will analyze the main technical challenges of integrating decentralized utilities in energy systems built for centralized infrastructure and/or illiberal markets.

The second chapter will place energy communities in the access-oriented Sub-Saharan African energy scenario. After an overview of the socioeconomic trends in the region, it will present the current challenges to electrification and clean cooking in rural areas, as well as national and subregional policies in both domains. Regulatory frameworks will be analyzed in order to assess their

[1] The other sources can be found in the bibliography

suitability for energy communities, which require at least favorable regimes for off-grid utilities where the wholesale market is not liberalized.

Following a methodological section which outlines the research design and case selection process, the fourth chapter will present the case study analysis of two energy communities in Zambia and Tanzania, focusing on economic and organizational aspects. The findings will be analyzed in chapter five: the author will discuss the results of the research, linking them to the wider discourse on EC and assessing their role in energy for development practice. This work will provide recommendations for both project developers and policy actors in the areas analyzed throughout the research - from EC's economic structure and technical aspects to regulatory frameworks.

1. Theoretical framework: energy communities

This chapter presents the conceptual background based on which the case studies will be selected. It provides a comprehensive overview of the literature on energy communities, as well as on the evolution of practices through time. Moreover, it describes the economic and organizational models that have been observed up to this moment, and it discusses EC's impact on energy transitions and energy poverty.

1.1. Concept and evolution

The concept of Renewable Energy Community (REC) is commonly understood as a regulatory category of the European Union. In this context, REC are defined by Article 2(16) of the Renewable Energy Directive (EU) 2018/2001 (RED II) as a legal entity that:

a) is based on open and voluntary participation, autonomous, and effectively controlled by shareholders or members located in proximity to the renewable energy projects owned and developed by the community;
b) includes shareholders or members that are natural persons, local authorities (including municipalities), or small and medium-sized enterprises (SMEs);
c) primarily aims to provide environmental, economic, or social community benefits to its shareholders or members or to the local areas where it operates, rather than focusing on financial profits.

This conceptualization reflects some specific features of the socioeconomic and institutional context of the European Union, where the legal status of an entity is a fundamental element for promoting its diffusion through advocacy and finance.

Leaving the regulatory aspect aside, multiple scholars have coined academic definitions of ‘energy community’. According to Bauwens et al. (2022), the key dimensions in which classifications vary are the meaning of ‘community’ (e.g., place, process, actor, network, technology), the energy activities to include (generation, consumption, demand-supply management), and their objectives (e.g. environmental, economic, social, political, infrastructural, and energy autonomy). For instance, Sousa et al. (2019) highlight the ‘community as a process’ element of REC, while energy activities are a secondary consideration and objectives are not mentioned: according to the authors, “energy communities are initiatives where citizens, collectively, participate in the energy system by acting as prosumers[2]. This includes sharing energy generation units and electricity storage in a peer-to-peer market”. On the contrary, Berka and Creamer (2018) describe energy communities as “…energy initiatives that are collectively owned or controlled by a community, whose primary aim is to provide social, environmental, and economic benefits to its members or the local area”. The definitions created after the regulation of REC at the EU level tend to strongly resemble the above-reported Article 2(16) of the Renewable Energy Directive (EU) 2018/2001 (RED II), proving Brussels’ influence on the European understanding of energy communities. However, for the purpose of this work it is more relevant to note that energy communities existed as a socio-economic phenomenon before becoming a regulatory one. In the 2000s, social sciences scholars in North America and Europe defined renewable energy communities as “collective efforts by members of a community to develop renewable energy projects that are designed to meet local needs and priorities and to promote democratic decision-making and control over energy generation” (Hoffman and High-Pippert, 2010) and as “projects where local people have a significant financial and decision-making role in renewable energy generation, aiming to deliver benefits to the community” (Walker and Devine-Wright, 2008).

While the concept of energy communities (EC) has been primarily discussed in Western scholarship, its core principles are also a recurring theme in Global South academic discourse, particularly in the fields of energy and environmental justice. To begin with, directing revenues toward community development projects closely aligns with the ‘distributive justice’ framework, which concerns the equitable allocation of energy-related benefits. Moreover, the ‘local benefits principle’ - stipulating that resources should be distributed in a way that enhances public goods in local communities, especially those historically marginalized - is embedded within the concept of distributive justice (Dorman and Ciplet, 2022). A notable contribution to the literature on local energy justice is Shanil Samarakoon’s *A Justice and Wellbeing Centered Framework for Analysing Energy*

[2] A prosumer is an individual who produce and consume energy, enabling themselves to participate in energy trading by selling excess solar energy and buying energy from the grid.

Poverty in the Global South (2019). In this work, the human geographer criticizes the dominant access-oriented approach to energy poverty and advocates for a bottom-up model of energy justice. Specifically, he integrates the dimensions of recognition (representation in decisions related to the energy system) and procedural justice (community engagement and participation in such decisions) alongside distributive justice. Additionally, the top-down implementation of energy projects in developing countries often undermines their success. For instance, the limited impact of global improved biomass cooking stove programs has been attributed to a lack of understanding of local public interests and cultural contexts (Urmee and Gyamfi, 2014). Beyond internalizing benefits, a more effective strategy for integrating renewable energy in remote communities must address land ownership issues, establish a direct connection between energy supply and communities, promote participatory systems, and foster local energy leadership (Sanusi and Spahn, 2020). This holistic approach aligns well with energy community designs.

While the absence of regulatory frameworks outside Europe allows for greater flexibility in defining EC, it is necessary to identify their essential characteristics. Most importantly, revenues or benefits generated by the community's activities must be primarily allocated to its members (either directly or through development projects), who should actively participate in the energy system. In terms of technology, the system should be decentralized and make use of renewable energy sources wherever possible. In more concrete terms, an energy community is a decentralized energy system where consumers actively contribute to its functioning and determine the surplus distribution model through voting powers. The backbone of an energy community is common (usually co-owned in legal or symbolic terms) decentralized generation infrastructure: in order to be part of it, an individual, household, business, or public institution consumes the generated energy or subsidize it at other members' benefit (e.g., municipalities can serve as anchor customers) and participate in its production directly - by contributing to facility operation and maintenance - and/or indirectly, by exercising decision-making rights and/or supporting it financially. Community members – and intermediaries where present – determine the benefit distribution criteria for energy and revenue.

In this work, EC are defined as "decentralized community-scale energy systems that directly target the development and empowerment of communities to produce [and] consume their own energy and engage in decision-making processes. [...] Such systems can be organized through cooperatives, where beneficiaries share infrastructure and services, and have to deal with the challenges of diverse participation, co-management, and fair reimbursement of beneficiaries" (Röder, Stolz, and Thornley, 2017). This definition was introduced in the study *Sweet Energy—Bioenergy*

Integration Pathways for Sugarcane Residues: A Case Study of Nkomazi, District of Mpumalanga, South Africa, which analyzed the outcomes of a local energy community project in South Africa.

Before exploring the evolution of energy community practices, this section clarifies the differences between renewable energy communities and other configurations for local energy generation, management, or consumption. This clarification is essential to define the scope of this work.

Energy communities share the goal of promoting local-level energy generation and consumption with Integrated Community Energy Systems (ICE), Integrated Local Energy Communities (ILEC), and Citizen Energy Communities (CEC). However, EC differ from ICE in that the latter are more technology-driven than community-driven: their main goal is to integrate various sources and technologies into a local energy system to optimize performance. Moreover, they are typically managed by specialized actors such as utility operators, local governments, or private companies with technical expertise. ILEC, on the other hand, share EC's community orientation. They are usually governed by community members and emphasize stakeholder engagement but are technology-neutral and may include fossil fuels in the energy mix. Such models are more complex to implement, as they require polycentric energy systems and specific regulatory frameworks (Koirala et al., 2016). CEC constitute an EU regulatory category similar to Renewable Energy Communities (REC) from a legal standpoint. However, their definition allows for the use of non-renewable sources, national-level participation, and involvement in energy distribution. In contrast, renewable energy communities have an explicit vocation to advance sustainable development and empower local communities. This research adopts a less strict approach to energy sources: while clean designs are preferred, the author will explore hybrid configurations as well, as long as they effectively contribute to community-oriented energy access. As the following paragraph will show, this goal transcend regulatory frameworks.

Outside Europe, the first configurations that can be classified as energy communities according to this work's definition emerged sporadically in the 1970s. The most relevant early design in a developing country dates back to 1971, when development specialist Paolo Lugari transformed the poor and remote Colombian village of Las Gaviotas into a functioning ecovillage. In this case, all local activities became community-based, including energy production and management. The project's orientation toward sustainable development led to the adoption of solar and wind power, and scholars often present this case as proof of the model's broader applicability. Despite the harsh environment in terms of political instability and poor soil quality, Las Gaviotas achieved a level of economic success that proved difficult to replicate elsewhere: similar initiatives in developing Asia reportedly failed (Yuan, 2023). According to Lugari, the key factors behind the Colombian experiment's success were the creativity of community members and the adaptability of the project (e.g., when Chinese enterprises started dominating the raisin market, then the main local agricultural export, Las Gaviotas diversified into bottled water from aquifers). Its success as an energy community was linked to its economic autonomy and supported by socio-organizational elements such as broad, intergenerational participation.

An element that deserves further attention in analyzing similar cases is the choice of technology in relation to local culture. Affordable and open-source technologies (in this case, a pedal-powered cassava grinder) proved effective but faced low social acceptance, as they conflicted with the community's gender norms (Yuan, 2023).

Other experiments of energy *prosumerism* took place in the United States, where the phenomenon acquired a countercultural and somewhat exclusive connotation. A well-known example is Village Homes in Davis (California), an ecologically integrated community where individuals produced their own energy using solar water heating, passive cooling, and energy-efficient infrastructure (Francis, 2002). As in Las Gaviotas, the energy system was coupled with local food production: 12 acres of community-managed farmland supplied 25% of household food needs. In this case, economic viability was not a concern, as households paid to join the community. Moreover, the energy infrastructure was not collectively owned, aligning Village Homes with energy-autonomous models similar to community flexibility aggregations.

In Europe, agricultural cooperatives producing their own energy emerged in rural central and eastern Europe already in the first half of the 20th century (e.g., in Belgium, Germany, and Poland). Collective investment in renewable energy technology took off in the late 1970s, when the Danish government proposed expanding nuclear energy in response to the oil crisis. This led to grassroots mobilization by anti-nuclear movements (e.g., OOA), which played a pivotal role in developing community renewable energy. Key features of these early Danish initiatives included wind power, ownership by local cooperatives, and a favorable policy environment. National incentives such as tax-free grants and income tax exemptions were introduced in the early 1980s (Gorroño-Albizu, Sperling, and Djørup, 2019). These configurations succeeded in attracting capital and scaling up. Feed-in tariffs, which provided long-term, fixed prices for electricity fed into the grid (often above market rates) were adopted in the mid-1980s to guarantee investment security and encourage local renewable production. The symbolic Tvindkraft project exemplifies the success of this innovation wave: the wind turbine - built and funded in 1979 by teachers and students of the Tvind Free School

- was one of the largest of its time and remains operational today (Interreg Europe Policy Learning Platform on Low-carbon Economy, 2018).

Other local energy cooperatives emerged in Europe in the 1980s, such as the Belgian Ecopower (1985) - an electricity producer and supplier still active in Flanders, originating from a co-housing project around a watermill in Rotselaar (Energy Cities, Friends of the Earth, Greenpeace, and REScoop, 2019) - and the Findhorn ecovillage in Scotland (1989). Findhorn represents a hybrid model combining private grid ownership with community governance. Although still operational, the Findhorn energy system now faces challenges due to aging infrastructure, as the upfront costs of new technologies are prohibitive for low-income residents and current policy support remains insufficient (Copeland et al., 2023).

Between the 1970s and the 1990s, similar configurations emerged sporadically across Europe and North America, with Las Gaviotas (Colombia) being the only widely recognized successful case in the developing world. During this period, local energy systems emerged not only as economic responses to oil price shocks, but more significantly as cultural phenomena rooted in the ecological movements of the 1970s. This expression of localized energy autonomy was largely confined to high-income settings, with Denmark as a notable exception due to its supportive policy framework.

The formation of the European single market significantly influenced the trajectory of community energy in Europe, as the European Commission's First Energy Package of 1995 promoted the liberalization of national electricity markets. Market liberalization can facilitate energy community development insofar as it enables bottom-up initiative and direct participation in the generation and retail segments of the electricity market. However, it improves the viability of EC only when it successfully lowers entry barriers: privatization alone tends to favor more established actors (Nicolli and Vona, 2019). The number of energy communities in Europe increased exponentially during the 2000s. While the lack of a standard definition prevents precise quantification, 10,540 initiatives across 30 European countries in 2022, with 2,010,600 people involved and installed renewable capacities of 7.2-9.9 GW (Schwanitz et al., 2023, p. 1) were identified by adopting a very wide definition[3] of EC, compared to the few examples in a limited number of countries (as seen, mostly in central and northern Europe) that existed until the 90s. A country that exemplifies the impact of

[3] The initiatives taken into account respect the following criteria: (1) citizen leadership, (2) noneconomic benefits, and (3) active in energy services provision. This definition includes projects that engage in the production and distribution of renewable energy, invest in energy efficiency projects, and campaign or consult on all such activities, including education and awareness raising to foster behavior change towards a sustainable, low carbon energy transition. Some initiatives that are not primarily active in the energy sector are included as well, including some that only partially meet one or more criteria in countries where citizen-led energy ecosystems are emerging. (*ibid.* p.7)

market structure on energy community development is Poland, where the long-standing tradition of rural energy cooperatives was shrank by centralized policy during the soviet era (with 85% of cooperatives being shut down between the late 40s and 1956), and slowly re-emerged in the early 2010s (Brodzinska et al., 2025). While state-led systems severely limit bottom-up initiatives and private sector involvement, they do not inherently rule out EC. For instance, energy communities in rural areas are an explicit budget heading of India's[4] PM-KUSUM scheme, where farmers can sell surplus power from decentralized solar PV to the grid. However, this policy has achieved limited implementation rates[5] (Government of India, 2025). The main difference between state-dominated energy markets and those displaying high concentration despite formal liberalization is agency: in the first case, EC initiatives rely heavily on policy schemes, while in the second case citizen initiative is possible but faces bureaucratic and scalability constraints (e.g., complex procedures for accessing the grid). In the highly centralized Chinese market, the village-level solar initiative in the prefectural city of Foshan (Guangdong) rests on a public-private partnership between the CCP[6]'s village committee chairman (who leads the community) and a solar energy enterprise, supported by a state-owned bank. Moreover, the community is supported by government subsidies and feed-in tariffs. On the contrary, the EC in the Sungdaegol district of Seoul is a grassroot initiative with broader civil society collaboration, involving academia, public institutes, the solar installer, and the prosumers (Mah, 2019). Despite formal liberalization of generation and grid access, the Korean energy market presents high concentration, with the Korea Electric Power Company and its subsidiaries generating 70% of supply in 2022 (S&P Global Market Intelligence, ReGlobal, 2023). Both the Chinese and South Korean EC achieved limited impacts on the local energy mix, with small portions of solar energy consumption increases. It is still relevant to note that the Sungdaegol model was replicated in 80 villages across South Korea (Mah, 2019, p.135).

Within the EU, the legal framework for energy communities was introduced to support these configurations in advancing the green transition through decentralized renewable generation. RED II requires Member States to create enabling frameworks for the establishment and operation of Renewable Energy Communities (Article 22), and its recast sets a binding target of 42.5% renewable energy consumption by 2030, with 66% of electricity to be produced domestically from renewable sources. REC are thus framed as instruments for promoting the energy transition in ways that are more socially acceptable. Although consistent data on their impact across the Union is not yet

[4] The Indian energy market is partially liberalized, with competition allowed in generation activities only.
[5] Official program data displays an implementation rate of 6% for this budget heading, much lower than for the other two (approximately 62% and 13%)
[6] Chinese Communist Party

available, early evidence from countries that have incentivized energy communities suggests generally positive - though varied - effects on consumer energy affordability (Neumann and Türk, 2024).

Outside the EU, energy communities are rarely[7] a regulatory category. In addition to greater flexibility in definition, the sporadic emergence of this phenomenon in the developing world invites alternative theoretical frameworks than the energy transition: within the energy justice and development discourse, the use of renewable energy is framed as a means to promote electricity access and affordability in remote or marginalized communities.

The next paragraph explores contemporary conceptualizations of organizational and economic models of EC, aiming to establish an analytical framework for energy communities in Sub-Saharan Africa.

1.2 Models of energy community

This section examines how existing models of energy communities have been classified in the literature with regard to stakeholder involvement, activities performed, and governance structures. Their economic arrangements are also analyzed in terms of financing, revenue generation, and benefit distribution. All the existing literature that classifies EC models according to these criteria is based on European practices. Portuguese scholars Reis et al. (2021) created a taxonomy of business models observed in European energy communities, identifying five main categories:

I) Energy Cooperatives

Energy cooperatives are characterized by direct citizen participation as co-owners of generation assets and by democratic governance mechanisms (e.g., one-member-one-vote systems) (Wierling et al., 2018). Though institutional forms vary based on national legislation, these cooperatives are generally established as either for-profit companies or non-profit organizations. The key distinction lies in how surplus revenue is used: while both models sell energy on the market, for-profits distribute dividends to shareholders, and non-profits reinvest earnings into local development. Activities commonly include energy generation, supply, and, where permitted, operation of local distribution networks (Reis et al., 2021). Shareholders typically manage the cooperative and decide how to allocate revenue. Participants usually include households, businesses, and municipalities in the case of larger cooperatives. This model is the most common in Europe, with over 2,500 cooperatives serving more than two million citizens (REScoop.eu, 2025). Its multi-stakeholder

[7] In some US states, EC are regulated (e.g. New York).

orientation makes it well-suited to various contexts, especially where the goal is to improve electricity access and promote local development. While co-ownership of infrastructure is an advanced form of energy democracy, its viability in underdeveloped contexts hinges on policy interventions or stakeholder support to offset upfront costs, such as through grants or blended finance mechanisms.

II) Community Prosumerism

Community prosumerism refers to the collective private investment in energy generation and storage infrastructure, primarily aimed at reducing personal energy costs and enabling local energy trading. Unlike cooperatives, these arrangements typically rely on more flexible legal or contractual forms such as Power Purchase Agreements (PPAs) that offer favorable terms with energy suppliers. Wider participation strengthens aggregated demand and generation potential, enhancing bargaining power. Local grid controllers may act as intermediaries. Although members can choose to reinvest profits in community initiatives, assets in this model are not necessarily jointly owned. Community members may use long-term PPAs to individually purchase infrastructure. This decentralized setup requires robust systems to monitor energy flows, financial transactions, and data for billing purposes (Reis et al., 2021). While the main objective is cost reduction, this model still reflects energy democracy to the extent that decisions are made unanimously. Local energy markets may emerge, enabling prosumers to negotiate tariffs directly with consumers, often at rates more favorable than those on national markets. However, challenges such as conflict among market participants may arise. Therefore, scholars recommend the use of intermediaries to ensure smooth operations (Sousa et al., 2019; Verschae et al., 2016). In remote or rural areas of developing countries this model would only be feasible with substantial technical and financial support from the public sector or specialized actors such as development banks or energy-focused social enterprises.

III) Third-Party Sponsored Communities

This category differs in terms of agency. Unlike grassroots or community-private partnerships, third-party sponsored communities are conceived as business or policy interventions. In the case of private sector investment, utilities or tech companies may fund projects to expand their market, retaining asset ownership and full decision-making authority. These initiatives are considered energy communities when developers involve the local community in governance, especially with the goal of tailoring solutions to local needs. These arrangements often result in long-term PPAs, where the two sides of the agreement respectively benefit from increased revenue and reduced costs. In contrast, when the investor is a public institution, NGO, or social enterprise, the primary objective is usually to foster development in underserved areas. Financial and technical support is still provided, but greater emphasis is placed on community participation in both governance and asset management.

Profits are typically reinvested into development projects. Although self-investment models offer better long-term savings, high upfront costs of such configurations are a prohibiting factor in low-income settings (Li and Okur, 2023). Non-profit or policy-driven third-party models can balance financial sustainability with democratic governance. However, factors like community ownership, donor dependency, and sociocultural dynamics must be considered, and will be discussed in upcoming sections.

IV) Community Flexibility Aggregation

This model enables small consumers - such as households in an energy community - to pool their flexibility (i.e., ability to shift electricity usage) and sell it to grid operators. Because individual households are too small to access these markets directly, a community aggregator coordinates their collective capacity, enabling participation in ancillary, reserve, and balancing markets.

Members sign agreements to modify consumption patterns when needed, either through automated dispatchable programs or by responding to price signals in non-dispatchable schemes. While aggregators typically provide the infrastructure and bear the upfront costs, members have little control beyond their participation contracts. The main benefit is economic: reduced energy bills or new income streams. Moreover, it heavily relies on an enabling business environment and on an advanced ICT infrastructure.

While these features make this model less scalable in an emerging market, it is still relevant to explore as a potential local solution. As the next chapter will show, the proliferation of mini grids in Sub-Saharan Africa may offer a platform for implementing decentralized Demand Side Management (DSM) strategies.

V) Community Energy Service Companies (ESCOs)

This model involves a partnership between a community and an external energy service company (ESCO), which provides both technical and financial solutions to develop local clean energy systems. Unlike basic energy suppliers or consultants, ESCOs also finance infrastructure. Although communities involved may be geographically dispersed or interest-based, this analysis focuses on geographically defined communities. As in third-party-sponsored ECs, residents collaborate with ESCOs to tailor services to local contexts (Reis et al., 2021).

Community ESCOs are a specialized form of third-party energy communities, with greater emphasis on technical expertise and participatory governance. Two common business models are used: 'guaranteed savings', where the ESCO assumes technical risk and guarantees a minimum level of energy savings, and 'shared savings', where the ESCO covers all upfront costs and recovers expenses through a share of achieved savings (Kurowska-Pysz and Kunikowski, 2021; IEA, 2018). The latter is especially useful in contexts where communities lack capital. For rural electrification, Renewable Energy Service Companies (RESCOs) adapt this model by offering PPAs or fee-for-service contracts that stabilize energy costs. These configurations have been successfully implemented in developing countries, supported by partnerships with NGO, joint borrowing, or multilateral development bank assistance (Urmee and Harries, 2012).

Except for flexibility aggregation, all these models can be supported by enabling policies like feed-in tariffs (which allow communities to sell electricity at above-market rates) or pay-as-you-go billing systems, often used in off-grid and mini-grid contexts in developing countries, including in the ASEAN region.

Each model provides different levels of community benefit and governance involvement, as outlined in Figure 1. These criteria will help classify case studies by economic and organizational structure.

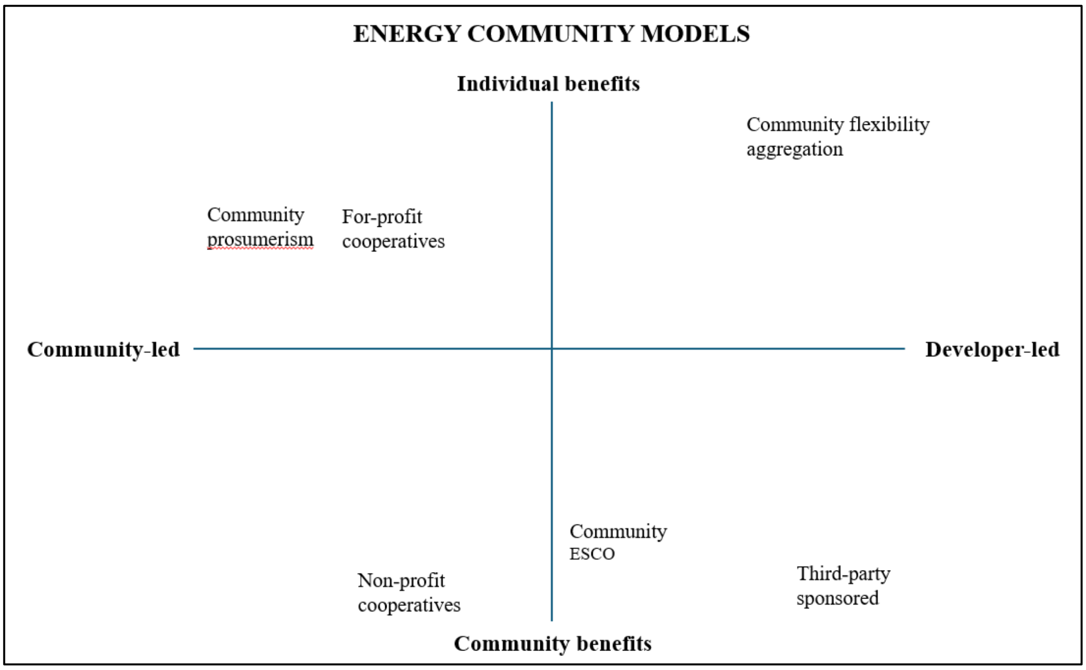

Figure 1: Own interpretation of Reis et al. (2021) EC models

Community-led projects (e.g. energy cooperatives) usually present a higher level of participants' engagement in governance and function in rural settings with strong local identities, while in developer-led (e.g. community flexibility aggregations) ones they tend to be passive investors. However, the first type usually presents limits in scalability because of geographical, technical (e.g. related to expertise) and economic (e.g. investor saturation) factors. In contrast, developer-led projects favor scalability and capital attraction, but are more likely to face acceptability challenges (Bolinger, 2001).

While here all the categories described focus on electrification and lowering energy bills, energy communities can serve other purposes as well. Access to energy is a topical theme in rural Sub-Saharan Africa, but it is not sufficient for development, and electrification is not the only way to achieve it. Other fundamental issues to address are its productive use and household consumption. Therefore, energy communities in this context can act as facilitators for both increasing the productive use of energy and decarbonizing household consumption, especially by providing access to clean cooking.

1.3 Impact and challenges

Before analyzing the impacts and challenges of energy communities, it is important to acknowledge that the absence of a consistent scholarly definition significantly limits data availability. Furthermore, a standardized methodology for assessing their social impact has yet to be developed by either researchers or policymakers (Bielig et al., 2022). As seen, estimations of the total installed capacity and studies on EC's effects on energy bills at national level exist, but other potential social impacts are not quantitatively assessed. Consequently, the micro-level (community) impacts discussed in this section rely on interdisciplinary qualitative research and aim to identify the key challenges to EC implementation. This methodological gap is also evident at the macro level (impact on the energy transition). Although the EU's legal definition of Renewable Energy Communities (RECs) should in theory help data collection, the only available data-driven analyses pertain to the impact of energy communities on electricity grids and markets.

While this study focuses on local impacts, assessing how such configurations interact with different market structures helps identify the preferred EC model to adopt in a given regulatory environment. As previously noted, whether electricity markets liberalization is an opportunity or a challenge for the evolution of energy communities depends on its success: where concentration is still high, grassroot initiatives still meet barriers. In such cases, while the participation of civil society in energy markets opens a window for developing local energy markets, at the national level state-market binary structures remain dominated by large companies: in the EU, the emergence of REC has not yet impacted market structures, and evidence suggests that reform is necessary for factually integrating energy communities. More specifically, a recent study published by the European Commission (2024) suggests that incremental adaptations such as pricing reforms need to be implemented in combination with radical regulatory innovations (e.g. involving aggregators in local energy markets, fractal-based market restructuring[8]) in order to reach real economic integration of EC.

Such reforms would improve the economic viability: at the moment, one of the most common barriers to project development is the long pay-back time associated, which discourages investment from risk-adverse financial institutions and private investors (Gorroño-Albizu et al., 2019). An even more significant challenge to energy communities is the centralized structure of energy systems: not only does it complicate the integration of EC in the energy market, but it can prevent their functioning as well. For instance, high decentralized energy resources penetration can lead to local congestion and reverse power flows that grid infrastructure built for centralized systems is not designed to handle. In such cases, congestion is even more likely when generation is peripheral to the main grid, as demand tends to be lower due to scarce population density. While this issue does not apply to off-grid contexts, it is still relevant when considering scaling up local systems. On the demand side, a major challenge for community flexibility aggregation is forecasting individual behavior: in the case of off-grid aggregations, it is caused by variable end-uses and the lack of historical data, while in the larger (grid-connected) ones centralized price signals can lead to load peaks as well as control and stability problems at the distribution level. Another frequent technical issue relates to interoperability, given the lack of real-time coordination tools for local balancing (Bjarghov, 2021). More specifically, existing metering systems typical of centralized infrastructure do not support dynamic pricing capabilities or real time data collection (e.g. in sub-hourly intervals). In addition to this technical bottleneck, access to data in centralized energy systems is usually owned and controlled by utilities, complicating access for prosumers (Sivaram, 2024).

Therefore, eventual structural problems need to be addressed both in terms of market and infrastructure. While doing so would significantly reduce hurdles to EC development, it might not be sufficient for derisking energy communities, as other socioeconomic factors affect project resilience. Even in case the high upfront spending was incentivized by a revenue-facilitating market structure, unsustainable reliance on volunteering (especially in energy cooperatives), a lack of interest in participation and insufficient energy literacy could complicate access to capital. Each of these barriers is more commonly found in low-income rural settings (Chodkowska-Miszczuk et al., 2021), where self-investment is not feasible as an alternative. Other social factors that hinder project success are demographic development, as elderly are less interested, and opposition to renewable energy (Brummer, 2018). Therefore, context-specific design and policy or risk-prone investors' support is

[8] Creating three market layers with multiple pricing mechanisms: a national one including Transmission System Operators, a regional one including Distribution System Operators, and a local one including Energy Communities.

essential for expressing the energy justice potential of EC. Without such elements, energy communities not only do not contribute to reducing energy inequality, but they risk exacerbating disparities at the local level by excluding households not having the financial capabilities to directly purchase infrastructure. Overcoming these barriers maximizes community benefits: successful energy communities favor behavioral change, raise support for other community services, and promote social inclusion. Moreover, they potentially impact other local development indicators such as employment levels and political participation in marginalized regions (Brummer, 2018).

The lack of a consistent impact assessment methodology limits the possibility of determining correlations between specific organizational or economic features and project success: while it complicates deduction, it offers an opportunity to flexibly tailor project design to the socioeconomic and energy context of a certain area by adapting the existing models or creating new ones.

Conclusion

While the relatively recent regulation of energy communities at the EU level sparked a wave of research work on this topic, EC as a phenomenon is not an invention of this decade, as sporadic configurations could be found both in Europe and in the Americas already during the 1970s. Despite renewed scholarly attention, a standard definition of energy community was not yet agreed upon beyond the vague regulatory one coined by the European Commission. Energy communities diverge in terms of organizational structure, goals, and scale, but share essential features that expose them to common challenges: decentralized infrastructure operation clashes with the centralized structure of energy systems, which complicates balancing and access to the data needed for forecasting. Scaling up EC encounters impeding challenges due to grid structure. Therefore, operating electricity-focused energy communities can be especially challenging in well-developed energy systems, requiring continuate professional support – therefore substantial budgets – in the best case and transformation of infrastructure in the worst. From this point of view, developing energy communities in energy systems where penetration is low faces fewer technical challenges: decentralized infrastructure would precede or substitute national grid expansion in remote areas, and the diffusion of such models for energy access is already favoring regulatory adjustment. However, market structure is another fundamental factor to consider: effectively liberalized electricity markets, with low entry barriers in generation and retail, present the most favorable environment for building economically viable ECs. Nothing prevents SOEs in state-controlled markets from creating energy communities as part of policy initiatives, but lacking freedom of initiative limits replication. Moreover, reliance on policy schemes implies reliance on political will: changing budget priorities might affect implementation. Financial sustainability in state-led contexts is not less relevant than in competitive markets, as it translates into a lower need for public funds. Therefore, planning supply and demand-side incentives with phasing out in mind is crucial for long-term functioning of an EC. To this end, favoring the productive use of energy is instrumental, especially in low-income areas of developing countries.

Electricity is not the only product that can result from energy communities: for instance, producing solar and bioenergy at the community level has the potential to provide clean cooking access while addressing affordability concerns. The following chapter will explore socioeconomic, energy access, and regulatory/policy trends in Sub-Saharan Africa, with the goal of contextualizing the EC chosen as case studies and offering insights into potential future developments of this phenomenon.

2. Sub-Saharan Africa

Despite contrasting opinions on whether Sudan and Djibouti belong to this region, considering that the two countries' energy scenarios more closely resemble those of Sub-Saharan Africa than MENA countries, this work will define Sub-Saharan Africa as displayed in Fig.2.

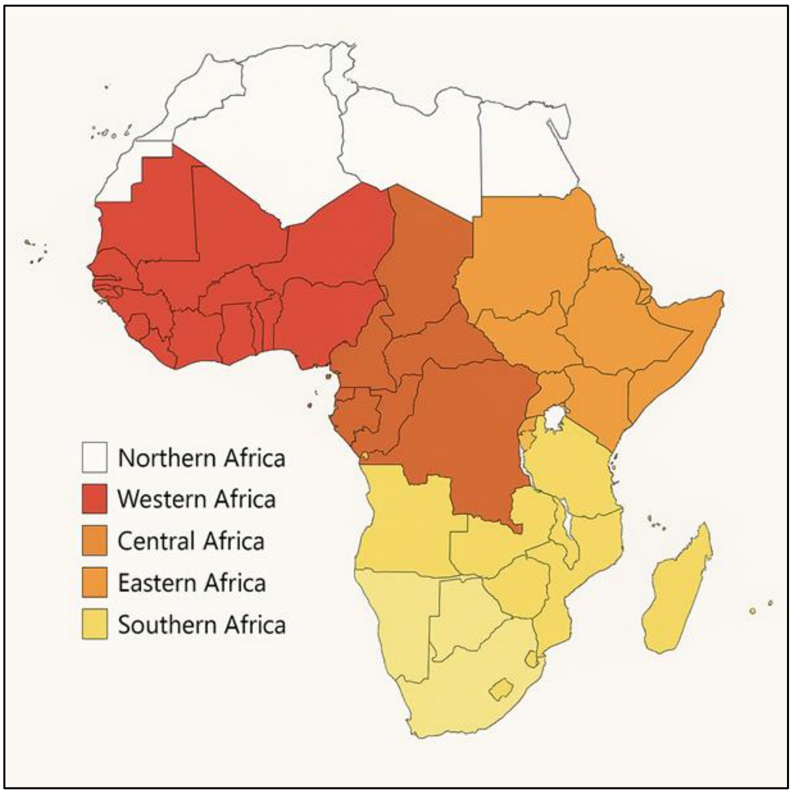

Figure 2: Own elaboration representing the African Development Bank's subregional classification

This chapter is the backbone of this work: not only does it offer a regional background for the case studies, but most importantly it justifies the necessity of investigating bottom-up approaches to energy access in Sub-Saharan Africa. By exploring the relevant socioeconomic trends, the following section puts emphasis on the human-centric approach to development applied in this work, allowing for community-tailored project design. The state of energy systems in the region, as well as the main technical and economic challenges to energy transmission in remote areas will be analyzed, contributing to laying the foundations for a more nuanced understanding of energy communities in Sub-Saharan Africa.

2.1 Socioeconomic trends

Sub-Saharan Africa is the demographically youngest region on Earth and possesses considerable natural resources, with many economies experiencing volatile growth due to the instability of commodity markets, supply chain dependencies, and resulting external debt challenges. Although demographic growth has slowed down in the past decade, the population still grows at 2.5 percentage points per year. In the past three years, the region as a whole has experienced GDP growth of 2.6% and 2.9% in 2023 and 2024 respectively, which is projected to figure at 3.9 percentage points in 2025 due to lower inflation and increased private consumption (UNECA, 2025). In terms of GNI per capita, most countries (22 out of 48) classify as low income, meaning that the average annual income per capita does not exceed 1,135 USD[9], while 20[10] are lower-middle income (GNI per capita ranging between 1,136 and 4,465 USD), 6 are upper-middle income (4,466-13,845 USD), and only the Seychelles classify as high income (over 13,845 USD). All these figures, as well as the unemployment rates ranging from 0.9% to 34.4%, vary significantly according to age, gender, and subregion (World Bank, 2025). In 2023, 71.7% of young adults had precarious jobs and the youth NEET[11] rate in SSA was 21.9%, with 3 out of 5 being women (ILO, 2024, p.1). In addition, Sub-Saharan Africa ranks 5th out of 8th on gender equality in economic participation and opportunity, with a gap of approximately one third between men and women (World Economic Forum, 2025). As the next sections will show, the gender dimension in rural areas is severely impacted by scarce access to clean cooking technologies. In the last five years, Eastern Africa[12] registered the highest growth rates, while Southern Africa[13] has significantly stalled and the other two subregions (Central and West Africa) experienced a light acceleration and deceleration respectively. While weak macroeconomic

[9] World Bank Indicators valid for 2023-2024 measurements, it is adjusted according to the GDP deflator.
[10] Including Djibouti
[11] Not in Employment, Education, or Training
[12] Which comprises Burundi, Comoros, Djibouti, Ethiopia, Eritrea, Kenya, Rwanda, Seychelles, Somalia, South Sudan, Sudan, Tanzania, and Uganda.
[13] Comprising Eswatini, Lesotho, Angola, Botswana, Madagascar, Malawi, the Mauritius, Mozambique, Namibia, Sao Tome and Principe, South Africa, and Zambia.

outlooks in West Africa are significantly influenced by internal and regional security and governance challenges (African Development Bank, 2025) such as terrorism and frequent regimes changes, growth and employment trends in Eastern Africa and Southern Africa reflect a more complex picture. Southern Africa comprehends almost all the upper-middle income countries on the continent, while Eastern Africa is entirely composed of low and lower-middle income ones. However, while global data (World Bank, 2025) show that lower-income countries grow faster than middle income ones, the main reason for this trend is stagnation in the subregion's largest economies: South Africa due to dependency on commodity prices and faulty governance, and Angola due to its resource-intensiveness, with oil accounting for almost one-third of the country's GDP (African Development Bank, 2023). On the contrary, countries driving growth in Eastern Africa (especially Kenya, Rwanda, and Uganda) have a more diversified economy with growing services sector (World Bank Data, 2025).

In addition, some Eastern African countries received significant foreign capitals investment in the past decade, especially in the form of large infrastructure projects. Some examples include the Karuma Hydropower Project in Uganda (mainly sponsored by the Chinese Exim Bank) and the Rwandese Bugesera International Airport Expressway (partially sponsored by the World Bank Group's Multilateral Investment Guarantee Agency and a Portuguese construction firm). Notwithstanding the complex implications of foreign government investment, development infrastructure projects in certain sectors are directly correlated to economic growth (e.g. investments in energy and transportation capabilities), and to human development when directed toward health and education (Horvat et al., 2020). These tendencies are reflected in employment figures, with a 6.78% average unemployment rate in Eastern Africa[14] and 13.94% in Southern Africa, which presents even lower figures for youth occupation[15] (International Labour Organization, 2025).

In terms of sectors, 49% of the population in Sub-Saharan Africa works in agriculture, making it the most common field despite a decreasing trend, while 37% (projected to rise) is employed in services, and only 13% in the industrial sector. However, agriculture accounts for only 16.9% of the region's GDP, services for 45%, and industry for 27.1%, anticipating a stark urban-rural economic divide. Considering that this research especially focuses on solutions for access to electricity in rural areas, this aspect deserves further attention: as a matter of fact, Sub-Saharan Africa is the region where the difference in extreme poverty shares is the most pronounced, with 46% of the population living

[14] The calculation does not take into account Djibouti and the Seychelles, for which recent data is not available on the World Bank Data platform. For the Sudan, data is from 2022 due to the ongoing civil war started in 2023. Somalia is included despite being an outlier, with an employment rate of 18.4%.
[15] NEET represent 28.95% of the youth population (15-24 years old) in the subregion

with less than 2.15 USD[16] a day in rural areas, and ‘only’ 20% in urban ones (World Bank, 2022). Rural poverty is multidimensional phenomenon: the scarcity or lack of infrastructure hinders access to basic public services such as safe drinking water, with only 16% of rural people having it while the figure for urban areas is 54%, and as the next section will show, energy. Likewise, education levels differ significantly: in the cities, only 13% of the population does not have any formal education, while the rate in the countryside is 42% (OECD/UN ECA/AfDB, 2022). Such factors indirectly limit formal economic activities: for instance, people who live within 5 km of a city are more likely to have a bank account than those living more than 30 km away (World Bank, 2024). Financial inclusion varies greatly between countries: in South Sudan only 6% of the population has a bank account, while where the financial sector is more developed (eg. Kenya, South Africa, Senegal) the rates range between 56% and 85%. However, even in such countries the figures reflect inequality indicators: access to financial services is correlated with higher levels of education, income, and with geography, reflecting the urban-rural divide (World Bank, 2024). This aspect is of crucial importance for bottom-up rural development, as not being able to make cashless transactions is only the top of the iceberg: without access to financial services, most rural people do not dispose of assets or land titles that can serve as collateral for securing loans, affecting project bankability. While mobile money has proven to be a more accessible and successful way to increase financial inclusion in SSA, it is important to note that this is not per se a solution to the urban-rural divide in finance, as connectivity is necessary for using this type of account.

The bankability of a project measures the willingness of an investor to fund it: while the exact meaning of this concept depends on the investor’s risk-prowess and goals, it is generally true that end-users with unpredictable cash-flows affect it negatively, especially in the private sector. Other factors determining the bankability of a specific project include the presence of de-risking mechanisms (e.g. credit guarantees, insurance, first-loss commitments) and the legal arrangement between the parties involved. Such elements intersect with macroeconomic factors (mainly economic volatility and/or macroeconomic policies) and the fiscal space (whether public entities are able to support the project), determining whether a business environment is ‘enabling’ (McCoy and Schwartz, 2023). As above-mentioned, macroeconomic vulnerability is high in the region, though at varying levels according to the commodity-intensiveness of the country’s economy. Therefore, the series of international shocks that occurred during the past five years[17] have significantly impacted the fiscal space in Sub-Saharan Africa: with external debt growing at double-digits rates, governments in the region spent a larger share of their countries’ GDP on debt interest payments (3.2%) than on

[16] 2017 PPP
[17] Covid-19, the Russo-Ukrainian conflict, the Israel-Hamas war, and multiple internal conflicts in African states

education (2.9%) (Institute for Economic Justice, 2025), with 17 recorded debt service-to-revenue ratios above 20% in the whole continent (African Export Import Bank, 2024). While debt interest payments represent similar - if not smaller - shares of GDP as in advanced economies (e.g. in 2023, debt interest payments represented 3.9% of Italy[18]'s GDP and 3.21% of Ghana's), debt sustainability in SSA is affected by higher borrowing costs (in November 2024, Italy's 10-year government bond yield stood at 3.29%, while Ghana's stood at 29.84%) and debt service-to-revenue ratios (8.94% in Italy, 40% in Ghana). As limited financial resources are combined with limited institutional capacity (especially at the local level), development financing by external actors is often necessary. The actors most commonly involved are multilateral development banks (e.g. The World Bank Group, the African Development Bank, the International Monetary Fund, the European Investment Bank, the Asian Infrastructure Investment Bank), development-oriented UN agencies (e.g. UNDP, UNIDO, IFAD) and foreign governments (especially those with agencies or banks specialized in development or infrastructural projects, such as the China, the US, Germany, and France). According to an IMF estimation, low-income countries in SSA[19] will need gross external financing of 70 billion USD annually (6% of GDP) from 2024 to 2028. The substantial growth of external debt[20] in the region is a major issue for development: while offering sporadic opportunities[21] such as debt for development swaps (converting debt into development project financing), not only a worsened financial position drives away the already scarce private sector investment, but it exposes countries to exploitation mechanisms such as debt-trap diplomacy, where foreign governments support countries in distress by funding large infrastructure projects in exchange for economic concessions or political influence. While raising legitimacy questions, this type of lending can still lead to a positive outcome when directed towards projects that foster economic growth (Mutai et al., 2024).

These vulnerabilities primarily affect the project design and evaluation stages. While enabling environments can evolve throughout the project cycle, community engagement and context-specific design are typically most critical during implementation (World Bank, 2025). For this reason, it is relevant to explore certain social trends in Sub-Saharan Africa that must be addressed when designing energy community projects. Recognizing the region's diversity, this section will examine only cross-cutting issues, leaving country analyses to the case studies chapter.

[18] Italy is taken as an example because of its comparatively high debt to GDP and debt service-to-revenue ratios
[19] This classification includes Burkina Faso, Burundi, Central African Republic, Chad, Democratic Republic of the Congo, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sierra Leone, Somalia, Sudan, South Sudan, Togo, and Zimbabwe
[20] Obligations to non-resident creditors—such as foreign governments, international financial institutions, or private lenders—are substantial relative to its economic capacity to repay.
[21] An example is a World Bank-supported initiative in 2024, where Ivory Coast restructured €400 million high-interest bonds in exchange of investing the savings in education.

According to the Afrobarometer[22], 65% of people on the continent prefer that their countries finance national development through domestic resources rather than relying on external loans (2021), but public perception of development assistance varies greatly across Sub-Saharan Africa. While data from all SSA countries is not available, a survey conducted in 31 countries in the region reveals stark differences, both in the general perception of external aid and the opinion regarding specific actors or models. For instance, West African countries register similarly negative attitudes towards the use of external loans but have divergent views on aid conditionality (e.g., both project and human rights related ties register record low rates in Senegal and record high in Liberia), while in Southern Africa the opposite is true: attitude towards external loans varies significantly (from 44% in Mozambique to 22% in Zambia) while both types of conditionality register relatively positive figures in all surveyed countries. Despite the concept of external aid raising suspicion among public opinions, perceptions of development agencies are mainly positive, with the majority of people appreciating the work of UN agencies, the African Union, and regional organizations (SADC, ECOWAS, IGAD, etc.).

As shown in the previous chapter, the success of energy community projects is influenced by both public opinion on renewable energy and demographic trends. Demographics are not a major challenge in SSA, where the median age is just 18.4 (UNDP, 2025). Since regional data on renewable energy perceptions is unavailable, this section analyzes opinions on land security and pollution instead. Land insecurity is a significant issue in rural areas, where rates exceed the global average by 20% in East, West, and Southern Africa. Overall, 26% of the population fears losing land or property within five years (Printex, 2022), with the highest figures in Burkina Faso (44%), Liberia (43%), and Eswatini (42%). Predictably, concern about pollution is higher in urban areas (72%), but it is also substantial in rural communities (61%) with negligible variation by income or demographic status (Afrobarometer, 2023), suggesting potential support for clean energy projects.

The next sections will analyze energy trends in the Sub-Saharan Africa, exploring current scenario for access to electricity, clean cooking, and consumption. Moreover, it will investigate regulatory frameworks of electricity markets and the policies or investments in place for favoring access.

2.2 Energy access scenario

As acknowledged, the population in Sub-Saharan Africa is projected to grow significantly, and it will represent approximately 16.5%[23] of the world population in 2030 (UNDESA, 2024). Moreover,

[22] Pan-African think tank specialized in public opinion trends.
[23] 1.4 billion people

urbanization is progressing at steady rates (between 1.3% and 5.4% across the region). Consequently, the demand for electricity on the continent is expected to grow at annual rates of about 5% between 2025 and 2027 (IEA, 2025, p.179). However, scarcity of supply and infrastructural failures significantly hinder energy consumption in Sub-Saharan Africa. 600 million people lack access to electricity (representing 83.3% of the global deficit), and grid connected households or businesses across the region experience frequent outages due to these factors: access to electricity is seldom paired with reliability of supply. Furthermore, 962 million do not have access to clean fuels and technologies for cooking. Cooking technologies are considered ‘clean’ when their usage allows to meet the World Health Organization’s standard for air quality, according to which they should emit less than 0.23 mg/min of fine particulate matter ($PM_{2.5}$) and less than 0.16 g/min of carbon monoxide (CO) (WHO, 2021). The technologies fitting this definition are electric and solar cooking, ethanol, and alcohol-based stoves, biogas, gas, and LPG stoves (though the latter pollute more than the other technologies). Therefore, traditional biomass, charcoal, kerosene, and coal, do not meet this requirement despite the implementation of improved (i.e., more energy efficient) designs. Applying this definition, only 23% of the population in SSA had access to clean cooking in 2023 (IEA, 2025c), with wide inequalities between urban (41.7%) and rural areas (8.5%). Households without access to clean cooking (which usually rely on biomass) spend on average two hours collecting fuel and three hours for cooking and meal preparation (IEA, 2022), with a high toll on health and economic opportunities: household air pollution is the second cause of premature death among women and children in the region. In addition, the economic loss related to informal employment of women in the energy sector was estimated at 186.2 billion dollars in Sub-Saharan Africa (International Bank for Reconstruction and Development and The World Bank, 2020) which corresponds to over 1% of the region’s GDP[24] at the time.

Low figures of access to electricity are primarily due to insufficient power supply and scarce infrastructure across the other segments of the energy system. Most capacity on the continent is concentrated in North Africa (82%), with the remaining share mostly located in South Africa despite shrinking in the last decade. In terms of electricity generation, Central, Western, and Eastern Africa have surged constantly in the past 10 years, but still relatively to very limited capacity to begin with.

[24] GDP value in 2018 (Current USD)

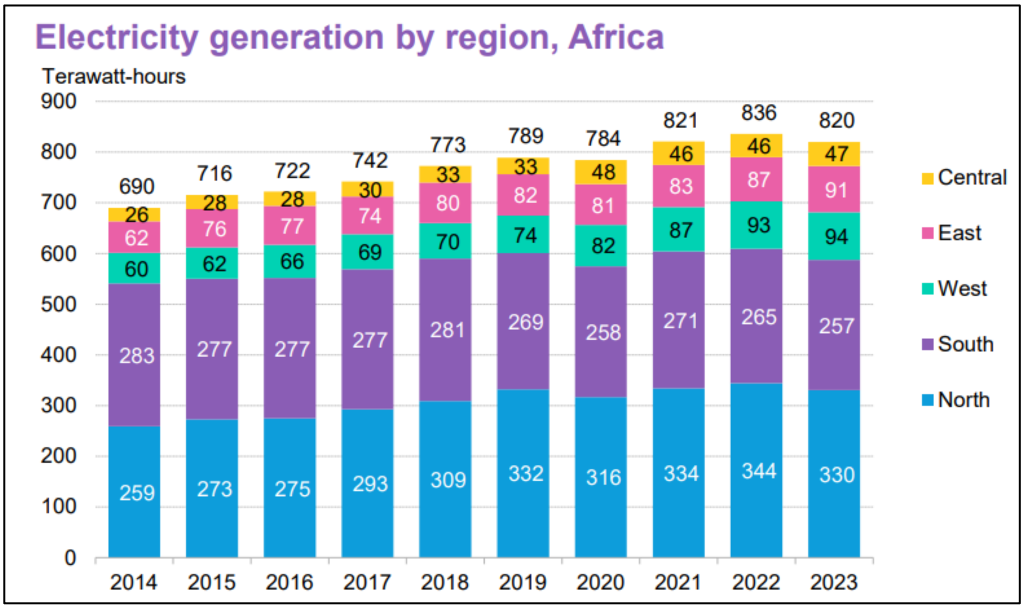

Figure 3: Electricity generation by subregion of Sub-Saharan Africa, Bloomberg (2024)

While adequate electricity generation is positively correlated with quality of access, infrastructural, technical, and regulatory deficits in the transmission and distribution segments are responsible for low figures, and especially for the urban-rural divide. Basic energy access is defined as having a source of electricity that can reliably provide lighting and phone or radio charging for at least 4 hours per day (and 22 kWh per person/year), specifying that the primary source of electricity must be externally charged systems or connected sources such as the local provider, solar home systems, mini-grids, or main grid connections. For instance, having standalone batteries does not amount to access. This definition expresses the binary metrics for measuring access to electricity: while 600 million people in Sub-Saharan Africa lack basic access, even more are not able to use household appliances such as a television or a refrigerator. According to the multi-tier framework for energy access (World Bank, 2015), the access to electricity can be classified according to 5 tiers: basic access as described above (Tier 1), Tier 1 appliances plus general lighting, air circulation, and television with at least four hours of access and 224 kWh per person/year (Tier 2), Tier 2 appliances plus refrigerator and washing machine with at least eight hours of access and 696 kWh per person/year (Tier 3), Tier 3 appliances plus a microwave, heating, and iron with at least sixteen hours of access and 1,800 kWh per person/year (Tier 4), Tier 4 appliances plus energy-intensive appliances (e.g., cooling systems) with at least twenty-three hours of access and 2,195 kWh per person/year is Tier 5. While no aggregate data is available at the regional level, research on scarcely electrified areas shows that Tier 5 is seldom reached. In North-West Nigeria[25] (2019), 40% of the households resulted to

[25] The study covers the states of Kaduna, Kano, Katsina, Kebbi, Jigawa, Sokoto, and Zamfara

belong in Tier 1, with very wide discrepancies between urban and rural areas: while most urban households were reported to be in Tiers 2 and 3 (61.5%), 73.3% of rural ones were in Tier 0 (total absence of electricity or inferior to Tier 1 criteria) (Luzi et al, 2020). In Ethiopia, which to this day performs slightly worse than Nigeria in binary terms, the figures were very similar: 73% or rural households belong to Tier 0, while 61.9% in urban areas were in Tier 2 or 3 (Padam et al., 2018). Respectively, 2.3% and 6.4% of rural households reached Tier 4 or 5 in the surveyed regions.

While these metrics intend to measure the impact of policy interventions or investments for improving access, their focus on households overlooks the fact that economic development is mostly powered by local businesses. For instance, threshold Tier 5 access could suffice for supporting micro-businesses in some sectors (e.g. retail shops, small-size cold storage, phone-charging), but not more energy-intensive activities (e.g. irrigation in agriculture, maize milling) or scaled-up ones.

Different degrees of access and consumption are linked to infrastructural capacity. Extending grids into rural areas with low population density is costly and technically difficult, as the region disposes of insufficient transmission infrastructure: Sub-Saharan Africa currently has less than 170,000 km of transmission lines. To put this figure into context, the European territory has 500,000 km despite being more than twice as small as SSA, with a population of around 745 million people (in Sub-Saharan Africa, it is of 1.27 billion). The distribution segment is in similar state, with low penetration rates and high technical losses (around 20% for State Owned Enterprises, which are the main operator in 38 countries in the region) (Oxfam, 2024). While grid connection technically allows for higher levels (Tier 4 and 5) of consumption, it is currently proving unfeasible in remote areas of SSA. Scarcely populated and low-income areas register low take-up rates, mainly due to high connection costs on the customer side (typically ranging from 50 to 250 USD in rural Africa) and the unsuitability of house construction materials (e.g., mud and grass do not comply with the standard requirements for wiring infrastructure installation). As a consequence, most energy investments in the regions focus on power generation, leaving transmission and distribution severely underfunded. Between 2001 and 2023, generation attracted 97% of private investment, while only 0.2% supported transmission expansion and 1% went to distribution networks, contributing to overcapacity in certain countries (Ndayishimiye et al., 2025). Large shares of energy investment are currently financed by foreign actors. For instance, over 40% of projected upstream CAPEX in the oil & gas sector (2022-2030) – which accounts for about half of total energy investment in Africa - will be provided by Majors[26] (30%) and INOC[27] (10%) (Africa Energy Chamber, 2025, p. 30). Chinese development

[26] Non-state controlled, publicly listed, integrated multinational oil & gas companies such as ExxonMobil, Shell, TotalEnergies, etc.
[27] SOEs from outside Africa

finance currently plays a major role as well: its decline by 85% between 2015 and 2021 resulted in over 1/3 (8 billion dollar) losses in the last decade's energy investment by public and development finance institutions (IEA, 2025b, p. 205). Such dependence exposes energy systems to shifting geoeconomic strategies and budget priorities, which especially affects commercially unviable environments such as least developed countries[28] and rural areas of EMDEs.

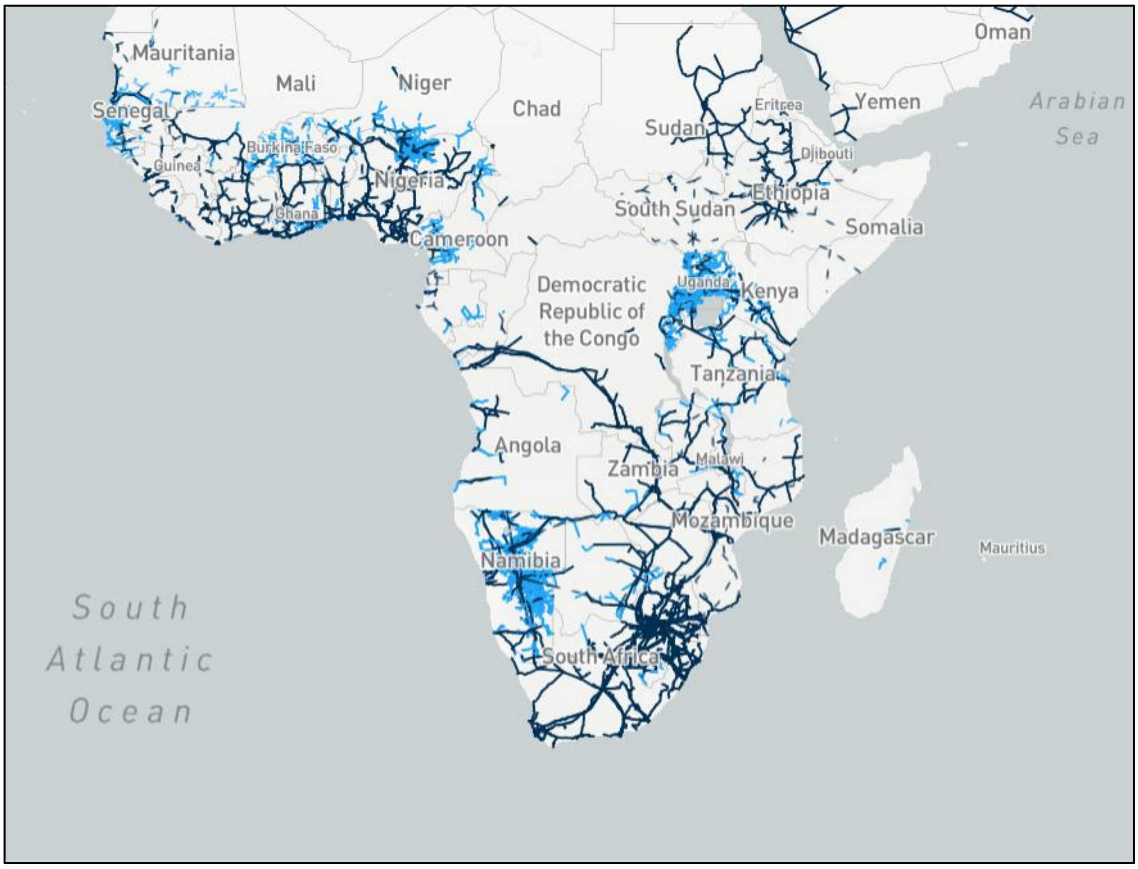

Figure 4, Grid networks in Sub-Saharan Africa (light blue indicates low and medium-voltage, dark blue indicates high-voltage >66 V), The World Bank (2025)

Alternatives to national grid extension include the deployment of mini-grids or standalone solutions (solar lanterns, solar lightning systems, and solar home systems are the most employed in SSA). Mini-grids are characterized by low to medium-voltage local power generation and distribution, which favors the reliability of electricity supply. Their ability to enable productive uses of energy depends on their capacity. They can both function in isolation from the main grid or connect to it in case it expands, but this work focuses on decentralized functioning. As of 2022, 11 million

[28] In Africa, all low- and lower-middle income countries except for Kenya, Nigeria, Ghana, Côte d'Ivoire, Morocco, Egypt, and Eswatini fall under this category

connections were established via mini-grid in Sub-Saharan Africa (Domegni and Azouma, 2022), with a surge in solar ones in the past decade due to the lowering costs of technology notwithstanding the energy storage required to compensate intermittencies. Some challenges to grid connection persist in the case of mini-grid deployment, such as inconclusive regulation and absent or ineffective tariff policies (i.e., that fail to boost connections while lowering returns) which contribute to high upfront costs for both investors and customers due to high risk perception and low take-up rates. However, off-grid solutions remain less costly: connecting a household in a remote area to the national grid is estimated to cost between 2,000 and 3,000 USD, while for mini-grids the cost ranges between 500 and 1,200 USD. Standalone solutions – generally coming with lower capacity – are less expensive, with Solar Home Systems (SHS) at between 150 and 500 USD per household (Kyriakarakos et al., 2019). SHS are the clean standalone system with the higher scalability potential: while the smallest models ranging from 50W to 300W can only provide Tier 2 access, larger ones (up to 800W) can easily reach Tier 3 (Bhatia and Angelou, 2015). Both where communities are connected to the national network or where they have access to clean off-grid technologies, diesel generators are a very common yet expensive (fuel prices can surpass 1 USD/kWh in rural areas) backup solution to grid failures or scarcity of supply due to the non-dispatchability of renewable sources. In Ethiopia, 31.5% of rural households rely on off-grid technologies (including mini-grids), and 12.2% are connected to the national grid. While such figures include households not reaching Tier 1, the remaining 56% have no electricity at all.

Low access to electricity significantly hinders economic development, but access is not a sufficient condition for consumption, which averages 180 kWh per capita a year in SSA[29] (in Europe, it is 6,500 kWh per capita/year) (Baskaran and Coste, 2024). As seen, low uptake is a common challenge to energy access projects, especially in rural low-income areas: the most successful way to encourage productive use of energy - which also helps with finding an anchor customer - is to invest in communities that already enjoy a higher standard of living. As a matter of fact, venture capital firms inclined to finance energy access start-ups in commercially unviable areas have recently redirected investments towards industrial or commercial use and away from residential (IEA, 2025b). When this is not the case, combining access with incentives for households to acquire appliances that require electricity can favor higher uptake. In this case, households prioritize its productive use: for instance, where access is combined with buying a fridge, it is often utilized for selling cold drinks.

The use of electricity for cooking remains very rare even in electrified contexts: in Senegal, 48% of people who declare to use electricity for lighting use firewood as a primary cooking fuel,

[29] Without counting South Africa

while the rest uses charcoal or gas in equal proportions (Blimpo and Postepska, 2017). Even in OECD countries with full access to electricity[30] such as Italy, Latvia, Lithuania, Hungary, Poland, Romania, and Türkiye, the shares of population utilizing electricity for cooking are low, ranging from 0.1% in Romania to 18.2% in Italy (European Commission, 2023). As anticipated, access to clean cooking is generally lower than access to electricity, mainly due to the high cost of appliances and to the fact that households prefer paying for electricity that powers profitable activities, especially where firewood is collected for free. In rural North-West Nigeria, less than 1% of households has LPG stoves, with the remaining utilizing firewood (89.6%), charcoal (1.2%) crop residue (5.8%), garbage or plastic (2.4%) as a fuel. Figures are similar in rural Ethiopia, where only 0.5% of households use clean fuels.

While electrification reveals its limitations for decarbonizing household consumption, other clean alternatives to traditional biomass are being explored in the region.

Liquified Petroleum Gas (LPG) is the least clean among these, but it is also the most common technology adopted by people gaining access to clean cooking in the developing world (70%), despite per capita consumption remaining low in Sub-Saharan Africa (around 4kg/person/year, while it's of 30 kg/person/year in Latin America) (World Liquid Gas Association, 2024). The sharp price increase experienced during Covid-19 reportedly slowed adoption in SSA, but the main reason for low consumption is the weakness of distribution infrastructure (irregular transport, inadequate storage facilities) - especially in rural areas, which results in high prices for cylinder refill where apposite stations are present. Therefore, most rural households stack (combine) LPG with traditional biomass.

Biogas and bioethanol are less widespread technologies which depend on contextual factors such as the availability of livestock or suitable feedstock crops respectively. Therefore, they are mostly suitable for rural areas. Biogas results from anaerobic digestion - breakdown in absence of oxygen - of organic materials (mostly livestock waste, as crop residues are avoided due to scarce knowledge of shredding technology) and water through a biodigester, where methanogenic bacteria decompose biodegradable elements and produce biogas, which is primarily composed of methane and - in a smaller portion - of carbon dioxide. It can be directly used for cooking or fed into a generator to produce electricity for small scale use. Moreover, this process produces digestate, which can be used as a fertilizer. The completely decentralized nature of this process implies that in case of higher demand there would be no implications for infrastructure. This technology is cheaper than LPG: the use of biogas and digestate can save up to 80% compared to using LPG and synthetic fertilizers (Garfi

[30] The access to electricity rate is 100% in all these countries

et al., 2019). In Nepal, where the biogas industry is highly developed thanks to a blend of public funding and PPPs since the 90s, there are 117 licensed biogas construction companies and 17 biogas plant manufacturers, which resulted in almost 431,629 domestic biogas digesters, more than 321 institutional and 1,812 at the community level (Loahni et al., 2021). In Sub-Saharan Africa, adoption of biogas at the aggregate level is still low, corresponding to approximately 1/20 LPG adoption in the past decade (IEA, 2022). Biogas initiatives were carried out in the Amhara region (Ethiopia), where 4,500 digesters have been installed, resulting in an annual reduction of 1,984 tonnes of CO_2 emissions and of other toxic elements such as PM_{10}. Moreover, the payback period for this project amounted to only two years, which is a promising signal. The difficulties encountered by 12% of the users related to insufficient training on how to use the bio-slurry and distance of the biodigester from a water source (Gabisa and Gheewala, 2019): the first issue can be solved by designing training programs and monitoring their implementation throughout the project cycle.

Bioethanol is produced from sugar- and starch-rich crops (e.g. sugarcane, maize, cassava, sorghum). The production of energy from bioethanol requires a more complex process: after harvesting, it begins with juice extraction in the case of sugar, and with conversion into fermentable sugar for maize and cassava. Then, the required strains of yeast are introduced, and fermentation begins, converting the mixture into ethanol, carbon dioxide (in a smaller portion), and water. After distillation, the fuel is usually ready to be utilized as an alternative to firewood or charcoal. Its adoption rates are similar to biogas, mostly driven by plants in Zimbabwe, Malawi, and Kenya. However, the one in Malawi is the only currently operational plant, as the other two were closed down respectively due to drought and financial issues. The use of plant-based sources makes this method more reliant on external conditions compared to biogas. Land use can be problematic as well: since the crops required are essential for food production, using them for bioethanol might create a zero-sum game that might not be welcomed by the local population. For instance, Eastern Africa presents favorable conditions for bioethanol production, especially in Ethiopia, Kenya and Tanzania for sorghum and cassava (Kedir et al., 2022). However, land in Tanzania is mostly owned by small farmers who make a living of agriculture. The market for biofuels presents commercial opportunities (on a larger scale than digestate resulting from biogas production) which might be more profitable for landowners. Nevertheless, the Tanzanian government closed bioethanol production programs as they may cause social unrest in response to diminished food and land security (Deenanath et al., 2012). Therefore, suitability in similar socioeconomic contexts could be favored by investors providing farmers with acceptable revenue guarantees.

The following section will offer an overview of the current regulatory framework of the electricity sector in SSA, as well as a deeper analysis of off-grid technologies regulation and policy support. Clean cooking initiatives will be explored as well, in order to identify gaps and promising ground for decarbonization-oriented energy communities.

2.3 Regulatory frameworks and policy initiatives

Electricity markets in Sub-Saharan Africa present different structures, ranging from integrated monopolies by SOEs to vertically unbundled power sectors (where the generation, transmission, distribution, and retail segments function separately) which allow limited private sector participation. The most common reforms undertook in SSA markets include the institution of an independent regulatory agency, unbundling, and the legalization of Independent Power Projects. Furthermore, over 20 countries in the region established Rural Electrification Agencies (e.g. Nigeria, Uganda, Tanzania, Senegal). Independent Power Projects (IPPs) are privately developed, financed, and operated electricity generation facilities that are legally distinct from the national utility and typically sell electricity through long-term Power Purchase Agreements (PPAs) to state-owned utilities or distribution companies. While at least one of these reforms was carried out by 75% of countries in the region, regulators are in some cases weak and ineffective, such as in DRC and Chad, where fundamental elements of power sector regulation (e.g., tariff methodology, licensing rules) are not defined. 9 countries combine partial[31] or complete unbundling with IPPs: Ghana, Nigeria, Kenya, Uganda, Zimbabwe, Namibia, South Africa, Zambia, Tanzania, and The Gambia. Independent Power Projects are carried out in many vertically integrated systems as well, such as Angola, Gambia, Cameroon, Cape Verde, Madagascar, Togo, Rwanda, Senegal, Swaziland, Sierra Leone, and Mauritius.

The generation segment is therefore the most liberalized across the region, while transmission is the least due to structural reasons: nationwide grids are operated as monopolies under regulatory oversight in advanced economies as well. In this sector, competition is “for the market” instead of being “in the market”, meaning that aspiring operators compete for a single license or (long-term) concession (OECD, 2019). Therefore, single national TSO were created where the segment was subject to functional and/or legal vertical unbundling (e.g. Kenya’s KETRACO, Ghana’s GridCo, Nigeria’s TCN), as it is the case in most OECD countries. The legalization of IPPs led to about 125 private plants until 2014, with half of them in South Africa. Distribution was partially liberalized in few cases, such as regional companies in Nigeria and concessions in Uganda, Côte d’Ivoire, and

[31] South Africa, Namibia, Sudan (which does not allow IPPs), Ghana, Uganda, Ethiopia and Nigeria only separated generation and distribution companies

Cameroon, while in most countries the main distribution utility remains state-run or heavily state-owned (e.g. Kenya Power, Eskom in South Africa, TANESCO in Tanzania), and retail markets remain mostly monopolistic. The Southern African Power Pool (SAPP), a subregional cooperation mechanism which includes 12 countries[32] and has the most evolved electricity market in SSA, displays high concentration in retail, with a firm – likely the South African Eskom[33] - representing 48% of the overall market share in 2023 (Wright et al., 2024). Despite the high availability of renewable energy sources, the lack of arrangements allowing balancing through subregional transmission is an obstacle to RE deployment, therefore an entry barrier that directly affects competition in retail. The other subregions have similar cooperation structures (WAPP, EAPP, CAPP) but more embryonal or ineffective implementation.

Off-grid technologies have been regulated in some countries, including Rwanda, Tanzania, Nigeria, and Kenya. In Rwanda, a mini-grid regulation framework that excuses electricity generation below 50 kW from licensing was introduced in 2015, while mini-grids between 50 and 100 kW need to undergo a simplified licensing process. This framework extends to private operators, facilitating rapid deployment of off-grid utilities. Moreover, it specifies that 50% of the electricity consumed a year must be generated from renewable sources (Rwanda Utilities Regulatory Authority, 2019). In Nigeria, obligations are nuanced according to higher capacity thresholds, with mini-grids generating less than 100 kW only having to register with the electricity regulatory commission and those generating between 100 kW and 1 MW being required to obtain permits. Moreover, some projects enjoying public subsidies display a hybrid ownership model, where the federal government offers financial aid and local communities ensure land availability and offer security services (O. Babayomi et al., 2023). In Kenya, mini-grids of all sizes require licensing, though in a streamlined version in the first case since the procedure is based on standard templates, and simplified interconnection guidelines facilitate eventual scaling-up. In Tanzania, they can either sell electricity to the state-owned TANESCO through PPAs or directly to end-users under tariff approval. Furthermore, public investment[34] in mini-grids is institutionalized through the Tanzania Energy Development and Access Project (TEDAP), which offers grants for this purpose. Ghana and Senegal undertook more of an incentive-focused than a regulatory approach: in both cases, mini-grids are incorporated in national regulations for electricity generation and distribution (therefore, they require licensing) and more

[32] SAPP's operating members (with active electricity generation and trading) are Botswana, DR Congo, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. Angola and Tanzania are not operating yet.
[33] The source does not disclose the company's name. However, given that Eskom is the largest operator in the subregion and acts as a monopolist in South Africa – which is the largest energy market in Sub-Saharan Africa – it is reasonable to infer that Eskom is the firm representing 48% of the SAPP market share as reported by Wright et al. (2024).
[34] By the government, The World Bank, and GEF

tailored provisions regard the mandate of the Agence Nationale pour les Énergies Renouvelable to support private development of mini-grids via PPP schemes in Senegal, as well as the provision of renewable energy funds for mini-grid expansion in Ghana, where the application of uniform tariffs to customers could instead disincentivize investors. In contrast, countries such as Ethiopia, Kenya, Nigeria, Tanzania and Zambia adopt a cost-based tariff methodology, which favors higher revenue while not directly addressing the issue of low take-up.

In terms of policy initiatives, most of those targeting energy access in rural areas focus on affordability, such as subsidies for end-users and/or suppliers. In the past decade, private sector views on the use of subsidies for stimulating take-up in rural areas have shifted, with an increasing number of operators seeing them as a necessary tool for improving the economic viability of projects (GOGLA, 2024). An issue that remains pressing regards the phasing out of such instruments, as well as how to avoid market distortions that would lower investor trust in the long term. Recent developments in Vietnam, where the government's roll back on utility-scale renewable energy subsidies triggered bankruptcy risks in the power sector, show both how abrupt phasing out negatively shakes market confidence and how the prolonged use of subsidies can create investor expectations of guaranteed returns, which complicates transitions to market-based pricing. Vietnam's feed-in-tariffs were crucial for launching the power sector: sustainability in the long term depends on matching infrastructural development and market reforms that lower subsidy dependence. As Sub-Saharan African energy sectors – except perhaps for South Africa – are still to develop adequate generation capacity, the use of such regulatory instruments is welcome in this phase. An example of large-scale energy access project providing capital subsidies for off-grid technologies development is the Nigeria Electrification Project, an AfDB-financed initiative that includes the development of solar hybrid mini-grids for productive use in rural communities, the provision of grants for companies that create productive appliances for remote communities, and the installation of decentralized power systems in universities. The second measure is a form of output-based aid, as the grants are disbursed to a company upon the successful installation of productive appliances in remote communities. Similar schemes are very common in rural electrification projects, especially for supporting the costs companies face for household grid connection and consequently lowering customer charges (e.g. Ethiopia's OBA program under the Electricity Access Rural Expansion Project Phase II and Uganda's Grid-Based OBA Facility Project). Other countries adopt cross-subsidization, where costs for new connections are redistributed among current clients, but this mechanism cannot apply in an off-grid context where all users are new and no established customer base exists to absorb these costs. However, given the infrastructural limitations to main grid access, the crucial complementary role of off-grid technologies is gaining its place in policy planning. One common measure is to remove taxes and import levies on solar equipment to stimulate private sector investment, as well as micro-financing to support enterprises or households outside the banking system. For instance, the OPEC Fund provided micro-loans to rural households in Benin, Cameroon, and Kenya for buying solar-powered products for both residential and productive use (e.g. water pumps and irrigation systems), providing energy access to about 90,000 people. Another innovative instrument for access is Pay-As-You-Go (PAYG) systems, where companies offer solar kits (ranging from the Pico products of less than 10W to solar home systems of about 350W) with low upfront deposits, customers pay lay-by through mobile wallets and acquire ownership when the payment is completed. In the mostly rural Kakamega county (Kenya), 61% of the population whose primary energy source is solar obtained it through PAYG processes (Ajwang', 2018). This model is mostly suitable for areas with high digital penetration and developed solar markets such as Eastern Africa.

Despite the gravity of related health issues, clean cooking is a severely underfunded policy sector. In 2022, global investment reached a record high of 215.1 million USD, where 4 billion USD a year would be required to reach universal access in the region by 2030. Most investments are directed towards LPG companies, which collected 59% of funding in 2021-2022 globally (Clean Cooking Alliance, 2023) and 80% in Sub-Saharan Africa. Contrary to access to electricity, where large projects can easily reach a high number of users, clean cooking initiatives are more difficult to implement, as their success requires technical assistance and behavioral training of (often small) remote communities, and abandonment of such technologies is quite common in Sub-Saharan Africa: while not fitting the definition of clean cooking, the adoption rates of the available improved cooking stoves in Ethiopia stood at 12.3% (Adane et al., 2020), while abandonment rates in a regional study corresponded to 80%. Therefore, it seems to be a less 'appealing' problem to address for donor-based organizations and private investors alike, resulting in population growth outpacing progress (IEA, 2025c).

While the growing global attention on the issue and number of enterprises in this sector created some momentum in Sub-Saharan Africa, only 13 countries adopted a national strategy for clean cooking. Eastern Africa is the most ambitious subregion in this sense, as Kenya, Tanzania, and Ethiopia all established clean cooking targets of universal access by 2028, 80% by 2034, and universal access by 2035 respectively. Senegal recently adopted a national strategy aiming at universal access by 2035 (IEA, 2025c). Sierra Leone, Togo, and Nigeria aim to achieve a demanding objective as well (universal access by 2030) but the latter includes improved biomass stoves in the definition of clean cooking, and so does Ghana which set an LPG target of 50% by 2030. In terms of technologies to promote, all these countries identified LPG and electricity as the most suitable for urban areas, whereas preferences diverge when it comes to rural segments. Where all countries foresee a widespread adoption of improved biomass/charcoal stoves, Ghana and Kenya see biogas as the rural alternative to LPG while Ethiopia and Nigeria prefer bioethanol, and Tanzania counts to rely on solar stoves due to its favorable geography – and likely to the aforementioned social resistance to bioethanol. Barriers to adoption converge across countries: common difficulties related to LPG include the lack of infrastructure outside the main cities and high or volatile price for fuel, abandonment for technical and economic causes, and preferences for biomass (especially in rural areas) because of changing food taste with clean technologies. Regarding the last point, all the five countries included an awareness campaign on the health, economic, and environmental benefits of clean cooking in their national strategy.

In addition to similar incentives to those for off-grid electricity (micro-finance, PAYG, subsidies), the most common policies across the five countries aim to facilitate local production and/or imports, adopt national regulatory standards, empower/engage communities. In particular, the Kenyan government intends to subsidize clean cooking appliances by selling carbon credits – therefore without burdening public accounts. Moreover, clean cooking will be compulsory in public institutions, bringing value chains closer to end-users. However, rural communities will benefit from this policy less than expected, as public services tend to be scarce in such areas. In terms of regulation, Ethiopia and Ghana are supposed to align national standards with ISO, while Tanzania is set to implement guidelines on the quality standards of energy, appliances and cookstoves. Nigeria adopted national standards for LPG appliances and is set implement a more interventionist approach, enforcing an obligation for local producers to prioritize supplying the domestic market. Regarding supply, all countries except for Nigeria – which focuses on import tax exemptions for LPG enterprises – planned to put in place measures to stimulate local production by creating jobs in bioenergy, improving access to raw materials through infrastructure expansion (especially for LPG, electricity, and bioethanol), and PPPs. Community engagement is mostly directed towards women and young people, which are the demographic groups most interested by change in cooking practices, and focuses on training (e.g., Nigeria provides training on the operation and maintenance of LPG appliances) and leadership (e.g., access to finance for women-led clean cooking businesses in Ethiopia).

While most of these national clean cooking policies were recently launched, numerous international donor-funded programs were carried out in the past years, with Norway and the United Kingdom being the main donors in this sector (IEA, 2025c). For instance, the African Biogas

Partnership Program[35], which run for a decade (2009-2019) in Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda, and targeted all rural families that own 2 or more stabled cows to support fuel production, succeeded in installing 60,000 fixed-dome household bio-digesters. Moreover, about 300,000 ha of land were fertilized by digestate (with 20-30 per cent crop production increase), and the founding of 90 biogas construction enterprises created 4,200 jobs. While complete transition away from biomass was not possible due to insufficient biogas production, where nearly 93% of households previously on wood or charcoal fuels - after this project 46% reported stacking in Kenya, 71% in Tanzania, and 89% in Uganda, with significant economic gains (38,000 women benefitted from biogas by reportedly saving 2.5 hours a day). Another similar example was the Gaia project in Ethiopia, when bioethanol-based stoves were provided and successfully operated in refugee camps, but people continued stacking in order to make some traditional dishes taste better. Despite the economic gains, access to clean cooking combined with stacking practices does not offset the health externalities related to the continued use of traditional biomass, which are particularly serious when it is utilized indoors. Improved biomass cookstoves, which are more energy efficient than traditional biomass, can reduce $PM_{2.5}$ significantly enough to product health benefits only for households who cook inside their primary living areas, with reduction rates ranging from 63% to 78%. It is unclear whether such reductions derive from shortest utilization times or from the fact that households cooking in their main living area subsequently move their traditional three-stone cooking outside when they adopt improved stoves (Bluffstone et al., 2019). Even with 78% $PM_{2.5}$ reduction, the air quality resulting from improved biomass would not comply with clean cooking health standards. The fact that such technologies would mostly benefit poor rural households – which tend to cook indoors – is a double-edged sword: if on one hand it can be seen as a valuable intermediate technology, on the other hand including improved biomass as a clean solution in national strategies risks leaving low-income rural areas behind in actual clean cooking policies.

Conclusion

Sub-Saharan Africa generally presents risky business environments, constrained fiscal space, and weak financial integration. External debt burdens worsen the financial standing of low- and middle-income countries, deterring private investment. Although citizens prefer domestic development solutions, international actors are generally welcomed. The urban-rural divide is stark, and land insecurity is a critical issue in project design. However, across demographic and socioeconomic groups, both rural and urban populations strongly support pollution reduction, indicating potential backing for clean energy projects. Access to electricity rates are low compared to other developing

[35] funded by the Netherlands and Energising Development

regions, and access to clean cooking registers much worse numbers, with dire health and economic consequences. In both cases, the outlook is significantly worse in rural areas, where income, educational, and infrastructural deficits weigh heavily on local development. Electricity networks do not reach areas far from the main urban centers due to financial and technical constraints, but scarce access is not the main reason for low consumption across the region: affordability is. Given the wide distances to cover and low population densities in rural areas, the cheapest solutions to favor energy access and consumption are off-grid systems. While standalone technologies are limited in their capacity and normally do not support productive activities, local systems such as mini-grids, microgrids, and common infrastructure for clean cooking and agricultural uses (e.g. water pumps) potentially do. Regulatory adjustment is slow in most Sub-Saharan African countries, but the largest markets for off-grid solutions started introducing favorable conditions for operators, namely by reducing administrative and economic burdens compared to national grid connection. On the customer side, enabling policies such as subsidized tariff structures for favoring take-up risk undermining the long-term financial sustainability of energy systems if phasing out plans are not implemented and accepted by the communities involved.

With affordability being a primary constraint for access to electricity and clean cooking in remote regions, and community engagement being a fundamental element for project success in rural areas, some sporadic experiments of energy community schemes are emerging in both domains. The next chapter outlines the methodology applied to the whole research and specifically to the selection of relevant projects, setting the scene for the case study analysis.

3. Methodology

This chapter walks the reader through the research design of this work by explaining and justifying the methodological choices made. Then, it presents the data collection, analysis, and classification processes that led to the selection of the case studies.

3.1 Research design

This work adopts a qualitative approach – in particular, a multiple case study research design – which is considered the most suitable for conducting in-depth analysis of a restricted phenomenon such as the emergence of energy communities in Sub-Saharan Africa. Given the relatively low number of available case studies, qualitative analysis allows for a more nuanced investigation that is better fit for answering the "how", "why", and "what" questions (Yin, 2018) compared to quantitative analysis, which is more appropriate for measuring impact and requires larger datasets in order to produce statistically significant results. Trustworthy qualitative research should entail three features:

credibility, transferability, and dependability. Credibility is defined as the congruency of findings with reality: although it relies on perceptions and subjective judgment, it can be enhanced through various methods, such as the processes of triangulation, the involvement of informants – such as supervisors – in verifying research, and peer debriefing. The author implemented all three methods. Triangulation refers to the use of several sources or procedures to repeatedly establish identifiable patterns (Stahl and King, 2020). Data triangulation was applied in this work: multiple studies, official documents, and reports on the same issue were utilized to verify theoretical, contextual, and empirical findings. For instance, the regulation of off-grid technologies in selected countries was identified through analyzing official legislation or policy documents as well as scholarly papers on the issue. Transferability relates to the findings' generalizability: while qualitative research is non-replicable by design (Stahl and King, 2020), patterns and descriptions may be applicable to other contexts. This quality is contingent on a 'thick' description of the case studies – including the context or environment – and on transparent data collection, so that other researchers can evaluate its transferability to their area of work. Dependability stems from the ability of the researcher to scrutinize his work through peer review and self-reflection before publishing. Self-reflection can be exemplified by the practice of 'bracketing', which means to clearly separate data from the researcher's own interpretative comments, which helps acknowledge and control bias due to his own passions or values - for instance, in influencing the selection of case studies.

A multiple case study research design was adopted in order to explore the relevant initiatives in-depth. Case studies allow to "focus on understanding the dynamics present within single settings" (Eisenhardt, 1989, p.534). While single holistic case studies are useful for identifying an exception or extreme situation, multiple case studies can be used to spot a pattern, either predicting a literal replication (similar results) or a theoretical replication (contrasting results) (Yin, 2003). Despite the possibility to identify patterns, transferability is limited to cases with similar features to those analyzed: given the great variations among energy communities in terms of contextual and organizational elements, this work does not aim at generalization but at analyzing specific features of diverging case studies in order to assess their feasibility and added value.

3.2 Data collection

Data for the case study analysis is collected through primary and secondary sources. Primary sources are defined as the project documents of all the initiatives analyzed during the case study selection and for supporting the theoretical and contextual chapters of this work. Such documents are published by actors directly involved in the energy community, such as investors, cooperatives, and public agencies, as well as legislation or policy documents. Secondary sources include all the documents needed for contextualizing the case studies and/or confirming the findings, such as academic papers and books on energy communities and energy trends in Sub-Saharan Africa. Academic literature was retrieved through apposite databases, mainly Google Scholar, LUISS Library Discovery, and Sciences Po Online Library. Thematic reports from international, governmental, and non-governmental organizations are considered a primary source where such organizations directly collect the data through fieldwork or other methods (e.g. country reports on energy access by the World Bank), and secondary where they use datasets from other organizations (e.g., the data in IEA reports was gathered from national energy authorities).

3.3 Data analysis and classification

In order to select the case studies, this research adopted the working definition of energy community - and rural Sub-Saharan Africa as the spatial delimitation - for applying an exclusion/inclusion criterion to the reviewed literature. Then, a thematic analysis was conducted, which is a method for "identifying, analyzing, organizing, describing, and reporting themes found within a data set" (Nowell et al., 2017, p.2). While this method is usually utilized for analyzing the case studies, this work adopts it for selecting them: by investigating specific aspects of the phenomenon, the most interesting case studies in light of the research questions will be analyzed in-depth in the next chapter. The thematic analysis was carried out in six phases:

a) familiarization with the data: reading and triangulating the entire dataset before starting to code it

b) code generation: generating qualitative code allows to identify specific aspects of the data to analyze while capturing the phenomenon's complexity.

c) searching for themes: this phase involves sorting the extracted data into themes, which should remain consistent throughout the research

d) reviewing themes: the researcher should confirm whether the data forms a coherent pattern or not. Incoherent data will be replaced with a new code and overlapping themes will be reduced into a more manageable set of information.

e) definition of themes: the choice of theme names should reflect the research questions and represent the parameters through which the researcher concretely investigates them

f) production of the report: in order to make the findings accessible to the readers, the researcher should build an effective argument for choosing the themes, discussing all the findings and eventual unexpected results.

This method was chosen due to its applicability to a multiple case studies research design and to its focus on raising the research's trustworthiness: through the six phases, the author can increase the work's credibility as discussed above. The following table shows the results of the thematic analysis.

3.4 Case studies selection

By applying the exclusion criteria to the case studies literature analyzed, 13 case studies were selected and codified by vertically analyzing their organizational, technical, and financial features. The following table summarizes the case studies according to the qualitative code and is followed by an explanation of the rationale for selecting the case studies object of the next chapter.

PROJECT NAME	COUNTRY	TECHNOLOGY	ORGANIZATIONAL MODEL	FINANCIAL SUSTAINABILITY	OUTCOME	SOURCES
1. Community Energy Development Programme	Malawi	Mixed	Non-profit energy cooperative	Mixed	Positive	Dauenhauer and Frame (2016), Community Energy Malawi (2023), Scottish Government (2019)
2. Hydro mini-grids in Bondo	Malawi	Hydro mini-grid	Third-party sponsored (business)	Transitional	Positive	Kadziponye and Sailence (2024), UNDP (2020), van den Akker (2024), Frame et al. (2022),Hare (2024)
3. Chipopoma Community Energy Project	Malawi	Hydro microgrid	Village committee	Low	Mixed	Kadziponye and Sailence (2024), Hare (2024), Vallecha et al. (2023)
4. Mpanta solar mini-grid	Zambia	Solar mini-grid	Non-profit energy cooperative	Low	Negative	Stritzke and Jain (2021), UNIDO (2017), Muhoza and Johnson (2018), Mayenga et al. (2025)
5. Tiribogo biomass gasification power plant	Uganda	Bioenergy-based mini-grid	Community ESCO	Moderate	Conflicting information	Eder et al. (2015), UK Aid et al. (2020), UOMA (2019)
6. LUMAMA hydro mini-grid	Tanzania	Hydro mini-grid	Non-profit energy cooperative	High	Positive	Hartvigsson et al. (2021), Oemmelen et al. (2025), Botto Poala (2018), Odarno et al. (2017), Ahlborg and Sjöstedt (2015)
7. Leganga solar mini-grid	Tanzania	Solar mini-grid	Village committee	Low	Negative	Odarno et al. (2017)
8. Tsumkwe hybrid mini-grid	Namibia	Hybrid mini-grid	Third-party sponsored (policy)	Low	Positive	Azimoh et al. (2017), Metha et al. (2022)
9. RESOLVE	Kenya	Hybrid microgrid	Energy cooperative	Unknown	Unknown	Best (2016)
10. Kitonyoni and Mwania mini-grids	Kenya	Solar mini-grid	Energy cooperative	Moderate	Positive	Bahaj et al. (2019), En4Dev and University of Southampton (2015)
11. Tabia Selam solar-PV water pumping system	Ethiopia	Solar PV water pump	Village committee	Low	Positive	Vallecha et al. (2025)
12. Beruda biogas plant	Cameroon	Biogas plant	Third-party sponsored	Unknown	Positive	BERUDA (2018)
13. Solar ovens for cooperative economic growth	Malawi	Solar cooking stove	Third-party sponsored	Unknown	Positive	Community Energy Malawi (2024)

Table 1: Thematic analysis

Before presenting the case studies choice, it is necessary to define the theme names. ‘Project success’ is not assessed by applying the traditional ‘iron triangle’ (timely delivery within budget according to specifications and plans), which is considered a too narrow criterion for evaluating a development project (Ika et al., 2017). In addition to managerial elements, development projects should deliver qualitative and/or quantitative impact (e.g., increased electricity consumption for X households, transition to clean cooking technologies for X % of the local population) in the long term: a project could appear successful upon closure but fail in terms of sustainability, or the opposite could happen. Furthermore, success is stakeholder-relative: while donors may define it as financial accountability and implementing partners as technical sustainability, beneficiaries tend to be more focused on concrete socioeconomic changes (e.g., higher income, improved public services, etc.). This work explores all these dimensions within the case study analysis. Project success (positive outcome in the thematic analysis) is defined by both its operationality – with it currently reaching at least 50% of the target customers – and its economic efficiency, which is measured by comparing the levelized cost of energy (LCOE) of each system to the alternatives. The LCOE is the average total cost of building and operating the asset per unit of total electricity generated over its assumed lifetime, and it results from the ratio between the sum of upfront (CAPEX) and operational (OPEX) costs and the total amount of energy produced by the system (minus losses) over its lifetime. The calculation takes into account the discount rate (the weighted average cost of capital if the project is financed with debt and equity, the social discount rate if it is grant-funded), which measures the opportunity-cost of money and the riskiness of the investment. This work adopts the discount rate applied to electricity projects in SSA by the World Bank (r=10%) (Trimble et al., 2016, p.10).

$$\boxed{\mathrm{LCOE} = \frac{\mathrm{CAPEX}_0 + \sum_{t=1}^{T} \frac{\mathrm{OPEX}_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}}$$

Equation 1, Levelized Cost Of Energy (own elaboration)

Mixed outcome indicates the fulfillment of the first parameter only, implying limited sustainability and replicability. For the "Community Energy Development Programme", 'positive' takes into account the percentage of successful projects.

The definition of 'technology' includes both the energy source utilized and the type of infrastructure providing access, while the 'organizational models' code adapts the models explored in the first chapter to the observed case studies. Another model was observed during research, as multiple case studies display a form of – theoretically representative – democracy: in this case, village committees composed of community members are in charge of infrastructure management and governance (e.g., they coordinate maintenance and carry out revenue collection duties). The existing taxonomies for measuring the financial sustainability of development projects are either predictive (e.g., the UNDP assesses its probability upon project completion, ranging from "likely" to "unlikely") or rather dichotomic (e.g., the Global Environment Facility conducts post-completion evaluations and the sustainability parameter – which expressly includes its financial aspect – can be rated as "yes", “no”, “in process”, or “unknown”) (GEF, 2019). The following taxonomy was created by the author on a comparative basis in order to offer a more precise description of the case studies: the categories encompass all the financial sustainability outcomes encountered in the literature review. ‘Financial sustainability’ – the project’s ability to collect enough revenue for covering operation and maintenance expenses in the long term – is assessed on a four-grades scale: ‘low’ indicates heavy reliance on external aid and absent/unsuccessful plans to phase it out, ‘moderate’ indicates partial self-sufficiency and in-progress measures to reduce dependency, ‘high’ is defined as complete financial independence in standard conditions and elements suggesting the financial ability to address emergency (e.g., a dedicated fund), and ‘transitional’ indicates a project in the process of improving its financial sustainability. The qualitative code does not expressly include ‘technical challenges’ as a parameter because all the projects encountered such hurdles at some point, but only the ones with a ‘positive’ or ‘mixed’ outcome – totally or partially – succeeded in overcoming them.

The first criterion applied for choosing the case studies is the availability of information: only the projects with information on their impact and on all the coded parameters were taken into consideration. Among these, the researcher chose according to the following objectives:

1) Comparing two projects with similar organizational structures and different outcomes in terms of financial sustainability

2) Offering some geographical variation by including cases in at least two subregions

3) Reflecting on the factors affecting project resilience by analyzing overlooked issues in the existing research on EC

As a result, projects n. 4 and 6 were chosen as case studies.

Projects n. 4 “Mpanta solar mini-grid (Zambia) and n. 6 “LUMAMA hydro mini-grid (Tanzania)” display similar organizational designs but very different outcomes, allowing the author to focus on the economic aspects.

Some of the excluded cases deserve further attention. The Community Energy Development Programme (CEDP), which was carried out in Malawi (2011-2015), is the most interesting in terms of scale and was not chosen due to the lack of disaggregated data. It was the first national-scale initiative in SSA focused on energy communities and was co-funded by the Scottish Government as part of the broader Malawi Renewable Energy Acceleration Programme. The CEDP provided grants, technical assistance and community training on energy technologies and project management to pre-existing community-based organizations that won the relative public call. Energy technologies were chosen according to context suitability, which was assessed through multi-stakeholder dialogue. This initiative has provided energy access to 19,848 rural Malawians (WAME, 2015). Project n. 11 "Tabia Selam solar-PV water pumping system (Ethiopia)" is a very small-scale initiative financed by an international NGO in the Tigray region, which was excluded due to the scarce availability of project documents, and it raises a lateral theme to this work but a very central one to energy investment in fragile contexts: how to build community-based project resilience in conflict-affected areas – an issue which currently concerns 14 Sub-Saharan African countries (Raleigh, 2025).

Unfortunately, the clean cooking projects falling under the operational definition of energy communities could not be chosen as case studies due to the lack of public reports and the reluctance to share quantitative data – the researcher contacted the actors involved in community-based biogas and solar cooking initiatives in Cameroon, Kenya, and Malawi without obtaining sufficient information for a case study analysis. It is still relevant to note that these projects constitute a significant innovation in the understanding of energy communities, and most importantly – as the above-mentioned literature from rural developing Asia confirms – a potentially affordable alternative to biomass. In the case of future more documented initiatives or fieldwork in SSA, it would be interesting to investigate their ability to decarbonize household consumption.

Conclusion

This chapter described the research methodology and reasoning implemented by the author to develop this work as rigorously as possible despite the absence of direct observation. The first section outlined the theoretical foundation of applying a case study research design in this context, while the second and third ones presented the concrete process of data collection, analysis, and classification. The last section presented the results of the case selection process, indicating the scarcity or inconsistency of project documents as the main challenge encountered by the author. The chosen case studies present different outcomes and similar organizational structures, pointing towards the relevance of economic and financial aspects. The following chapter describes two energy communities in Zambia and Tanzania, providing in each case an overview of the regulatory landscape as well.

4. Case studies

This chapter will analyze the chosen case studies with a focus on their economic structure and governance, as well as on the impacts produced and on their financial sustainability. Each analysis will be preceded by an in-depth presentation of the energy access and regulatory context in the country where the project was carried out.

4.1 Zambia: solar mini-grid in Mpanta

This project was developed in 2013 by the Zambian Rural Electrification Agency as the first solar PV mini-grid in the country, with the goal of providing access to electricity to about 450 households, small businesses, and local public services. This section aims to provide insights on the reasons behind its failure, since the Mpanta mini-grid was decommissioned in 2021.

4.1.1 Context

Zambia is a large, landlocked country in Southern Africa with a low population density. It shares its border with eight countries (Angola, Botswana, Democratic Republic of Congo, Malawi, Mozambique, Namibia, Tanzania, and Zimbabwe). In 2013, access to electricity rates in Zambia were 61.4% in urban centers and 8.4% in rural areas, lower than the regional average by 11.1 and 12.3 percentage points respectively, while access to clean cooking technologies was 34.1% in urban areas and only 2.3% in rural areas, with over 60% of rural population at the time. These figures are on a declining trend in both demographics, as population growth (2.7% per year) outpaced access. Zambia's GDP per capita was 1,820.72 USD in 2013 (currently 1,235.08 USD), classifying as a lower-middle income country. The country experienced strong economic expansion during the first decade of this century, with annual real GDP growth averaging 7.7% - reaching lower-middle income status in 2011. Between 2011 and 2020, growth slowed to an average 4.1% rate, to then rebound strongly after the Covid-19 slowdown and external debt default in 2021 - ranging between 5 and 6 percentage points until 2023 and subsequently experiencing challenges such as agricultural production shrinking due to serious draught (Zambia was severely hit by El Niño in 2024), macroeconomic imbalances due to protracted debt restructuring and the war in Ukraine, as well as a cholera epidemic. The Zambian economy is heavily commodity-intensive, as copper mining alone represents 15% of the country's GDP, around 70% of total national exports, and 44% of government revenue, mainly through royalties (IMF, 2024). Consequentially, growth tends to reflect copper price fluctuations. Its resource-richness is not limited to copper, and mining diversification is being pushed as it has reserves of cobalt, lithium, manganese, natural graphite, and several rare earth elements that are instrumental to the energy transition. Other than mining, the other economic sectors identified by the government as key for development are agriculture, manufacturing, and tourism.

Zambia has an overall electricity generation capacity of 3,871.32 MW which mainly relies on renewable sources (89%) - namely hydropower (99% of it) – but electricity only accounts for 11% of energy consumption, which is mostly residential (65%) and reliant on biofuels or waste (71% overall, 87.3% in the residential sector). Still, electricity consumption per capita (709 kWh/year) is much higher than the regional average (180 kWh/year) and is on a positive trend. Given the uneven distribution of water sources, draught, and water insecurity (as mentioned, the use of unsafe water recently led to a cholera epidemic), diversification efforts towards solar – and coal in the energy-intensive mining areas – are underway and they currently contribute to 9% and 5% of the energy mix respectively (Ministry of Energy, 2025).

Zambia's electricity sector is partially unbundled and structured as a monopoly in the retail sector, while 17 Independent Power Produces currently[36] operate their own assets but can only sell electricity to the state-owned ZESCO – which is vertically integrated and the only retailer in the country - through PPAs. The only exception is the Copperbelt Energy Company, which operates its own distribution network for mines in the Northern (i.e., Copperbelt) region. Copper is a crucial resource for electrification, more specifically for solar power wiring, transformers, batteries, cables for energy storage, and distribution networks (especially HV) – while aluminum is more common in transmission lines and LV distribution due to its lower cost, but Zambia is an importer as it does not have large primary resources. While the country is the second-largest copper producer in the continent after South Africa, most of it is exported (especially to China) and only 20% is processed domestically (WTO and ADB, 2023). Regarding regional integration, Zambia has licensed some power traders that operate in the SAPP region (EN Power exporting to the DRC, Kanona exporting to the DRC and South Africa, and GreenCo importing from Mozambique and South Africa).

Access to electricity in rural areas is promoted by the Rural Electrification Authority, which was established in 2003 as a government body (the board is composed of government, NGOs, and associations representatives, all appointed by the Minister of Energy) and is in charge of procurement and financing for public, private, or third-sector rural electrification projects. An off-grid task force comprising government agencies[37], development actors[38], and private sector representatives[39] was set up in 2016 to accelerate electrification and coordinate regulatory efforts. Off-grid utilities were explicitly regulated in 2018, when a cost-reflective tariff structure was introduced by the Energy

[36] According to the latest updates from the Zambian Ministry of Energy (2025)
[37] Ministry of Energy (MoE), Department of Energy, Energy Regulatory Board (ERB), Rural Electrification Authority (REA), Ministry of Finance (MoF), Ministry of National Development Planning (MNDP), Office of the Vice President (OVP)
[38] African Development Bank (AfDB), Department for International Development (DFID; UK), European Union, International Finance Corporation (IFC), Swedish International Development Cooperation Agency (Sida), The World Bank
United States Agency for International Development (USAID)
[39] Zambia Renewable Energy Association (ZARENA), Solar Industry Association of Zambia (SIAZ), companies in the off-grid sector and some specially nominated representatives

Regulation Board (ERB)[40]. Mini-grids are currently subject to different regulatory requirements according to their size (they are mostly[41] unregulated up to 100 kW, while for bigger utilities operators apply for tariff/service charges approval and tariff structures can be reviewed by the ERB where deemed necessary). In any case, tariffs must be cost-reflective. Regarding licensing, the same rules as for grid-connected utilities apply.

Therefore, in 2013 – which is the starting year of the Mpanta mini-grid project - the off-grid sector was not specifically regulated, and while the electricity market had a similar structure as today (though with less IPPs), tariffs were heavily subsidized (Kruger and Eberhard, 2019).

Mpanta is a rural area on the coast of Lake Bangweulu in Lupapa Province (Northern Zambia). It is populated by 2,673 people who mostly rely on seasonal fishing, which is banned by the government from December to March. Given that the mini-grid was supposed to connect about 450 households, its successful implementation would have provided access to at least half of the population. The next paragraph describes the project's evolution, as well as its economic and organizational structure.

4.1.2 Description of the solar mini-grid in Mpanta

The Mpanta mini-grid had an initial installed electricity generation capacity of 60 kW and was supposed to provide Tier 2 access[42] to households (powering small appliances) and Tier 3 access (limited productive use) to small businesses, schools, and a health center. It was composed of 300 × 200 W mono-crystalline solar PV modules, 720 × 650 A/2 V deep cycle batteries, 4 × 15 kVA inverters and 4 × 100 A/240 V DC charge regulators. The whole system operated at 240 V DC to AC and comprised two 0.4 kV distribution lines within a distance of 1 km, one for households/businesses and the other connecting the clinic (Strizke and Jain, 2021).

[40] The national regulatory authority

[41] For wholesale purchase, operators are only required to disclose the production price.

[42] In terms of load and not of availability, since this level of access was initially provided 24/7

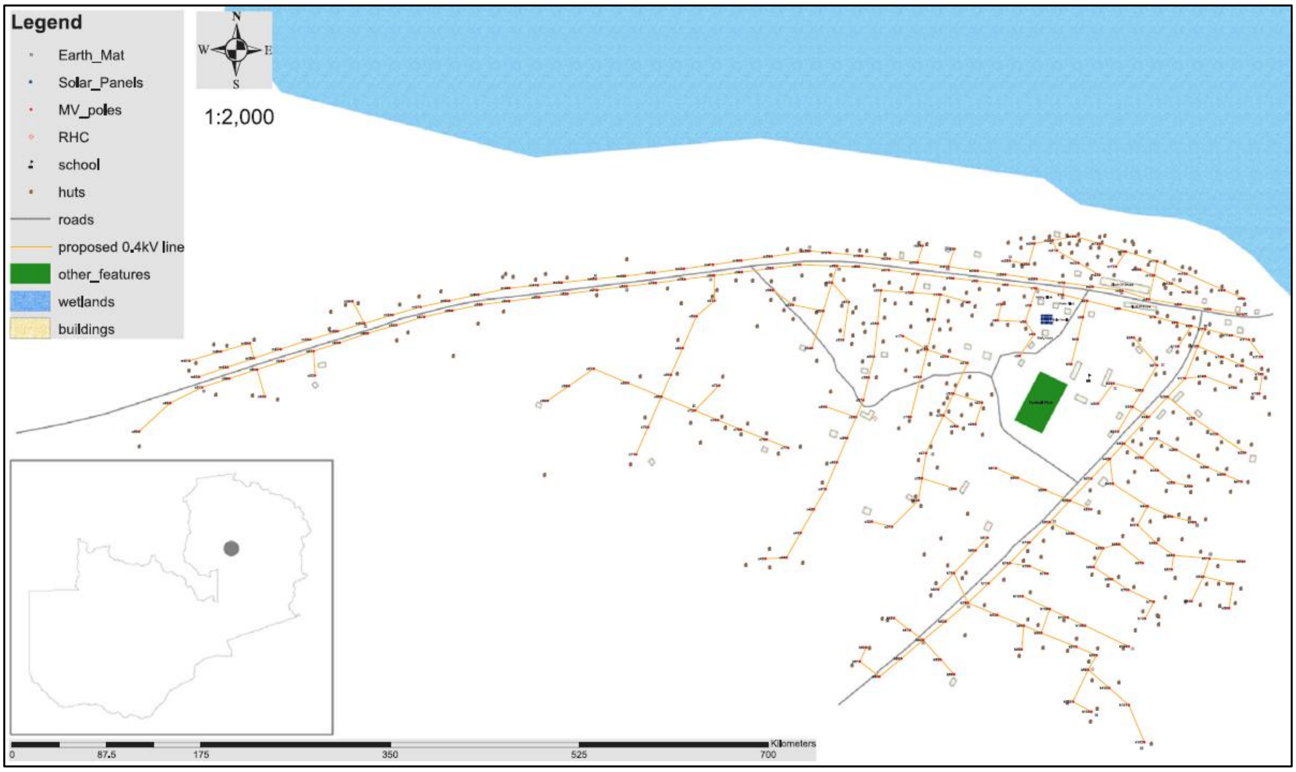

Figure 5, Mpanta solar PV mini-grid 's initial design (Zambian Rural Electrification Authority, 2016)

While this design was initially implemented, it was later downsized due to technical challenges – one charge controller was destroyed as the grid was repeatedly hit by lightning in December 2013, January 2015, and January 2016. A lightning arrester was installed, the system was re-wired, inverters and change controllers were replaced and optimized (they were reduced from 4 to 2 and their capacity[43] from 48 kW to 36 kW, the string size was increased from 10 to 14 panels). The number of panels was reduced to 224 arranged in four arrays of 56 modules (corresponding to approximately 44.8 kW), causing a 25.3% output reduction and the availability of power for only 14 hours/day, which corresponds to an average output of 209 kWh/day. The combined storage capacity of two batteries banks (one composed of 240 batteries and the other of 120) was 936 kWh (720 × 2 V × 650 Ah), which potentially guaranteed uninterrupted power for two days.

Before the reduction, the annual gross energy output was 102,000 kWh, given that solar energy production in northern Zambia is estimated at 1,700 kWh a year for each kW installed (SolarGIS, 2021), corresponding to 91,800 kWh considering power losses (estimated at 10%). After the reduction, the annual net energy output was 68,544 kWh/year.

[43] The original data included the reactive power and was measured in kVA (kilovolt-amperes), the author applied a 0.8 power factor to convert it into kW. According to the IEA, 0.8 is the adequate power factor for small-scale rural contexts (Forsyth, 2020, Lopes et al., 2012).

While the energy produced was sufficient given the low demand, the number of connections almost halved after the downsizing. By June 2016, only 250 households were still connected, and the system successively failed due to financial challenges.

The Mpanta mini-grid was funded as a development project by the United Nations Industrial Development Organization and the Global Environment Fund, with a pure grant of 1.3 million USD. Annual expenditure for operation and maintenance amounted to 43,343 USD, which takes into account the average yearly management costs (salaries, office rent, materials and equipment, travel expenses) and component replacement costs (charge controllers, inverters, batteries). The following calculation illustrates the levelized cost of energy (LCOE) between 2013 and 2021 (t=9 years), which will be instrumental for assessing the economic efficiency of the system.

Equation 2, Levelized Cost Of Energy (Mpanta, 2013-2021). Full calculation in Annex 1

$$\boxed{\mathrm{LCOE} = \frac{1{,}554{,}981.5}{389{,}288.6} \approx 3.99\ \mathrm{USD/kWh}.}$$

This calculation considered the real lifespan of this system, but another assessment taking into account the normal lifespan of a solar-PV mini-grid (20 years) will be conducted in the next chapter in order to discuss its economic efficiency compared to other options in case of continued operation – through it is already evident that the LCOE is significantly higher than it normally is for systems of similar scale.

The 450 target customers initially connected to the mini-grid and received electricity without paying, which led to the perception of electricity as a free good. Afterwards, a connection fee (5 USD) and a wiring fee (1.5 USD) were introduced together with monthly fixed tariffs. The tariffs differed according to category (residential, commercial, social services) and number of rooms if residential. The following table shows the precise cost per category.

Table 2, Mpanta's monthly tariffs according to category and type (Adapted from Stritzke and Jain, 2021)

CATEGORY	**TYPE**	**MONTHLY CHARGE IN USD (2016)**
Residential	Less than 3 rooms	2.6
Residential	4 rooms	3.1

Residential	5 rooms	5.4
Residential	6 rooms	5.7
Residential	7 rooms	6.2
Residential	School and clinic staff houses	8.8
Commercial	1 room	5.4
Commercial	2 rooms	5.7
Commercial	3 rooms	6.2
Social services	Harbor depot/health center/primary schools/churches	4.4

By 2016, 131 users disconnected due to default (because of their inability to pay). Moreover, 60 users were disconnected because their grass-thatched house collapsed due to heavy rain, and 4 more because of illegal connection (Muhoza and Johnson, 2018). Among the 131 users whose connection defaulted, the main reason for their non-solvency is the discrepancy between expectations and reality: not only community members believed electricity was free, but the tariff structure – namely the fact that it was based on size instead of consumption - and the service's discontinuity were viewed as injustices. Many users indicated affordability as an issue as well: while rural household income was 107 USD[44]/month on average (Republic of Zambia Central Statistical Office, 2015), more recent local surveys (Stritzke and Jain, 2021) suggest much lower income levels in Mpanta (household expenditure was around 38.15 USD[45], despite economic shrinking due to Covid-19 it is reasonable to assume that income levels were not above 100 USD as the researchers indicate they were below 77 USD in 2015) , 6.5 USD plus at least 2.6 USD a month could be an impeding price as it amounts to over 10% of the disposable income. The sources suggest that the system was financially unsustainable because of the high number of users disconnected from the mini-grid: the estimated[46] revenue in 2016 was 16,069 USD, meaning that the system operated on a 27,273 USD deficit – which was subsidized by REA.

However, with this tariff structure the system would not have reached financial breakeven (without considering CAPEX as it was completely financed by a grant) even in case all the target users (n=450) stayed connected: in the same year, the revenue would have amounted to 28,909 USD,

[44] 810 ZMW converted into USD with the 2015 exchange rate
[45] 228 ZMW converted into USD with the 2015 exchange rate, about 13 USD with the spring 2021 exchange rate utilized by the authors during the survey
[46] It was obtained multiplying the number of connections (250) times the average monthly tariff in USD (2016 exchange rate) and adding the connection costs of the three customers who reconnected to the mini-grid

still registering a 33% deficit to OPEX (-14,433 USD). The minimum average tariff necessary to reach financial breakeven with 450 users in a year without new connections would have been about 88 USD/month (173 USD/month with 250 users) – which is higher than the average monthly income in the area. In case a pre-paid metering system was installed, the price should have been ≥ 0.70 USD/kWh[47] in order to cover OPEX.

In organizational terms - while ownership was retained by REA - the Kafta Multipurpose Cooperative (a local non-profit cooperative) was entrusted with mini-grid operation (on an interim generation and distribution license issued by the ERB), maintenance, and revenue collection. Initially, both a plant technician and an accountant were hired by REA to support the cooperative, but by 2016 only the technician was still operating. The cooperative was responsible for the tariff scheme as well: while the introduction of a pre-paid metering system was discussed, a community vote established the fixed fees illustrated above. In addition to the already mentioned reasons, the population reacted negatively to this decision also because of unclear communication by the cooperative: most people were informed of the mini-grid by other actors (REA, other community members, the school headmaster, etc.) without clear specification of the costs. Moreover, the revenue collection practices that the cooperative adopted were reportedly ineffective (Muhoza and Johnson 2018, Stritzke and Jain 2021).

The mini-grid was decommissioned in 2021 due to financial unsustainability and to the fact that the main grid reached the Mpanta area (2 km from the village) for the first time. As seen, financial challenges were due to the high LCOE and more than to the failure to collect sufficient revenue. While it is not possible to assess whether this project was more expensive than main grid expansion in rural Zambia in 2013, the cost of a connection to the mini-grid in Mpanta (3,173 USD, assuming that all 490 target households were connected) was higher than the average cost of a connection to the national grid in Sub-Saharan Africa (ranging between 2,000 and 3,000 USD).

The next section analyzes an energy community in rural Tanzania that faced similar initial challenges to Mpanta but succeeded in overcoming them by scaling up and increasing the tariffs.

4.2 Tanzania: hydro mini-grid in Ludewa (LUMAMA)

In 2006, the Italian NGO ACRA Foundation partnered with Njombe Development Office (a local catholic NGO) to develop a run-of-the-river mini-hydropower plant on Kisongo River with the initial goal of providing clean energy access to 580 users. Despite initial financial challenges, the project

47 Average losses due to demand fluctuations (10%) were subtracted from the net annual energy production (68,544 kWh).

was scaled up between 2011 and 2013, resulting in 1,433 connections and allowing the phasing out of subsidies by 2015. This section investigates the economic and organizational structure applied to this project.

4.2.1 Context

Tanzania is an Eastern African country of 69 million with access to the Indian Ocean and bordering eight countries. It is culturally and geographically diverse and spreads over 1,000 km. In 2006, 5.5% of the rural population (currently 27.9%) and 42.3% of people living in urban centers (currently 82.4%) had access to electricity – corresponding to approximately 24 and 9.5 percentage points lower than the regional average respectively. Urban access to clean cooking was 2.2% (currently 22.3%) and 0.3% in rural areas (currently 2.4 %) – again much lower than the regional average (42.3% and 8.8% respectively). At the time, around 75% of the population lived in rural areas (62.6% nowadays). In 2006, Tanzania classified as a low-income country with a GDP per capita of 476 USD, and it upgraded to lower-middle income status in 2020 (currently 1,186 USD).

The Tanzanian economy has grown steadily throughout this century (with annual growth ranging between 4.5% and 7.7% - touching record low at 2% in 2020), demonstrating resilience to shocks and diversified value streams: the expanding services sector amounts to over 40% of GDP, with agriculture at 25% and industry at about 33%. Like in the rest of SSA, agriculture is still the largest source of employment (2/3 of the working population) (The World Bank, 2025). Tanzania is mostly macroeconomically stable with relatively low inflation and a debt-to-GDP ratio slightly above 30% which is projected to be no higher than 33% by 2031 (Embassy of Switzerland in Tanzania, 2024). This outlook favored high levels of foreign direct investment, which drove economic growth especially in the mining, financial, ICT, and manufacturing sectors (which accounted for 82.4% of FDI in 2023) (Bank of Tanzania/TIC/NBS, 2024).

Tanzania's electricity generation capacity (3,404.20 MW) mostly relies on natural gas (69%) and hydropower (29%), with very small portions of biofuels (0.8%) and oil (0.2%). As in the case of Zambia, electricity accounts for a very small part of energy consumption (almost 3%), with biofuels and waste (76%) and oil products (17%) dominating the market. Unsurprisingly, electricity consumption per capita is very low (122 kWh/year). Energy is mostly consumed by the residential (65%, 96% from biofuels and waste – of which up to 90% is wood fuel), transport (15%, oil products only) and industrial (10%, mostly biofuels, waste, and natural gas) sectors. The state-owned vertically integrated TANESCO dominates the power sector on the mainland[48], and like in Zambia generation is the only unbundled segment, with IPPs selling electricity to TANESCO through PPAs. Currently, 24 power producers are licensed to operate on the main grid. Among these, Tanzania has several on-grid and off-grid small power producers (facilities with less than 10 MW of generation capacity) which since 2008 benefit of an enabling framework which allows them to sell power to the main grid as retailers and wholesalers to fund their operations (Babayomi et al., 2023). By the end of 2026, the SPP framework should be revised to enhance the cost-reflectiveness requirements of tariffs. The only active interconnector is a 220 kV line towards Zambia, but some projects in this sector (including a pilot IPP) are under construction, and a trading unit should be created within TANESCO by the end of 2025 (Africa Energy Summit, 2025).

As anticipated, off-grid operators can also sell electricity directly to end-users under tariff approval (which shall be cost-reflective, take into account the actual power sold, but can include cross-subsidiarization if high-consumption customers are charged more in order to help electrify poorer customers) and are required to obtain a license if their size exceeds 1 MW. Moreover, mini-grids can enter power sales contracts with business customers without regulatory approval (Greacem et al., 2015). The Rural Energy Agency (established in 2005 with similar structure and functions to Zambia's REA) created the Tanzania Energy Development and Access Project (TEDAP), a 22.5 million USD fund which offers 80% partially result-based grants for private sector off-grid renewable energy projects. Tanzania is a relatively enabling environment for off-grid energy development, and 7 private entities are currently licensed for off-grid generation (EWURA, 2024).

The Ludewa District is a scarcely populated mountainous area in the Njombe region (south-western Tanzania), and it counts 137,520 inhabitants overall. It has a temperate climate and is located in the Kisongo river basin; therefore presenting suitable conditions for hydropower development. It comprehends 77 villages, 9 of which were targeted and successfully electrified by the LUMAMA project. The main economic activities are agriculture (mainly maize, beans, wheat, sorghum, and cassava), fishing, livestock and bee keeping trade, and mining, meaning that most of the population relies on seasonal income.

4.2.2 Description of the hydro mini-grid in Ludewa (LUMAMA)

The hydro mini-grid in Ludewa District initially targeted three villages: Lupande, Mawengi, and Madunda (the project was named LUMAMA to include all three villages' initials). Feasibility studies

[48] Another state-owned company (ZECO) buys electricity from TANESCO and is in charge of distribution and retail in Zanzibar.

started in 2006, and the plant was commissioned and operational in 2010. It was developed in two phases: by 2010, the system had generation capacity of 150 kW and 260 users were connected – though it was designed for 580 customers. During the second phase (2011-2013) the mini-grid's capacity was doubled, allowing it to reach 1,200 connections in 2014, 1433 in 2019, and reached 6 additional villages as shown in Figure 6 (Kiwe, Mapogoro, Milo, Mavala, Mdete and Madindu) . The system is now composed of two 150 kW Pelton turbines (with rotation speed of 1500 RPM), 54 km of medium voltage transmission lines (of which 39 were constructed during phase 2), 26 transformers (17 added during phase 2), and 55 km of low voltage distribution network (40 km added during phase 2).

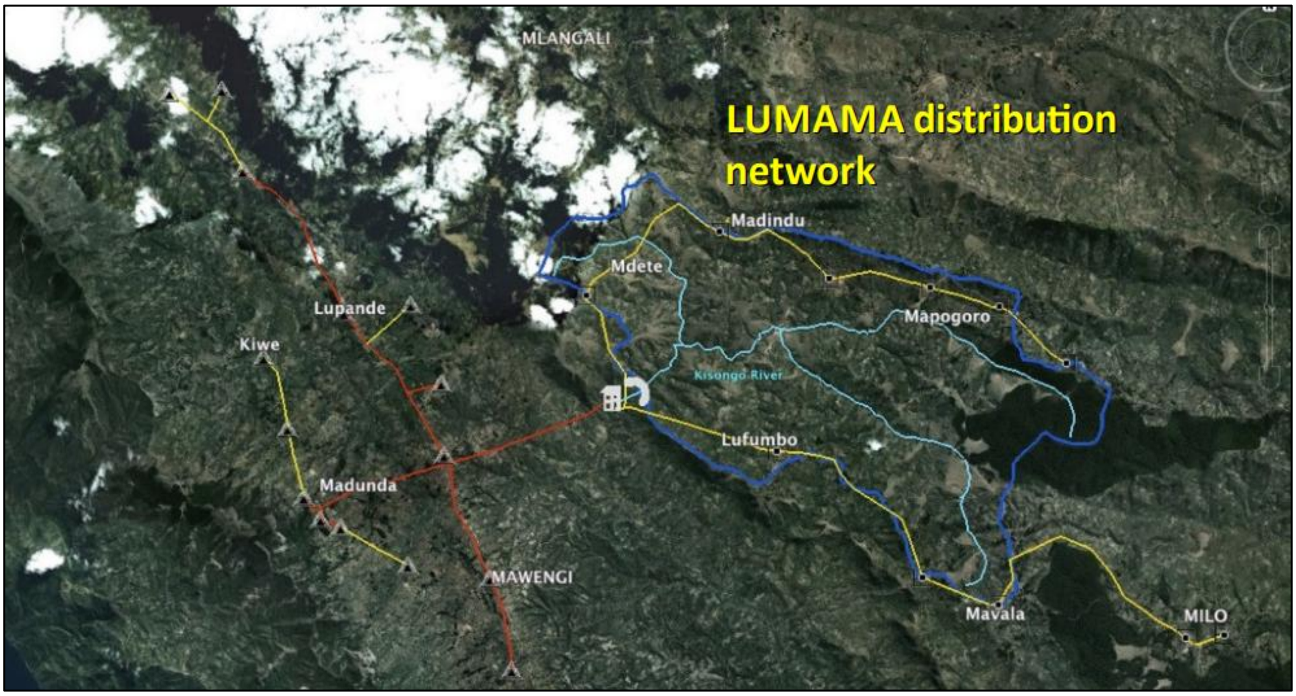

Figure 6, LUMAMA's expanded distribution network (ACRA, 2015)

Before the expansion, the system produced an average annual energy output of 558,450 kWh (gross), which corresponds to approximately 502,605 kWh/year considering transmission and distribution losses (10%). With a generation capacity of 300 kW, the figures double – respectively 1,116,900 kWh and 1,005,210 kWh.

The idea of building a decentralized hydropower system came from the local church, and the diocese of Njombe contacted ACRA-CCS to receive help with funding and implementation. The first phase of the project was entirely funded by Italian public and philanthropic investors (the Italian Ministry of Foreign Affairs, Regione Lombardia, and Fondazione Cariplo). ACRA decided to expand the grid due to the financial challenges faced by the 150 kW system: in 2011, income from electricity sales was only 20% of the operation and maintenance costs (Ahlborg and Sjstedt, 2015). The second phase was funded by the European Commission (through the Ministry of Finance of Tanzania), the World Bank (through REA), Intervita Onlus (an Italian NGO) and the Ministry of Energy and Minerals of Tanzania – in addition to grid expansion, the tariff system was revisited and prepaid meters installed. The infrastructure costed 4,031,326 USD overall.

Given that the average annual OPEX is 65,952 USD, the levelized cost of energy for this project is the following, with the lifespan of the system being 50 years[49]:

Equation 3, Levelized Cost Of Energy (Ludewa). Full calculation in Annex 1

$$\boxed{\mathrm{LCOE} = \frac{4,758,304.6}{9,883,386.2} \approx 0.48\ \mathrm{USD/kWh}.}$$

This cost is comparable to other off-grid alternatives in Tanzania, as diesel mini-grids range between 0.40 and 2 USD/kWh and solar-PV between 0.30 and 0.65 USD/kWh (Moner-Girona et al., 2016).

As anticipated, until 2014 tariffs were not cost-reflective: most customers paid fixed monthly fees based on the number of power points in their houses (1.5 USD, 1.92 USD, or 3 USD a month). Businesses and milling machines were already charged consumption – respectively at 0.12 USD/kWh and 0.09 USD/kWh. Some households and public services had meters as well, and purchased electricity at 0.072 USD/kWh, which is lower than the average national tariff at the time (0.135 USD/kWh). Initially, users only paid upfront 20% of the wiring cost (108 USD overall, which is a high cost considering that the average income of a Tanzanian rural household in 2013 was 503.22 USD a month), with the remaining to be paid within a year – however, many were not able to pay back in time and the connection of new users was delayed, leading to credit scheme defunding.

In 2014, fixed tariffs were replaced by pre-paid metering, and a monthly service fee was added to the electricity bills. Tariffs were increased to a similar level to TANESCO, and users were divided into five categories according to different uses as illustrated in Table 3:

Table 3, LUMAMA's Electricity tariffs since 2014 (Adapted from Botto Poala, 2018)

CATEGORY	ELECTRICITY CHARGE (USD/kWh)	MONTHLY SERVICE TARIFF (USD)
Households (1-7 power points)	0.09	1.5

[49] Conservative estimation based on the LCA of a community hydro mini-grid in Indonesia (Hanafi and Riman, 2015)

Households (> 8 power points) and public services	0.10	1.5
Businesses	0.12	1.5
Milling machines	0.16	3.3
Other electric machines	0.20	3.3

This structure – together with the expansion – allowed LUMAMA to reach economic viability. As a matter of fact, in 2015 revenue exceeded OPEX by 14% with an annual income of 76,299 USD and annual costs of 67,061 USD (ACRA, 2015). The system significantly improved its financial sustainability already in 2014, when revenue covered 92% of operational and management costs. After the introduction of this new pricing system, LUMAMA was able to cover unexpected events and depreciation costs as well by 2018.

From the organizational point of view, the mini-grid is owned, managed, and operated by the LUMAMA Electricity Association, of which all the users are members – reflecting the scheme of a non-profit energy cooperative: it is registered as an NGO and the profit are utilized for maintaining and upgrading the system. ACRA transferred ownership of the system to LUMAMA at the end of 2010 but has been involved in its governance until it exited the project in August 2014, as it provided a management expert who met on a weekly basis with the staff. Moreover, it contributed to capacity building in administration and accounting through specific training. The staff is composed of a manager, a technician, and an accountant – all coming from the nine villages and appointed by the board. Concretely, the governance structure is organized on three levels: on the first one, all members belong to a transformer, and they elect 6 representatives for each. There are 8 zones composed of all transformer representatives, and each zone elects 6 representatives to the general assembly (composed of 48 members), which meets at least twice a year and has the power to elect the board, decide on tariffs, adopt the budget and modify the regulation. The internal statute prevents local politicians from getting leadership roles in LUMAMA for independence reasons, but district government and the church have board positions. The board (composed of 5 elected and 2 advisory members) oversees finances, operations, and human resources. The main governance challenges regarded communication, authority, and trust. In the first phase, villagers felt left out as they were not timely informed of tariff increases. Moreover, some lamented the lack of participation arenas since not all the transformer groups used to meet regularly. Regarding authority, many users were initially skeptical of LUMAMA's professionality and management ability. In this sense, adopting strict payment rules (initially, users were disconnected after three months of insolvency since the notice, which was later reduced to one) and enforcing them also towards local political leaders contributed significantly to the EC's authoritativeness.

Eleven years after ACRA exited the project, the system is still operational and electricity is consumed for productive use by 30% of the customers (corresponding to 58% of annual sales).

Conclusion

The mini-grids in Mpanta and Ludewa were developed in very similar conditions: both were conceived as development projects, targeted low-income rural areas of countries with partially liberalized electricity markets, and were managed by a non-profit energy cooperative. Therefore, their different outcomes are more tied to specific techno-economic aspects than to contextual variables or organizational factors. At most, financial management and technical performance influence social perceptions of electricity - and the users' willingness to pay. For instance, both the tariffs' structure and the revenue collection system were determinants in these cases. The system's ability to provide a reliable service is key for success as well: in Mpanta, scarce performances fueled insolvency. While the benefits of electricity were reportedly appreciated in both cases, providing it at first for free created unmanageable expectations. In Ludewa, higher tariffs were consumption-based and accompanied by increased generation capacity, favoring the productive use of electricity. The tariffs introduced in Mpanta were too low to cover OPEX, but still unaffordable for many villagers. Therefore, operational costs should have been reduced to get the system closer to economic viability, and possible options will be discussed in the next chapter, which will assess the viability of energy communities starting from the case studies and provide recommendations.

5. Discussion and recommendations

This chapter discusses key aspects of the case studies (namely financial viability, technical design, and economic structure) and the viability of energy communities in Sub-Saharan Africa in a larger perspective. Moreover, it provides economic and technical recommendations for project developers, as well as policy proposals for regulatory and development actors.

5.1 Discussion

The case studies presented display very different levels of economic efficiency: while the LUMAMA hydro mini-grid is comparable to other off-grid system in Tanzania, the solar-PV mini-grid in Mpanta is extremely expensive to operate. In order to calculate the real LCOE of the system, the author applied the actual lifespan of the mini-grid (9 years) which is significantly shorter than the normal lifespan of a solar mini-grid (20 years). With the purpose of comparing it to other systems, it is necessary to calculate a hypothetical LCOE of the system with t= 20 years and the same CAPEX:

$$\text{LCOE} = \frac{1{,}300{,}000 + 368{,}290}{582{,}520} \approx 2.87 \text{ USD/kWh}$$

Even with 20 years of functioning, the system is more expensive than any off-grid alternative: according to model business case analyses of solar mini-grid in Zambia, the LCOE of a 69-kW system would be about 0.81 USD/kWh without subsidies. The LCOE in Mpanta is calculated as if the CAPEX was not a grant in order to give a more realistic idea of its economic efficiency. Without accounting for upfront costs (which were not sustained by the operator), the levelized cost of energy would be 0.632 USD/kWh. In the previous chapter, the breakeven tariff was calculated based on OPEX on a 9-year lifespan and was as high as 0.70 USD/kWh. However, it is more appropriate to consider CAPEX to assess its replicability, which in this case implies very low economic efficiency and financial sustainability. Considering the annual energy output, it is evident that OPEX is very high: in comparable cases, operation and maintenance costs are between 10,000 and 11,000 USD/year. Looking at Mpanta's OPEX more closely, it is possible to notice that the substitution of components accounts for 26,343 USD when distributed annually. These components are accounted for in OPEX because they were among the costs sustained for repairing the system in 2015-16. This figure can be reduced: for instance, the batteries utilized have a 5-years lifespan, and by installing batteries lasting 15 years instead (e.g. Lithium-ion) – as well as using optimized charge controllers with 10-year lifespan instead of 7 - the costs would have decreased to 11,384 USD/year (Strizke and Jain, 2021).

In Ludewa, the high annual energy output allows to sustain higher costs: without considering CAPEX - which was completely funded by grants in this case as well - the LCOE would be 0.0656 USD/kWh, a lower figure than the average national electricity charge in Tanzania (0.089 USD/kWh, which is still partially subsidized) signaling profitability for the operators given the current tariffs (the lowest is 0.09 USD/kWh).

Even considering that mini-grids suffer from diseconomies of scale, CAPEX was extremely high in both cases (21,600 USD/kW in Mpanta, 13,438 USD/kW in Ludewa) and definitely above average: comparable projects in SSA do not surpass 8,000 USD/kW (e.g. a 16 kW Solar-hybrid mini-grid in Nigeria costed 3,770/kW, a 250 kW hydro mini-grid in Zambia costed 7,146 USD/kW). Exchange rates play a role as well, but not significantly enough to justify such discrepancies. In the case of Ludewa, higher upfront costs compared to the hydro mini-grid in Zambia can be partially attributed to longer distribution lines, which cover 6 km only – and are low-voltage – in Zambia

(GET.invest, 2019). Still, the overall upfront cost of infrastructure in Ludewa (4,031,326 USD, therefore around 2,800 USD per connection) was lower than interconnecting to the main grid, which for 1,433 users would have cost 4,299,000 USD considering the upper end regional average cost of a connection (3,000 USD).

It is relevant to note that the costs associated with the system being an energy community (e.g. technical assistance) are mostly accounted for in OPEX – except for capacity building activities (e.g. trainings) carried out before operating the system that correspond to a small quota of CAPEX. Compared to available examples of energy communities in advanced countries, the LCOE in Ludewa is higher: for instance, LCOE in New Jersey ranges between 0.13 to 0.20 USD/kWh inversely proportional to size (200 kW to 5 MW), and in the UK they range between 0.21 and 0.23 USD/kWh – and tend to have slightly higher (+ 1%) upfront costs compared to commercial alternatives (Berka et al., 2017).

Mini-grids that were built as part of development projects – therefore, projects whose primary objective is impact rather than profits and whose success is measured accordingly - tend to present higher costs: for instance, the cost-reflective tariff in the Rural Renewable Energy Project (RREP) mini-grids in Sierra-Leone (funded by the British FCDO and implemented by UNOPS) is 0.85 USD/kWh, with almost 38 million dollars invested and the goal to install 4 MW capacity and provide electricity to 346,000 rural people (UNOPS, 2021). In this case, the cost per kWh installed (9,500 USD/kW) is still lower than Ludewa also due to scale but higher than regional commercial averages. Looking at a small solar-PV (24.4 kW) private sector project in Zambia, the LCOE (1.57 USD/kWh) – though still very high - is much lower than Mpanta's, despite having half its initial capacity. Still, it is relevant to note that the flat tariff adopted in Sinda was higher than in Mpanta but failed to make the system financially sustainable, reflecting a key issue for electrification of rural low-income areas: building economically efficient systems is crucial for sustainability, local ownership (deficits force government/development actors to keep deploying their financial and human resources for project support), and replication, but neither full subsidization nor ambitious tariff schemes - if not paired with economic development - can help attain this objective. The two Zambian cases show that affordability and technical reliability are key for take-up and continued connection. While diseconomies of scale imply higher tariffs than the main grid, the developer needs to strike a balance with customer budget constraints in order to reach financial sustainability. Therefore, it is not reasonable to expect immediate break-even, let alone immediate profit. The Ludewa mini-grid is an emblematic example: the system started being profitable after four years of functioning, where the higher tariffs were accompanied by increased generation capacity. In this case, take-up was progressive, and demand grew together with the system's capacity. Regarding economic development, the LUMAMA project included a business program for enterprises in Ludewa: ACRA supported 20 local businesses to start up new productive activities. Moreover, it provided grants for the purchase of electric machines (up to 1,602 USD) and training on how to use them. The NGO also supported the agricultural sector – which employs most of the local population – by diversifying cultivation and supporting maize milling at the same time. It regulated the number of milling machines that could be connected to the grid (one or two each transformer) and the price of the electric milling service: interested enterprises had to apply and the transformer chairman selected the candidate, while LUMAMA and ACRA partnered to advise on equipment and subsidize half its installation cost. As a result, production costs decreased – beforehand, mills used to run on diesel – and the price of milling services halved. Given that almost all households in Ludewa use maize flour porridge daily, their real income increased as a result. While the available data does not allow to precisely assess the quantitative impact of this measure on electricity consumption, the case study analysis showed that productive use of electricity accounts for over half (58%) the mini-grid's profits.

On the customer side, energy communities in SSA tend to offer higher tariffs than main grids when not subsidized – mainly because national retail tends to be subsidized despite trends towards cost-reflectiveness. For instance, ZESCO (Zambia) enhanced the already in force cross-subsidization through an emergency tariff structure in 2024 due to the draught crisis. Within this framework, households consuming less than 100 kWh/month have a 20% discount (and -5% up to 200 kWh/month) on the multi-year tariff for their category, which is normally 0.019 USD/kWh, and those with a monthly consumption higher than 200 kWh pay between 69% and 90% more than usual. In Tanzania, the first 75 kWh of electricity consumed are subsidized by 66% (of the 0.12 USD/kWh charge for 'lifeline users', reaching 0.040 USD/kWh), and everything above 75 kWh is subsidized by 9% (going from 0.13 USD/kWh to 0.12 USD/kWh for 'general users'). Given that the average electricity consumption per capita in Tanzania is 122 kWh/year and general access to electricity is 53%, it is reasonable to assume that at least ¼ of the households fall in the 'lifeline' category.

On the contrary, energy communities in Europe tend to offer better prices than national grids (according to the European Commission, the average household electricity prices were almost 0.21 USD/kWh in 2024) but tend to be heavily subsidized as tailored state aid is explicitly allowed – and encouraged – by the RED II (REScoop.EU, 2023). For instance, REC in small Italian towns (below 50,000 residents) are eligible to a 40% grant and a 20-years tariff reduction of up to 110 €/MWh financed by the National Recovery and Reconstruction Plan (GSE, 2025). Portugal, Gernamy, and Austria have similar operational support schemes while Spain and Ireland provide grants for CAPEX.

While they can still be a reasonable option in remote or insular areas where distribution costs are higher, the centralized structure of energy systems from a technical – and sometimes economic – point of view is a significant limitation to scaling up, which might deter investment when the target area has a low population density.

However, energy communities in rural areas of SSA are not only conceived as a cheaper alternative to the main grid (which tends to be more expensive for developers than well-designed EC), but mainly to more commercially oriented off-grid options which might present higher tariffs. For instance, unsubsidized mini-grid tariffs in Zambia reach 0.26 USD/kWh. Moreover, the other available options either have a smaller generation capacity (e.g. SHS) or do not have local ownership schemes (e.g. commercial or SOE-owned mini-grids).

EC do not guarantee bottom-up engagement: as seen in both advanced economies and developing countries, self-governance is a double-edged sword that can either facilitate the implementation of a development project or exacerbate differences. The cases analyzed mostly present the typical non-profit energy cooperative scheme, which is theoretically the most inclusive and development oriented. However, decisions are still taken at the apical level (e.g. LUMAMA's Assembly), requiring clear and timely communication to all community members – which might still have expected a more participatory and/or less expensive model. While a progressive approach to tariffs is necessary for reaching the desired scale in low-income contexts that are not familiar with electricity, the literature review and case study analysis have shown that most people prefer consumption-based tariffs rather than fixed ones: given that household consumption in SSA tends to be low, this does not necessarily imply higher costs for users, and is perceived as a fairer scheme.

Energy community projects present a long pay-back time in both OECD countries and Sub-Saharan Africa, and as far as this research goes, low profits for operators. For instance, while the LUMAMA project took 5 years of operation to reach financial break-even, if CAPEX was not grant-funded the pay-back time would have been around 500 years - without considering currency fluctuations. Therefore, it is evident that EC in Sub-Saharan Africa can only be conceived as part of development projects at this stage, mostly requiring the involvement of international impact investors. Another element pointing in this direction is that the second round of financial aid from ACRA was crucial for LUMAMA's success, signaling the need for long-term engagement and possibly multiple funding streams. However, the research showed that it is possible for EC in rural SSA to operate in a financially viable trend without subsidies or external aid. Moreover, mini-grid costs are on a decreasing trend, plausibly indicating lower CAPEX for EC in the future. In a context where local 'ownership'- intended as not only legal propriety but also as empowerment through management and fair distribution of benefits - of development projects gained significant relevance in determining sustainability, energy systems that are completely locally operated and as economically efficient as other off-grid options offer insights for replication. Given that the sustainability of the EC analyzed stemmed from several factors, the author will focus on non-contextual elements and offer actionable recommendations for project replication. The research showed no correlation between organizational models and project success. Therefore, it is desirable for implementing actors to carry out consultations with community members as it happens within the Community Energy Development Programme in Malawi, so that the ownership/management model is coherent with local societal structures and technical requirements of the energy system.

5.2 Economic recommendations

The case study analysis underlined some aspects of EC economic management that have proven critical in determining project outcome. As noted in both projects, subsidizing tariffs with prices not reflecting electricity consumption is perceived as more expensive and unfair by the users. Moreover, such tariff structure is not designed to make the mini-grid financially sustainable and results in prolonged dependence on external aid, as the minimum average monthly tariffs to cover OPEX without charging electricity consumption would have been 88 USD (Mpanta) and 46 USD (Ludewa), which is clearly unsustainable for the users given that the monthly income per capita in rural areas of Zambia and Tanzania is respectively 77 USD and 100 USD. Regarding consumption-based tariffs, cost-reflectiveness should be implemented in a way that is affordable for at least 75% of the users, as it would otherwise be counterproductive and fuel disconnections. For instance, if the Ludewa mini-grid introduced cost-reflective tariffs in 2010 with 260 connected users and a generation capacity of 150 kW, the minimum cost of a kWh should have been 0.12 USD in order to cover OPEX. This figure is higher than both the current charges and the main-grid tariffs, and by assuming an average household consumption of 30 kWh/month[50], it would result in a monthly expenditure of about 3.6 USD – which is relatively affordable in rural Tanzania. Therefore, in this context cost-reflective consumption-based tariffs could have been adopted right away even if the current monthly charges were applied as well. Conversely, in Mpanta the minimum cost-reflective tariff in the first year of functioning should have been 0.21 USD/kWh, which would have resulted in 6.3 USD/month per household – which is less affordable than the monthly tariffs implemented, though metering would have at least facilitated revenue collection. In this case, introducing consumption-based tariffs would have still been desirable, but strong cross-subsidiarization would have been necessary to implement cost-reflectiveness - given the low income level of the average household.

[50] Monthly consumption of households just connected to the mini-grid

While financial sustainability is currently attainable, profits are still too low to pay CAPEX back. Therefore, grants covering 100% of the upfront costs or blended models with a percentage of concessional financing are needed. In order to facilitate self-sufficiency and timely infrastructure building, such instruments should be front-loaded and time-bound, which also helps contain currency risks and is a common feature of effective subsidies in ‘infant industries’ (Ravikumal et al., 2025).

The research showed that – as it happens for many energy projects in developing countries – one of the main challenges for EC in rural Sub-Saharan Africa is to find anchor customers: as a matter of fact, some initiatives for rural electrification set a minimum productive load for mini-grid tenders (e.g Nigeria’s NEP, Tanzania’s TEDAP). To this end, it is desirable for the organizations involved to incentivize local businesses’ uptake through specific programs, similarly to LUMAMA’s policy for maize mills. Subsidizing the purchase of electric appliances for the productive use of energy is a popular measure in off-grid projects. For instance, NEP and the Beyond the Grid Fund for Africa both implemented such programs, as well as the Kenyan company PowerGen which provides refrigerators and freezers to commercial customers (SE4ALL, 2024, p. 147). According to a study conducted on 25 different sites, appliance financing can help increase average electricity consumption per user by 48% (Crossboundary, 2022, p.1). In absence of plausible anchor customers, developers can invest (or co-invest with local businesses) in revenue-generating activities coherent with local supply chains, therefore creating their own anchor loads. This model (i.e., the Keymaker) was successfully[51] implemented in Tanzania (and modeled for rural Nigeria), where a mini-grid developer started a fish trading business involving the use of electric freezers, facilitating local fishers’ activities and providing employment for villagers (Pueyo et al., 2022). Provided funding is available, such model could be replicated more easily in an EC by tapping into community members’ local networks, and if successful it would contribute to the system’s financial sustainability.

Given that access to electricity is not sufficient for clean cooking technology adoption, it would be reasonable to argue that mini-grid developers should subsidize small appliances and electricity for eCooking. However, this policy would be more expensive than financing other clean cooking technologies, and it would not produce sufficient electricity consumption for compensating expenditure overall, as people would reportedly continue stacking (Frame et al., 2022). A more affordable alternative that is coherent with an EC design would be biogas, which is particularly suitable for rural areas. While the community-level application is at an early stage in Sub-Saharan Africa, it was widely adopted in Nepal, where 1,812 community biodigesters are currently operational. In SSA, biogas-based community cookers were adopted in the peri-urban areas of

[51] The business later failed because the mini-grid stopped operating due to an unsustainable tariff structure

Nairobi[52] and in the rural village of Njinikejem[53] (North-West Cameroon). In the latter case, bio-digestate was utilized as fertilizer. It is relevant to note that a ton of bio-digestate costs about 75 USD (The World Bank, 2019, p.42), which could significantly help finances given that a community biodigester serving 20 households would produce over 100 tons/year[54].

5.3 Technical recommendations

The cost of replacing components doubled OPEX of the mini-grid in Mpanta: while the systems' finances should theoretically cover emergencies, it is rarely the case in the first years of operation. Therefore, utilizing components with a longer lifespan and installing prevention systems according to the geographical and meteorological features of the area would help financial sustainability and technical performance. As seen, the 5-year long lifespan of the lead-acid (AGM/LEAD) batteries utilized in the comparatively oversized storage system in Mpanta tripled operational costs compared to using Lithium-ion batteries despite being cheaper. Moreover, Li-ion batteries have higher efficiency (90%) and depth of discharge (80%), meaning that the LCOE would have decreased as energy losses would have been smaller and the storage system would have been of a lower size with a higher capacity. Given that Mpanta is located in a rainy area with a subtropical climate, it would have been more efficient to install a lightening arrester before the system started functioning, so that it would not have been necessary to re-wire it, replace inverters and change controllers after 3 years. Similarly, the reconfigured system was less modular than the original one as string size was increased while the number of inverters and controllers was reduced, complicating operations in case of further replacement needs. Especially where reducing OPEX is a necessity, it is preferrable to increase modularity, so that a damaged component can be replaced at a lower cost while ensuring continuity of operations. Regarding metering, it is advisable for load management and revenue collection purposes to install smart meters, which are able to register data in shorter intervals (e.g., with 15/30 minutes or hourly granularity), support bidirectional flows, and allow mobile payments. While the cost of a smart meter in SSA ranges between 80 and 110 USD in Africa (CrossBoundary, 2023), meaning at least 40,000 USD for a 500-users energy community, prepaid metering is the most efficient way to collect revenue given that 28% of adults in Sub-Saharan Africa have a mobile money account only (45% in Tanzania), which is especially popular in rural areas.

Given that CAPEX was very high in the cases analyzed, mini-grids should be suitable for scaling up and connecting to the national grid where possible. In Mpanta, the system's low financial

[52] For more information, see: https://unfccc.int/climate-action/momentum-for-change/activity-database/the-community-cooker
[53] For more information, see: https://www.beruda.org/projects.html
[54] Own calculation based on a conservative estimation of 300 liters produced a day

sustainability led to decommissioning instead of connecting it when the main grid expanded in the region, but connecting an existing profitable decentralized system could be convenient in areas with low-income customer bases. In Zambia and Tanzania, it is possible for off-grid utilities to sell agreed quantities of electricity to the national grid through physical connection, which would be an additional revenue stream for the energy community. While many of the technical challenges of mini-grid integration addressed in the first chapter do not apply when only agreed portions of surplus electricity are exported (e.g., demand and data management), the national utility needs to upgrade the distribution transformers and control systems so that they can handle/recognize bidirectional flows, as well as deploy SCADA systems for real-time monitoring. On their side, mini-grid operators need to install compliant inverters, whose requirements change according to the regulatory framework. For instance, in Zambia it must synchronize with the grid and automatically shut off during outages, as well as support remote metering in systems above 30 kW[55]. While not compulsory, it is desirable to build local storage systems as they significantly support flow management.

5.4 Regulatory and policy recommendations

While off-grid utilities currently find a comparatively favorable regulatory environment in Tanzania and Zambia, they are still unregulated in many Sub-Saharan African countries. In order to streamline deployment and avoid administrative burdens, capacity thresholds on mini-grid licensing are a desirable regulatory element. However, rural electrification authorities (or national regulatory agencies where not present) should ensure compliance with technical and safety obligations prior to operations. Regarding tariffs, cost-reflectiveness should be compulsory but policy frameworks for partially subsidizing it (e.g. not more than 30% of the price and inversely progressive to household income) for the first years of functioning should be available to operators who fund and/or implement economic development programmes that favor the productive use of energy. Moreover, pre-paid metering should be compulsory for energy communities, where revenue collection faults are more common due to the managers' inexperience. Phasing out of subsidies or other external aid should be programmed based on consultations with the implementing actors and take place progressively within 5 or 7 years at most, depending on whether technical challenges were met. Uniform national tariffs might negatively affect the financial sustainability of decentralized energy systems: for instance, the mini-grid within which the Keymaker model was tested failed because EWURA introduced a 0.18 USD/kWh standard tariff for solar and wind mini-grids, which was unaffordable for many community members and led to disconnections. With the tariff being much higher than TANESCO's (currently

[55] For more information, see:
https://netmetering.zesco.co.zm/assets/img/documents/Renewable_Technical_Specifications.pdf?

0.089 USD/kWh), even households which could afford it were not willing to pay. Instead, the Tanzanian SPP framework offers a replicable model regarding surplus management, as operators are allowed to sell electricity to the state-owned TANESCO under PPAs with or without physically connecting to the main grid.

In terms of incentives, the author favors output-based aid, but where CAPEX is high a blended format with upfront capital support is necessary. For instance, for a hydro mini-grid the same size as LUMAMA, the first turbine and related infrastructure could be funded before construction with a blend of grants and concessional financing, while the second should be financed upon completion of the first and proof of reliable service delivery (not more than 5 days of outage/year given than average mini-grid uptime in SSA is 99%) (Chikumbanje et al., 2020). A similar model could be applied to household connections - given that costs are high both on the developer and customer side – and pre-paid metering systems where financial need is demonstrated.

High CAPEX is also due to insufficient industrial capacity in the region: despite many countries being resource-rich, mini-grid developers need to import components. For instance, while the transformers industry started growing in South Africa, Tanzania, and Ghana; solar-PV, inverters, and batteries are mostly imported from China and India. Copper-rich countries like Zambia and the DRC should focus on building manufacturing capacity for domestic production of components for electrification (solar infrastructure, distribution networks, etc.). While Zambia aims at producing 3 million metric tons of copper per year by 2043 (currently 820,676), the industrial development plan (2022-2026) focuses on exports and does not outline a domestic processing strategy.

The Community Energy Development Programme in Malawi offers a replicable framework for stakeholder engagement in the preliminary phase. In this context, officials assess community-based organizations' skills requirements through basic audit forms, and tailor capacity building activities – which include technical, managerial, and financial project management - to the results (Dauenhauer and Frame, 2016). In case capacity building capabilities were more limited, such assessment would still help direct investments in human resources towards existing skill gaps, increasing their effectiveness. Moreover, national frameworks with these features would facilitate knowledge sharing and best-practice replication.

Conclusion

The evidence suggests that the main tension within energy community design regards its economic aspect: success or failure in reaching financial viability mostly depends on whether tariffs are both cost-reflective and affordable – and on effective revenue collection. Cost-reflectiveness is not intended for paying back upfront investments in the shortest time possible, but for making the EC financially sustainable by covering operational expenditure and sustaining emergency costs without external aid. A major issue common to rural electrification projects is finding anchor customers that ensure stable electricity consumption and revenue: while in some context it is necessary to create such conditions through direct investment, in others stimulating consumption by existing actors can be an effective means to both secure revenue and foster local economic development – which translates into higher incomes that benefit electrification efforts. This way, energy communities can maximize their impact on consumption - therefore sustainability in the long-term. When the projects analyzed were developed, high CAPEX remained a barrier to the commercialization of energy communities. While precise economic data from more recent projects is not yet available, the cost of – especially solar – mini-grid components is on a decreasing trend. Still, EC in Sub-Saharan Africa with adequate financial structures can be already effectively integrated into development projects, potentially contributing to both electrification and access to clean cooking.

6. Conclusions

The research investigates whether and how energy communities are a viable alternative to utility-managed (off-grid) systems in providing access to energy to rural populations of Sub-Saharan Africa. Concretely, the research question focused on identifying the main factors that determine whether EC projects succeed or fail in this context. The findings show that energy communities in rural Sub-Saharan Africa offer a valid alternative to commercial mini-grids when their economic structure balances affordability with financial sustainability and revenue collection mechanisms are effective. In practical terms, consumption-based cost-reflective progressive tariffs are the most efficient design for EC in low-income areas with low population density, independently of the organizational model adopted. Technical structure and performance affect financial viability more than direct user behavior: despite the dissatisfaction expressed, most disconnections in Mpanta were due to post-replacement high costs rather than to insufficient quality of access to electricity. Therefore, effective economic management was found to be the most influential variable for long-term sustainability. The issue of whether community-based governance is able to successfully manage an energy system is a recurrent theme in EC literature: while the case study design limits generalization of findings, the research presented repeatable patterns for capacity building and phasing out external aid. Negative returns on CAPEX require impact-oriented investment, implying the involvement of international development actors - and uncertainty related to current disengagement trends. The design proposed in this work adapts development goals to this context by aiming at local empowerment. It does so by combining community management of development projects with investment in interconnected, mutually beneficial sectors of the local economy (e.g., energy and agriculture in the Ludewa District), drawing from practices already established in other policy areas (e.g., peacebuilding and climate risk preparedness).

In addition, the research contributes to both a clearer understanding of energy community functioning and to the relatively scarce literature on clean cooking policies in Sub-Saharan Africa. The first chapter described the evolution of EC models and theoretically reframed energy communities within the energy for development context by integrating Samarakoon's concept of 'bottom-up energy justice'. Moreover, it contributed to clarifying the technoeconomic challenges of integrating decentralized utilities in mature energy systems, suggesting that developing energy systems should be built in a way that favors bidirectional flows. While not constituting the analysis's core due to the scarce availability of project documents, the second chapter offered an overview of the state of the art in clean cooking advancement strategies, bridging the issue to the central topic of this work as energy communities and the decarbonization of household consumptions can be mutually beneficial from an economic perspective.

As noted throughout this work, future researchers are encouraged to collect economic and impact-related data from existing EC oriented to clean cooking, as well as to assess to what extent the productive use of energy impacts local economic development. Moreover, it would be useful to assess the resilience of decentralized energy systems to armed conflict, which currently interests about 1/3 of the African continent. Another aspect relevant to infrastructure investment in rural areas of developing countries is the metrics utilized to calculate capital risks - which is typically assessed using MDBs' internal credit rating systems and country risk classifications. Given that rural areas present specific risk features such as seasonality and small market size, it would be worthwhile to investigate whether integrating these factors into current credit assessment frameworks could improve the accuracy of risk assessment and ultimately facilitate capital mobilization.

Annex 1

All calculations were carried out in LaTeX through Overleaf.

Levelized Cost Of Energy (Mpanta):

$$\text{CAPEX} = 1{,}300{,}000 \text{ USD}, \quad \text{OPEX} = 43{,}343 \text{ USD/year}, \quad T = 9, \quad r = 0.10, \quad E_t = 68{,}544 \text{ kWh/year}$$

The numerator is:

$$1{,}300{,}000 + \sum_{t=1}^{9} \frac{43{,}343}{(1+0.10)^t} = 1{,}300{,}000 + 254{,}981.5 \approx 1{,}554{,}981.5$$

The denominator is:

$$\sum_{t=1}^{9} \frac{68{,}544}{(1+0.10)^t} = 389{,}288.6 \text{ kWh}$$

Thus:

$$\text{LCOE} = \frac{1{,}554{,}981.5}{389{,}288.6} \approx 3.99 \text{ USD/kWh.}$$

Levelized Cost Of Energy (Ludewa):

$$\text{CAPEX} = 4{,}031{,}326 \text{ USD}, \quad \text{OPEX} = 65{,}952 \text{ USD/year}, \quad \text{T} = 50, \quad \text{r} = 0.10, \quad \text{E}_t = 1,005,210 \text{ kWh/year}$$

The present value of OPEX is:

$$\sum_{t=1}^{50} \frac{65,952}{(1+0.10)^t} = 726,978.6 \text{ USD}$$

So the numerator becomes:

$$4,031,326 + 726,978.6 = 4,758,304.6 \text{ USD}$$

The present value of energy output is:

$$\sum_{t=1}^{50} \frac{1,005,210}{(1+0.10)^t} = 9,883,386.2 \text{ kWh}$$

Thus, the LCOE is:

$$\text{LCOE} = \frac{4,758,304.6}{9,883,386.2} \approx 0.48 \text{ USD/kWh.}$$

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