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Evaluation methodology and selection of Best Practices for business and delivery models of mini grid methodologies

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Summary

The report was developed as part of the research activities of the Sustainable Energy Transition and Digitalization of Smart Mini-Grids for Africa (SETADiSMA) work package of the LEAP-RE project. SETADiSMA aims to tackle the African mini-grid sector, addressing technological and energy planning challenges, digitalization research and development and related capacity building. The work focuses on case studies in Kenya and Rwanda. This report is part of SETADiSMA?s Task 13.3 - Business Models and Socio-Economic Contexts, constitutes deliverable D13.6 - Evaluation methodology and selection of best practices for business and delivery models of mini-grid. This task aims to propose appropriate business, delivery, and socio-economic models for local development evaluating and comparing available data for mini-grid systems in off-grid areas. The task consists of following Actions: 1. Evaluation framework development to analyze the available business and delivery models; 2. Case studies evaluation, applying the evaluation framework through the combination of the four dimensions (synthetic evaluation); 3. Productive uses support through energy access and connectivity for new local businesses and the access to a global market, supporting the whole community and increasing its livelihood. Mini-grids, despite their benefits, still encounter many hurdles that need to be conquered. Analyzing real-world cases helps recognize areas for improvement in the mini-grid sector. This assessment provides holistic evaluation criteria and techniques that align with the Sustainable Development Goals (SDG) and widely applicable business and socio-economic metrics. The study involves a general review of available business models and the classification of models employed in the case studies. Additionally, the technical parameters of each case are examined, and the socio-techno-economic impacts that different approaches have on communities is also assessed. To complete the evaluation, the significance, function, and involvement of stakeholders are analyzed and mapped out in two countries under study; Kenya and Rwanda, specifically within the mini-grid projects. Based on the evaluation results, recommendations and examples of actions that foster sustainable development and ensure equitable access to electricity are presented.

Approval

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Evaluation methodology and selection of best practices for business and delivery models of mini-grid

SETADiSMA

Deliverable D13.6

This deliverable will report the results of evaluation framework development, analysis, and selection of the best business and delivery models for mini-grid. This is the first report of Task 13.3.

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Acronyms

ABC	Anchor-Business Community
BBFMO	Design-build-finance-maintain-operate
BMS	Battery management system
BOT	Build-operate-transfer
B2B	Business-to-business
B2B2C	Business-to-business-to-consumer
B2C	Business-to-consumer
CAPEX	Capital expenditure
DB	Design contract
DBFM	Design-build-finance-maintain
DBOM	Design-build-operate-maintain
DBOT	Design-build-operate-transfer
DCMF	Design-construct-manage-finance
DiD	Difference-in-difference
EPC	Engineer-procure-construct
ESCO	Energy service company
FI	Financial Institution
HMI	Human machine interface
IV	Instrumental variable
LCOE	Levelized cost of energy
MFI	Micro financial institution
M&E	Monitoring and evaluation
NGO	Non-governmental organisations
OEM	Original Equipment Manufacturer
OPEX	Operating expenditure
PAYG	Pay as you go
PPP	Public-private-partnership
PSM	Propensity score matching
PU	Productive uses
PV	Photo-voltaic
P2X	Power-to-X
RDC	Randomized control trial
RDD	Regression discontinuity design
SCADA	Supervisory control and data acquisition
SDG	Sustainable development goals
UM	Utility model

1. Introduction

Decentralized renewable energy solutions, such as mini-grids and micro-grids hold immense potential for expanding electricity access in rural areas of developing regions. Recently, mini-grids have gained recognition as an essential aspect of rural energy infrastructure development in Africa, providing a solution for delivering energy services to regions where grid extension is not economically viable[1],[2].

Despite their numerous advantages, mini-grids face technical and financial obstacles that need to be overcome. To address these challenges, mini-grid developers need to perform a comprehensive evaluation of their current operations, pinpointing potential issues and devising strategies to address them. These include a thorough evaluation of all aspects of mini-grid development, including business operations, socio-economic activities, and stakeholder involvement, which all are crucial for long-term success and positive socio-economic impact. This process helps to identify areas for improvement, increase profitability, and highlight the strengths and weaknesses of mini-grid sector practices. It also provides opportunities for new investment and business expansion [3].

This deliverable offers evaluation criteria and methods that are aligned with existing development goals, such as the Sustainable Development Goals (SDG), as well as widely applicable business and socio-economic evaluation metrics. It is important to note, however, that the impact of energy services, particularly in terms of socio-economic effects, may have indirect and complicated outcomes that may take a longer time to be realized, making their measurement challenging. Therefore, the report emphasizes evaluation methods that are easily digestible and consistent with existing research studies, to ensure meaningful interpretation of results.

The framework is based on extensive research and existing literature, and comprises four key dimensions: business model, technology, social, and stakeholders. To demonstrate its practical applicability, the framework has been tested and applied in case studies in Kenya and Rwanda, providing valuable insights and lessons learned for the mini-grid sector.

The document is divided into two parts. The first is related to Task 13.1; Action 1: Evaluation framework development to analyse the available business and delivery models – and provides the evaluation framework for each dimension. The second is related to Task 13.3 Action 2: Case studies evaluation, applying the evaluation framework through the combination of the four dimensions (synthetic evaluation) – and accordingly applies the evaluation framework to the case studies. Task 13.3. Action 3: Productive uses support through energy access and connectivity for new local business and the access to a global market, supporting the whole community and increasing its livelihood – is analysed and addressed in Action 1 and Action 2.

2. Maximizing the potential of mini-grid businesses: factors influencing success and impact

Developing and operating a mini-grid project must consider various factors, including customers, technical requirements, financial considerations, ownership structures, and operational roles. This is particularly challenging in rural areas of Africa, where the socio-economic situation is complex and presents unique challenges for mini-grid electrification compared to well-developed urban infrastructure [4].

From a technical perspective, mini-grids must be able to provide power in different environmental conditions. However, factors such as the intermittency of solar power, weather conditions, and time of day can affect the supply, especially during peak hours. To manage these challenges, energy-efficient technologies such as power-saving appliances, storage technologies, power trackers, and smart meters can be used. It is also important to manage demand-side by implementing demand response actions to reduce peak hour demands.

There are now numerous financial and operation vehicles available to support the development of mini-grids, which can enhance their viability. A viable mini-grid project requires financial sustainability, which includes cost management, pricing, recurring payments, cash flow generation, energy pricing mechanisms, revenue capture, and loan repayment. Careful consideration and analysis are required to select the optimal financial vehicle for different customer groups.

In the following subsection of the deliverable, we provide the theoretical aspects of mini-grid development in relation to business and delivery models, and socio-economic and techno-economic impacts.

2.1 The role of business models for mini-grid development

A business model outlines the way an organization create, deliver, and capture value [5]–[7]. In the context of mini-grid ecosystems, the created and delivered value would be the energy service, that is, the generation and distribution of electricity to different customer groups and the proactive utilization of energy services for economic purposes. The captured value would be the revenue generated from the energy service, which would benefit the developer, subsidiary facilitators, and local community. It is important that the mini-grid business model is designed to ensure financial viability and that the energy services provided are accessible and affordable to the local community.

The financial viability of a mini-grid project requires consideration of both technical and commercial aspects. Technical viability depends on factors such as operation, components, and performance, while commercial viability is determined by revenue, expenses, and profits. Besides, it is crucial to develop customized solutions to address the unique challenges presented by the region's varied socio-economic environment, by taking into consideration various elements of the electrification process, including ownership, financial aspects, technical and operational considerations, as well as promoting pro-active energy usage through income generating [3], [8]–[10].

Conventionally, the value network for off-grid systems in rural areas was cantered around developers, which included community cooperatives, government energy utilities, private investors, public-private partnerships, and non-governmental organizations (NGOs). These entities were responsible for obtaining funding and technology, managing relationships with stakeholders, and directly connecting with off-grid users. However, the value network has expanded, and new players are emerging to create new value. These facilitators, such as original equipment manufacturers, technical service providers, energy storage system suppliers, and financiers, have a business-to-business (B2B) relationship with the developer and a business-to-business-to-consumer (B2B2C) relationship with both the developer and the customer. As a result, developers are becoming orchestrators, focusing on their core competencies in the value chain while outsourcing and actively coordinating other segments of the value chain [4]. Figure 1 represents description of the value network of a mini-grid.

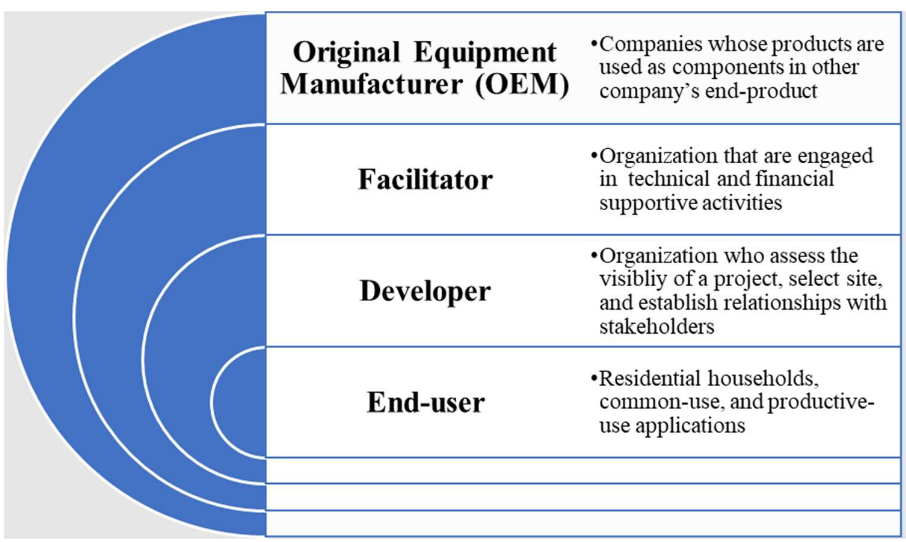

Figure 1: Value network of a mini-grid.

Hence, the role of the business model in a mini-grid project can vary. It may be directly responsible for delivering the energy system or provide supportive services to improve mini-grid reliability. For developers who are responsible for the whole project, the business model encompasses the operational and financial aspects of the development process [11]. This includes the following elements:

- Government bodies or international organizations provide subsidies or grants as financial aid to cover the initial installation and operational costs of mini-grids.
- Affordable tariff structures that are tailored to meet the specific needs of the local community, including options such as tiered pricing and pay-as-you-go (PAYG) models are implemented.
- Local businesses and organizations are collaborated with to offer maintenance and repair services.
- A micro-financing system is introduced, which enables customers to pay for services over an extended period.
- A metering and billing system is implemented to ensure that customers pay only for the energy they use.
- A customer service and support program is in place to ensure customer satisfaction.
- A monitoring and evaluation system is used to ensure that the mini-grid operates efficiently and effectively.
- A community engagement system is established to guarantee that the local community is included in the planning and operation of the mini-grid.

For the subsidiary facilitators, on the other hand, the business model patterns should align with the role of supportive activities in the mini-gird value network. These supportive activities can be through financial services, hardware and software supply, operation and maintenance activities, etc.

2.1.1 Existing business model patterns

Business model patterns (archetypes) are mechanics, themes and strategies used to define business model building blocks. They are used by developers and facilitators to create and deliver value in the mini-grid value network [12], [13]. In Table 1, some of the business model patterns that are found in literature are presented.

Table 1: Business model archetypes.

Business model pattern	Description of the model	Specific business model area	Reference
Appliance financing	To stimulate electricity demand in rural areas, the provision of appliances with credit will be offered.	Financial viability	[14], [15]
Revenue sharing	The participation of rural communities will be incentivized and maximized by sharing the total generated income with stakeholders.	Financial viability	[16]
Anchor-Business-Community (ABC) Model	By prioritizing anchor customers followed by businesses and community, the risk of uncertain power demand will be reduced.	Financial viability	[17]
Integrated developer	The roles of off-grid developers will be expanded to include productive-use applications, promoting communal economic activities.	Value proposition	[18]
KeyMaker	Mini-grid power-based rural manufacturers will be included in the value chain of product trading businesses.	Value proposition	[19]
FusionGrid (Energy-telecom-nexus)	Communities without access to mobile broadband coverage and electricity will be provided with integrated power, telecom, and digital services using mini-grids and base stations.	Value proposition development	[20]–[22]
Energy-Food-Nexus	Agricultural cooperatives will be the central load mini-grid, and excess power will complement household loads.	Value proposition development	[23], [24]
Split asset	To reduce the capital cost burden of developers, financing of generation and distribution assets will be divided between the developer, government, and community.	Infrastructure	[25]
Pay-as-you-go	Enabling users to pay for the electricity they use when they need it	Payment method	[26]
Pay-as-you-store (chill) / Chilling-as a-service	Enabling agriculture producers in the cold-value chain to pay for using cold storages when necessary	Payment method	[27]

2.1.2 Inclusive business models for mini-grids

The core idea behind an inclusive business model is the involvement of low-income communities in a company's value chain, enabling them to contribute and benefit from the business. In contrast to a traditional business model that prioritizes maximizing profits for the company and its shareholders, an inclusive business model aims to provide economic opportunities for marginalized or low-income individuals by involving them in the value creation process and enabling them to capture a portion of the organization's benefits, rather than solely aiming to maximize profits for the company and its shareholders. These often involve rethinking traditional business strategies and designing innovative solutions to serve these under-served communities and markets. Inclusive business model should ensure that all members of the community have access to the benefits of the project or program, regardless of their socio-economic status, gender, or other factors [28], [29].

In the context of mini-grid development, an inclusive business strategy should create economic opportunities, promote local ownership and sustainability, and ensure that the benefits of electrification reach the most marginalized communities. These imply the embodiment of inclusivity in the building blocks of the mini-grid business model, that is, in the community involvement in value creation and capturing system. The value creation and delivery system of a mini-grid refers to the processes and partnerships that generate and deliver value. This can include utilizing energy services to boost productivity within communities through partnerships with other organizations. The value capture system refers to the economic benefits obtained through the mini-grid's business model, which involves the participation of developers, users, and entrepreneurs in various productive activities.

There are several activities that can involve communities in mini-grid value creation. One way to increase community involvement in mini-grid projects is by engaging with them early in the process to ensure that their needs and priorities are aligned with the project. Another approach is to build the capacity of the community to operate and maintain the system by providing training and skills development opportunities. Job creation can also be achieved by offering employment opportunities for community members through installation, maintenance, and operation of the mini-grid. Mini-grid systems can also be used to provide social services to the community, such as lighting for schools and healthcare facilities. Educating the community about the most efficient and effective ways to use the power generated by the mini-grid can help to reduce energy waste and maximize value.

To capture the value of mini-grid projects, several activities can involve the community. One approach is to develop a revenue-sharing mechanism to ensure that the benefits of the mini-grid are shared with the community, such as through community-owned businesses. Facilitating community ownership of the mini-grid can also provide the community with an ongoing source of income. Access to microfinance can allow community members to start and grow businesses that benefit from the mini-grid. Moreover, offering value-added services that utilize the power generated by the Mini-grid, such as refrigeration or water pumping, can create economic opportunities for the community.

By involving the community in these ways, mini-grid value creating and capture can be enhanced, ensuring that the benefits of the system are shared with those who need it the most.

2.1.3 Mini-grid project delivery models

In the realm of mini-grids project development, a delivery model refers to the approach by which mini-grids are installed and operated. This model answers several relevant questions, such as who owns, delivers, and installs the assets, and who is responsible for their replacement or extension investments. The ownership and operation of mini-grids can be undertaken by the private sector or can be based on a partnership with other entities [4], [25]. Several project delivery models exist for mini-grid installations, including the following:

1) **Utility model (UM) or design-contract (DB) or engineer-procure-construct (EPC) Model**: A private company is contracted by a government or national utility to supply and install mini-grids, which are subsequently operated by the utility.
2) **Design-build-operate-maintain (DBOM) or energy service company (ESCO)**: The government finances and owns mini-grid assets, which are installed and/or operated by a private company or cooperative. Tariffs charged to electricity customers, along with optional government operating expenditure (OPEX) grants, cover the private operator's costs, including profit.
3) **Public-private-partnership model (PPP):** there are two common models:
    a) ***Split Asset***: The government finances and owns the distribution network, while a private sector or cooperative operator finances, builds, and owns the generation assets and operates the entire mini-grid. A variant of this model involves a grant to partially finance the generation assets, known as the "hybrid split asset/grant" model.
    b) ***Management model***: Government entity will plan, fund, and build a mini-grid. A private operator will then take over and be responsible for managing, maintaining, and operating the mini-grid, as well as collecting revenue from customers. There are various contractual options available for the operator to assume responsibility, including authorization arrangements, contracted operation, leasing contracts, and full ownership transfer.
4) **Build-own-operate or Private with Capital Expenditure (CAPEX) Grant**: A private sector or cooperative mini-grid operator finances, installs, owns, and operates the mini-grid assets and receives a CAPEX grant from the government.

5) **Cooperative model**: The cooperative model for mini-grids involves community ownership and the primary goal is to provide electricity access to the cooperative. The procurement and installation of the mini-grid may be outsourced to a third party, such as a community member, NGO or development partner.

These models can be implemented in different versions and combinations such as build-operate-transfer (BOT), design-build-operate-transfer (DBOT), design-build-finance-maintain (DBFM), design-construct-manage-finance (DCMF), and design-build-finance-maintain-operate (DBFMO).

The involvement of the private sector in mini-grid delivery models can mobilize financial resources and increase the efficiency and quality of services provided. To attract private sector investment, it is essential to design an overall package for risk and return that is appealing to private companies. This package may include competition and regulation to minimize costs and subsidies, capital grants and/or subsidies to finance the capital costs of building and operating mini-grids and ensure an affordable tariff level for end-users and financially viable for mini-grid operators. To maximize private sector investment and the rate of connections, operational and investment risks need to be mitigated[25] .

The degree of government control over key aspects of electricity supply, operational and capital subsidies required for the successful implementation of these models, and the tariff levels to be charged to customers are the major factors distinguishing mini-grid delivery models. Government contributions to the financing of mini-grids generally decrease as the private sector contribution increases. Higher CAPEX subsidies allow for lower tariffs. Government resources allocated to the development of mini-grids are consistent with the level of control that a government wishes to exert over the operation of the mini-grid. For delivery models with higher degrees of government control, the public sector needs to invest more resources in mini-grids, including potential cross-subsidization of electricity usage of rural customers if a national uniform tariff is to be charged [25].

Figure 2 describes the corresponding dependencies between public funding mechanisms for CAPEX and OPEX subsidies and the resulting tariff levels based on the degree of government control.

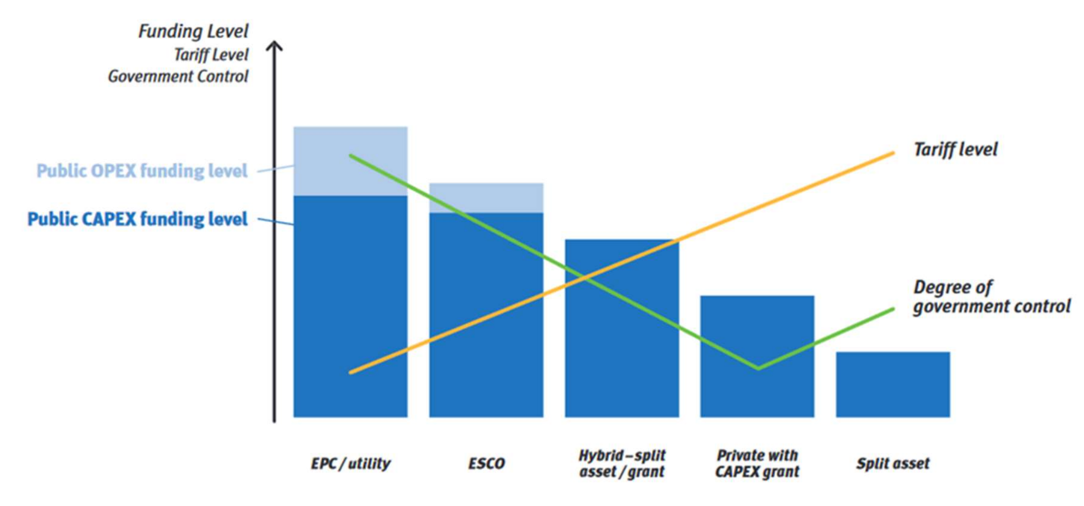

Figure 2: The relation between delivery models tariffs and governmental control.

2.1.4 Productive uses of energy

It has been evidenced that productive uses of energy lead to improvement in rural livelihood to varying extents. Furthermore, different studies have shown that levelized cost of energy (LCOE) can be lowered when the productive uses are powered by the mini-grid. While it is essential that end-users find suitable productive uses (PU) once the electricity is available, it can also be challenging for the users that are used to operating and establishing economic activities without electricity utilization. Therefore, investors and project implementers providing electricity access in rural areas may consider expanding their delivery models in order to guide the community on electricity use and PU engagement. The profitability of the mini-grid depends on a wide range of factors, which include average consumption and revenue per user. Stimulating demand by incentivizing the adoption of energy-using appliances and encouraging end-users to start new business contributes to improving mini-grid's commercial viability (especially true for solar mini-grids). PU has, therefore, twofold impacts, on one side, improvement of the economic well-being of rural customers, which, in turn, allows them to afford higher energy consumption. And on the other side, improvement of project viability, as the higher energy demand favours economies of scale. There is an increasing interest in initiatives that integrate the nexus of energy, agriculture, and water to promote PU of energy. Innovation in end-use appliances has unlocked applications for PU. The most mature market is irrigation, followed by cooling, refrigeration, and solar agro-processing. Milling, welding, and tailoring are also included in demand stimulation activities for MG in Rwanda [30].

Innovative business models, mainly in private sector, go beyond delivering only energy, in addition to energy supply other services are offered, thus apply an integrated business model. There are several examples of private mini-grid developers adopting a more holistic approach to rural electrification by integrating energy services along the rural value chain, especially in the agriculture sector. For analysis purposes, we differentiate the business models based on services offered regarding productive uses as follows: Energy Supply, Energy Supply Plus, Integrated developer, KeyMaker model. Figure 3 illustrates the main characteristics of these models. In the Energy Supply Plus, in addition to energy provision, other energy-related products and services are offered, such as provision of electrical appliances or micro-credit services. Additional complementary activities can include support for local entrepreneurs or awareness campaigns for target communities. In some cases, the integrated approach becomes part of the value proposition, which is the case of the Integrated developer, in which the developer owns production plants that utilize mini-grid electricity as a production input to add economic value to goods or services. The companies increase the revenue from electricity-enabled products, goods, or services, increasing the kWh value [31]. This commercial revenue can be used to cross-subsidize electricity consumption. An Integrated developer can target existing and create new rural supply chains, thereby contributing to economic diversification, job creation and income generation. In the KeyMaker model in addition to establishing a local agro-processing project, there is a clear focus on creating an end-market for the local farmers beyond the local community borders as means to reach profitability [32]. The considerable potential of the integrated models comes at the cost of increased complexity in terms of products offered, revenue model, and required networks. In these cases, mini-grids are becoming an integral part of rural development and have the ability to establish new value chains outside of the services and sales provided to rural customers. This approach is defined as "fourth generation mini-grids" by UNIDO [33]; it incorporates the latest technologies of the third generation, such as smart meters and remote monitoring systems, with rural industrialization strategies.

Although the number of cases is still relatively small, new solutions and business models still need to be tested. An exemplary organization testing new business approaches is Crossboundary Innovation Lab, which implements pilot projects with existing mini-grid developers and shares outcomes with donors and developers. In East Africa, appliance financing and internet connection are examples of services being tested. INENSUS GmbH is also testing and validating new business concepts through MG joint ventures, an example of a business concept developed by INENSUS is the KeyMaker model [34].

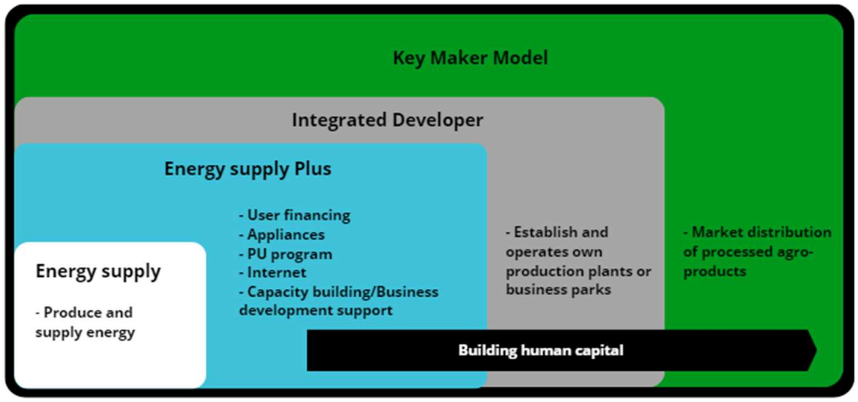

Figure 3: Classification business models based on value added services.

2.2 Socio-Economic impact

2.2.1 Common outcomes measured

Energy access projects aim to improve the socioeconomic welfare of its users (i.e., increased incomes, better education, improved health). In this sense, energy can be considered an intermediate good to enable development instead of a "final service." Compared to other smaller systems, a mini-grid can accommodate higher tiers and supply energy to commercial loads and productive uses, allowing the community for productive and sustainable growth and alleviation of poverty. The availability of electricity affects a range of economic, social, and environmental outcomes. However, the materialization of expected outcomes varies over time and among countries and sometimes involves lengthy causal chains. Impact evaluation help test the intervention's effectiveness. It is essential both for energy consumers and energy suppliers, and it is highly relevant to inform the design of future programs.

Figure 4 shows the most common outcomes measured, which are education, household income, employment, and energy use [35]. However, among the existing impact evaluation studies, there is a high heterogeneity of results, and inconsistency among studies is often found. There is a need for more research to understand under which conditions the effects might be more significant. Furthermore, few studies evaluate the mechanisms by which those changes occur; additional impact evaluations are needed to understand the intermediate impact channels and how to enhance desired outcomes.

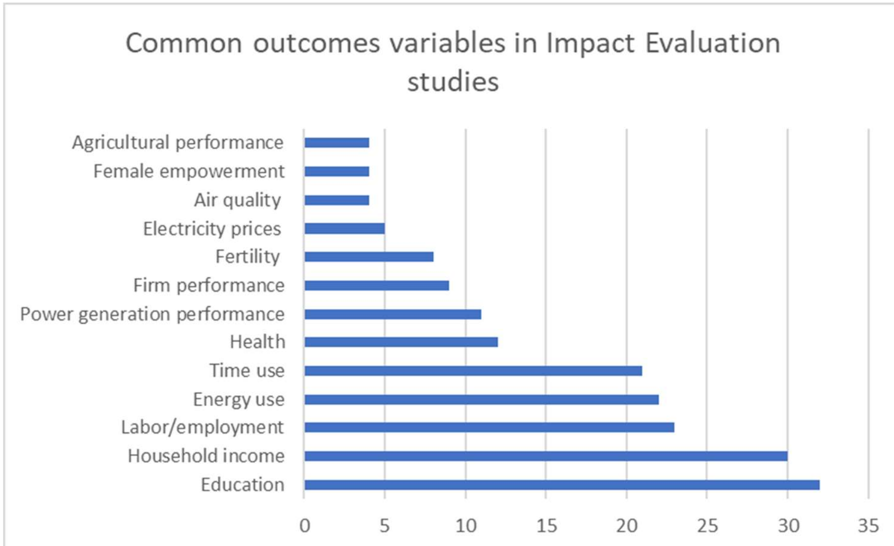

Figure 4: Most common outcome variable in impact evaluation studies.

2.2.2 Quantitative evaluation methods

Several methods can be used to evaluate the impact of an energy sector intervention. We can distinguish two main approaches: experimental design and non-experimental design.

Randomized experimental design is considered the best available approach, as it is designed to minimize bias and provide a high level of evidence for a cause-and-effect relationship. In a randomized control trial (RCT), the participants are randomly assigned either to the treatment or control group. It can be distinguished between simple RCT and cluster RCT. In cluster RCT, participants are grouped based on a common characteristic (geographical location, school, organization), and after the clusters are randomly assigned to the intervention or control group. Cluster randomize control is good when the intervention tested has happened at a community or organizational level (or when individual randomization is not practical). Cluster randomize control has some advantages, such as reducing the risk of spillovers between the treated and control group. However, it also has increased complexity and the need for larger samples.

Due to the complexity of the experimental and randomizing approach, most impact evaluation studies in the energy sector apply non-experimental design (or regression-based techniques). The most common method used is difference-in-difference (DiD), it involves calculating the difference between the pre- and post-intervention trends in a group that received the intervention and those in a comparison group. One potential drawback of using this method is that it relies on the assumption that the trend in the comparison group is the same as in the treated group in the absence of the intervention. However, this assumption may not always be valid, particularly when multiple programs are implemented in the same areas simultaneously. To address this issue, incorporating covariates into a fixed effects specification or combining the DiD method with matching techniques can help to mitigate the assumption.

Table 2 summarises the most commonly used designs that can be employed to evaluate impacts of an energy intervention such as a mini-grid project in a specific community [35].

Table 2: Quantitative methods for impact evaluation.

Experimental Designs	
Randomized Control Trial (RCT)	In an RCT, the participants are randomly assigned either to the treatment or control group. Randomization helps ensure that any difference between groups is due to chance and not other factors. Simple RCT is useful when spillovers among groups are not substantial.
Encouragement design	Experiments that use some incentives to participants to create a random variation in the use of an intervention. This can be useful when the intervention itself can not be randomized. Several studies have used this design based on electricity connection costs. It is typically used in simple randomized control but can also be assigned to a cluster randomization design.
Nonexperimental design	
Difference-in-Differences (DiD)	It is the most common technic. It compares the changes in outcomes over time between a treatment group that received the intervention and a control group that did not. It requires at least data from two time periods and two groups with similar characteristics.
Instrumental variable (IV)	Involves using a predictor variable correlated to the energy intervention but does not influence the outcomes of interest (dependent variable). It is useful when there is a risk of endogeneity (i.e., when unmeasured variables affect both the independent and dependent variables). It can be challenging to find an appropriate instrument; program placement rules can be considered a possible instrumental variable.
Propensity Score matching (PSM)	Method based on matching treatment participants with similar participants in a control group, creating two comparable groups that are similar in all relevant characteristics. This method has a higher risk of selection bias; it can also be combined with DiD to reduce the bias risk.
Regression discontinuity design (RDD)	It is most appropriate when there is a clear cutoff point determining who receives the treatment or intervention (i.e., if there is a particular town size threshold for electrification or an income threshold for a connection subsidy).
Synthetic controls	It involves utilizing a long time series of pre-intervention data to train a weighting algorithm that identifies optimal weights for a comparison pool of observations. A synthetic control unit approximating the treated units' outcome trends is produced. By comparing the actual outcome of the treated unit with the predicted outcome of the synthetic control unit, the causal effect of the intervention can be estimated.

2.3Techno-Economic impact

The deployment of mini-grids can have a significant technological impact on the region, enabling the use of renewable energy sources such as solar and wind power. In addition, mini-grids can provide improved reliability and redundancy in the energy supply, increased energy access in areas where the national grid is not available or is unreliable, reduced transmission losses, and the potential for smart grid capabilities that can enable more efficient use of energy and lower costs.

In terms of economic impact, the deployment of mini-grids can have several benefits. For example, it can create jobs in the manufacturing, installation, deployment, operation and maintenance of the systems. Mini-grids can also provide energy at a lower cost than diesel generators or other traditional energy sources, reducing energy costs for households and businesses, and potentially leading to increased economic activity. Moreover, the access to reliable and affordable energy can enable businesses to operate more efficiently and expand their operations, leading to increased economic growth and development in the region. Finally, the use of renewable energy sources can reduce the region's dependence on fossil fuels and greenhouse gas emissions, and thus providing environmental benefits and mitigating the effects of climate change.

2.3.1 Solar based mini-grids

Solar-based mini-grids have become increasingly popular for rural electrification. The rapid decline in solar panel costs, coupled with improvements in battery energy storage technology, has made it possible to build solar mini-grids that can provide reliable and affordable electricity to remote communities [36]. This technology has a number of advantages over traditional diesel generators, which have historically been the most common source of off-grid electricity.

Photovoltaic (PV) panels, which convert sunlight into electricity, are a primary component of solar-based mini-grids. The usage of panels, along with battery energy storage systems, allows for energy to be stored and distributed, even when renewable energy sources are not available.

Battery energy storage systems have a significant impact on the reliability and stability of mini-grids. With energy storage systems, energy can be stored during periods of excess production and released when demand is high, ensuring a constant supply of energy to the community [37].

2.3.2 Wind based mini-grids

Another technology that has been increasingly used for mini-grid deployment is wind power. Wind-based mini-grids consist of small wind turbines that generate electricity to supply energy to a local community. Wind power is a clean and renewable energy source that produces no greenhouse gas emissions, unlike traditional fossil fuel generators. Additionally, wind turbines are becoming more affordable, and as a result, are a viable option for remote communities that would otherwise rely on diesel generators.

One of the advantages of wind-based mini-grids is their ability to complement solar power. Wind power is often most abundant during the rainy season when solar panels produce less electricity, and vice versa. This means that combining wind and solar technologies in a mini-grid can provide a more consistent and reliable source of electricity throughout the year [38], [39].

However, there are some limitations to wind power that must be considered. Firstly, wind turbines require a certain amount of wind to generate electricity, and therefore, may not be suitable for all areas. Secondly, wind turbines can be noisy and may cause disturbance to local communities. Finally, wind turbines require regular maintenance to ensure their proper functioning, which can be a challenge in remote and hard-to-reach areas [40].

2.3.3 Hydro based mini-grids

Hydro-powered mini-grids are typically installed in areas with significant water resources, such as rivers or streams. The mini-grid is designed to capture the energy from the water as it flows through the system, which is then converted into electrical power. Hydro-powered mini-grids are particularly effective in areas with high rainfall or seasonal changes in water flow.

One of the advantages of hydro-powered mini-grids is that they provide a consistent and reliable source of energy, regardless of weather conditions. In contrast, solar and wind-powered mini-grids can experience fluctuations in energy output depending on weather conditions. This makes hydro-powered mini-grids particularly attractive in areas with unpredictable weather patterns or in remote areas where access to fuel for generators is limited [41].

Hydro-powered mini-grids can also provide additional benefits to the local community beyond just electricity generation. For example, the construction of the mini-grid infrastructure may also provide opportunities for irrigation or water storage, which can be used to support local agriculture. In addition, the construction of mini-grids can also provide employment opportunities and stimulate local economic development.

Despite the advantages of hydro-powered mini-grids, there are also some challenges associated with their deployment. One of the main challenges is the need for significant capital investment to build the necessary infrastructure, which can be a barrier in areas with limited access to financing. Additionally, the construction of hydro-powered mini-grids may also have environmental impacts on local ecosystems and wildlife habitats, which need to be carefully considered and mitigated.

2.3.4 Power-to-X conversion and smart features

Power-to-X (P2X) conversion technologies may play an essential role in mini-grids in future. P2X conversion involves converting excess electricity into another form of energy that can be stored, such as hydrogen or methane. This excess energy can then be used for heat or transportation, making mini-grids more versatile and sustainable [42], [43].

In addition to these aforementioned technologies, smart meters and monitoring systems are also utilized in mini-grids. These technologies allow for the measurement, data gathering and analysis of energy consumption and production, enabling effective energy management and control. By monitoring energy usage, customers and communities can become more energy aware and energy efficient, reducing unnecessary energy usage and saving money on energy bills.

2.4 Stakeholders

The mini-grid sector operates in a complex ecosystem that involves multiple actors with different interests and influences on the projects. Stakeholders take different responsibilities in different stages of the mini-grid lifecycle. Although there is not yet a deep understanding of which are the most effective partnerships in a mini-grid project (based on the recent literature), there is a joint agreement regarding the strong influence that the partnership model plays on the outcomes of mini-grid project. Therefore, all the stakeholders involved in a project should be managed as players in a value chain.

Broadly speaking, we can differentiate between the public, private, and third sectors. In the public sector, governmental entities play an essential role in supporting rural electrification, supporting co-creation processes among different actors, and creating an enabling environment for private companies' operations through policy decisions, financing help, and support programs. Public utilities developed, funded, and operated the first mini-grid projects. After the electric sector liberalization, private entities have taken some of the previous public sector roles and responsibilities (to some extent), such as developing mini-grid projects. After the private sector entered the market, private developers have a growing importance in providing electricity access to rural customers. Private players can be divided into two main categories: developers and facilitators. Facilitators are companies that provide services to MG developers or users but do not take primary responsibility for the project. The third sector represents non-governmental organizations (NGOs) and community-based organizations. NGOs collaborate with mini-grid developers in specific stages of the value chain. They can provide different services both to developers and to users. In some cases, those organizations can also implement the projects by exploiting the governments' subsidies. Community-based organizations are entities composed of community members, for example, cooperatives or "village energy committees" in charge of the management of the energy system.

Table 3: Mini-grid stakeholders and roles.

Stakeholders	Role	Examples
Mini-grid developers and operators	Company or individual that develops and operates small-scale electricity systems, known as mini-grid	Private or public sector developer/operator
Mini-grid Hardware supplier	Enterprise which products are used as a component in the mini-grid project	Technology suppliers, IT technologies, communication systems
PU hardware provider*	An individual or enterprise that supplies end-users and service providers with tools, machines, appliances, equipment or any hardware that can be used for commercial, industrial, or even labor-saving purposes	Electrical appliances provider
Service Provider *	A contractor or operator that provides a service (such as electricity, farming services, transport etc.) which the end-user applies to add value to their product or service.	Energy service company, cold storage, milling
Mobile money integrator	Mobile money integrator to manage electricity and appliances payments	Mobile money enterprises
Commercial lender*	A bank or financial institution (FI) offering debt, usually either to end-users, cooperatives, hardware suppliers, or service providers for PU activity	Banks, FIs, micro financial institutions (MFIs)
Sponsor	A financier promoting the uptake of PU activity through free or (blended) concessional financing, usually either to end-users, cooperatives, hardware suppliers, service providers, or through a technical assistance programme	NGOs, impact investors, FIs, donor agencies
Products distributor*	Distributor for the processed agri-food products to reach the regional/national market	National or international distributor
Technical assistance provider	An actor promoting the mini-grid diffusion and uptake of PU activity through measures such as analysis, sensitization, training and coordination, or facilitating access to financial risk-mitigation instruments, generally financed by government or donors rather than end users	NGOs, government agencies, development agencies, FIs, research institutes
End-users	An individual, enterprise, public facility or cooperative that uses electricity. A cooperative is a group of actors, typically in agriculture, who collectively engage in mutual objectives, such as the improvement of production, processing or market linkage for their product.	Community citizens, cooperatives, enterprises or facilities
Governmental units	Public agencies in charge of promoting rural electrification projects. For example: define policies, rules and programs for advancing electricity access goals	Ministry of energy, regulators, public agency promoting rural electrification, national grid generation and distribution utility

* Emerging trend

3. Evaluation framework development

There are two distinct concepts in project assessment related studies: Evaluation, and Monitoring & Evaluation (M&E). Evaluation involves analysing the performance or results of a project or program to gauge its impact and effectiveness. This assessment is typically done at the conclusion of the project or program and aims to determine if the goals and objectives were met and if the benefits outweigh the costs. Evaluation can also identify areas for improvement and highlight lessons learned. M&E, on the other hand, is an ongoing process throughout the life cycle of a project or program. It entails constant monitoring of the project's performance and progress, as well as regular evaluations of its outcomes. The purpose of monitoring & evaluation is to maintain the project's progress and ensure it remains on track, stays within budget, and achieves its goals and objectives. Stakeholders are also kept informed of the project's status through regular updates, allowing them to make informed decisions and make necessary changes [44].

In this deliverable, it's crucial to emphasize that our primary emphasis is on creating an evaluation framework rather than an M&E framework. This is because our main objective is to assess the effectiveness and impact of a mini-grid project that has been completed and operational.

Designing indicators is essential to develop an evaluation framework. An indicator refers to a clear and quantifiable measure of success or progress. It reflects a noticeable and verifiable change or improvement that indicates the degree of advancement towards the desired result or outcome in your strategy or action plan. These indicators can serve as specific markers or metrics to assess the impact and effectiveness of a project, program, or intervention. Additionally, they can be used to monitor progress and determine the level of achievement. The evaluation metrics may differ across the monitoring and evaluation phases, including inputs, processes, impacts, outcomes, and outputs of a project or program.

3.1 Matrix development for mini-grid characterization

This section of the deliverable presents a comprehensive framework for evaluating a mini-grid project, encompassing four key areas: economics, social, technology, and organization. These dimensions can be analysed through various evaluation methods in literature, as shown in Figure 5. By using this framework, we can examine different cases, identify their strengths and weaknesses, and extract the most effective practices. The sections below introduce the indicators selected to evaluate the different projects.

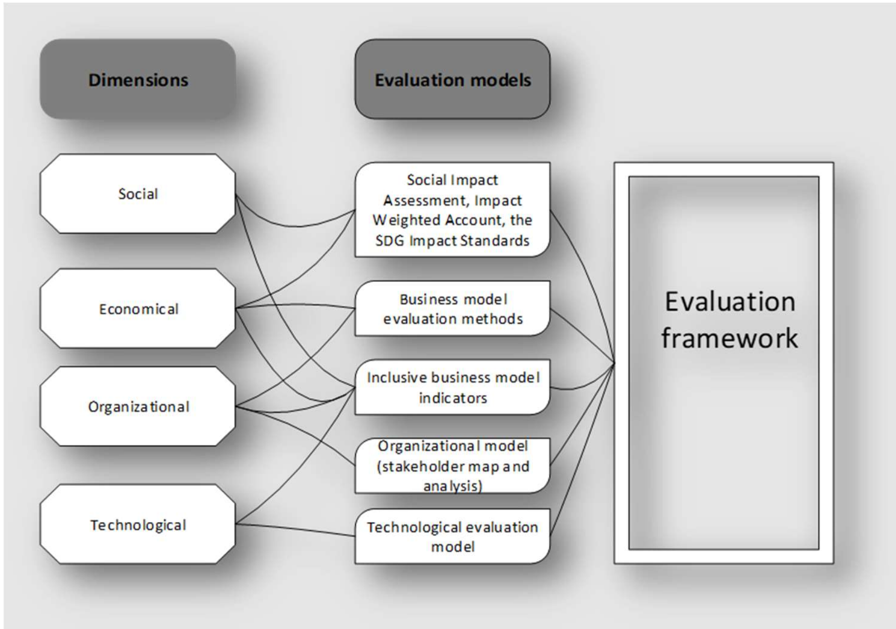

Figure 5: Evaluation framework design.

The evaluation framework can be found in Tables 4-7. Our proposal for evaluation indicators is related to elements that assess the business ecosystem, socio-economic factors, techno-economic considerations, and stakeholder analysis. These evaluation indicators have been adapted from various sources, including scientific literature from business model design (e.g. [3], [5], [7]) and evaluation related studies (e.g. [45]–[50]), rural electrification monitoring and evaluation guidelines and case studies (e.g. [51], [52]), socio-economic indicators (e.g. [35], [53], [54]), technical analysis of mini-grids(e.g. [55]), and stakeholder analysis (e.g. [56]).

Table 4: Business model evaluation indicators.

Indicator	Description	Recipient stakeholder
Quality of energy service	Ability to provide affordable, reliable, and safe energy services.	Developer/ facilitator
Customer segmentation	Customer segmentation based on energy need	Developer
Pricing mechanism	Pricing mechanism for billing (consumption-based, time-of-use, fixed-rate, etc.)	Developer
Payment channels	Mode of payment (postpaid, pre-paid) and payment mechanisms (mobile money, cash, voucher, etc.)	Developer/ facilitator
Community engagement	Participation in community's welfare	Developer
Financial status	Balancing revenue streams and cost to keep cash flow and recover the initial investment	Developer
Partnership	Establishing partners to enhance value creation and capturing process	Developer/ facilitator
Inclusivity	Providing economic opportunities to local community through the value creation process	Developer
Customer service and support	Providing assistance and support for users	Developer/ facilitator

Table 5: Socio-economic evaluation indicators.

Indicator	Description	Recipient stakeholder
Household and firms income generation	Ability to increase of household income or reduction of energy expenses	Users
Employment	New jobs created	Users
Education	Increased study time or years of schooling	Users
Access to information	Ability to access and make use of any information system resource (I.e., TV, radio, ICT)	Users
Health	Ability to obtain improved healthcare services, improvement of air quality withing the buildings and improvement of sanitation services	Users
Female empowerment	Greater economic independence and social participation	Users
Time-saving	Reduction of time spent at certain households tasks	Users
Firm performance/ productivity	Improvement of productive uses or increased productivity of firms	Users
Poverty gap	Decrease of poverty in the community	Users
Penetration of electrification	Distribution of poor beneficiaries and tier access among users	Users
Improvement of collective uses and security at village level	Electrification of public institutions (street lighting, schools, health centers)	Users

Table 6: Techno-economic evaluation indicators.

Indicator	Description	Recipient stakeholder
Renewable energy sources share	Utilization of PV panels/Wind generators or mini hydro generation as a power supply for mini-grids	Developer/Users
Battery energy storage systems	Presence of battery energy system, that brings a certain level of independence from surround weather conditions	Developer/Users
Smart meters and billing systems to accurately measure and bill customers for their energy usage	Users' consumption monitoring system, which simplifies tracking of electricity usage and provides secure and reliable way of data collection	Developer/ facilitator
Monitoring systems to ensure that the mini-grid is operating efficiently and effectively	Smart monitoring over system state and equipment conditions, ensures to follow system operation condition and apply predictive maintenance and remote support	Developer
ICT to allow customers to access the services provided by the mini-grid.	Utilization of digital services that became possible and available with ICT	Developer/Users
Automation systems to reduce the need for manual labor in the operation and maintenance of the mini-grid	Advanced control equipment allows to minimize manual system maintenance, consequently, decrease possibility of mistake and increase system reliability	Developer
Security systems to protect the mini-grid from theft and vandalism	Means of equipment protection from thief allows to keep system up and maintain system integrity	Developer/ Users
System flexibility	The ability of the system to meet changes at production and consumption over a certain time period	Developers
System scalability	The design feature of the system to be scaled up according to the increase of consumption or number of consumers	Developers
Reliability	The number of planned and unplanned electricity outages.	Developers

Table 7: Stakeholder evaluation.

Indicator	Description	Recipient stakeholder
Renewable energy sources share	Utilization of PV panels/Wind generators or mini hydro generation as a power supply for mini-grids	Developer/Users

4. Case studies

4.1 Descriptive analysis of mini-grid locations and context

4.1.1 Mini-grids in Kenya

Table 8 provides an overview of the mini-grid landscape on the different mini-grid projects in Kenya. They were commissioned between the year 2010-2019. The mini- grids have different ownership structures, including private and public ownership. Some of the mini-grids have been constructed as part of government parastatal initiatives, while others are owned by private entities. The mini-grids also vary in their generation capacity, ranging from 30 kW to 1200 kW, with different sources of energy generation such as hydro, solar, and diesel. The presence of storage systems also varies across the mini-grids, with some having lithium-ion or lead-acid batteries, or capacity banks. Additionally, the type of power system used for the distribution network also varies, with some mini-grids using a single-phase power system, while others use a three-phase power system. The mini-grids use different monitoring and data storage systems. Some use SCADA (Supervisory Control and Data Acquisition) and HMI (Human Machine Interface) systems, while others use smart meters or log sheets.

Table 8: Mini-grids in Kenya.

Country	Kenya								
Mini-grid index	MG-1	MG-2	MG-3	MG-4	MG-5	MG-6	MG-7	MG-8	MG-9
Year of construction	2014	2019	2016	2010	2018	2015	2019	2015	2015
Ownership status	Private	Private	Public	Public	Public	Private	Private	Public	Private
Government parastatal	None	None	MoE*	KPLC**	KPLC**	None	None	KPLC**	None
Generation capacity (kW)	1000	60	1150	800	120	50	60	1200	30
Generation source	Hydro	Solar	Diesel	Diesel	Solar (80) Diesel (40)	Solar	Solar	Diesel	Solar
Storage system	No	Yes	No	No	Yes	Yes	Yes	No	Yes
Type of storage system	-	Lithium-ion	-	-	Lead Acid	Capacity Banks	Lithium-ion	-	Lithiu m-ion
Capacity of the storage system (Ah)	-	144	-	-	3200	110	144	-	72
Power distribution system	Three phase	Three phase	Three phase	Three phase	Three phase	Three phase	Three phase	Single, three phase	Three phase
DN length (m)	3000	1000	39000	20000	3000	1000	1000	40000	1000
System monitoring and data storage	SCADA and HMI	Smart meters	Log sheet		Smart meter	BMS	Smart meters	Log sheet	Smart Meter

*Ministry of Energy (MoE), **Kenya Power and Lighting Corporation (KPLC)

4.1.2 Mini-grids in Rwanda

Table 9 presents data on mini-grids in Rwanda, specifically on MG-10 to MG-15, with most of them having been constructed between 2015 and 2022.The min-grids are privately owned, except for MG-13 which is owned by the government parastatal REREC. The generation capacities range from 1 kW to 50 kW, with sources including solar and hydro. Some mini-grids have lithium-ion battery storage systems, with capacities ranging from 8 kWh to 219 kWh. The type of power system used for the distribution network varies, with some mini-grids using single or three-phase systems, while others use DC. Besides, there are different types of monitoring and data storage systems, including digital meters, smart meters, and Excel data sheets.

Table 9: Mini-grids in Rwanda.

Country	Rwanda					
Mini-grid index	MG-10	MG-11	MG-12	MG-13	MG-14	MG-15
Year of construction	2019	2022	2022	2017	2015	2019
Ownership status	Private	Private	Private	Private	Private	Private
Government parastatal	None	None	None	None	REREC*	None
Generation capacity (kW)	32	50	11	1	30	38
Generation source	Solar	Solar	Hydro	Solar	Solar	Hydro
Storage system	Yes	Yes	No	Yes	No	No
Type of storage system	Lithium-ion	Lithium-ion	-	Lithium-ion	0	0
Capacity of the storage system (Ah)	219	50	-	8	0	0
Power distribution system	Single, three phase	Three phase	Three phase	DC Only	Three phase	Three phase
DN length (m)	3500	9000	2000	250	4000	4050
System monitoring and data storage	Digital meter	Excel	Excel data sheet	Smart meter		Excel and smart meter

*Rural Electrification and Renewable Energy Corporation (REREC)

4.1.3 Number of connections by customer type

Table 10 shows data on mini-grids located in Kenya and Rwanda, and the number of households, commercial and businesses, and industries that are connected to each mini-grid. Looking at the data, we can see that in Kenya, mini-grid MG-3 has the highest number of households connected (5500), followed by MG-8 (680) in Rwanda. The commercial and businesses category shows that MG-3 has the highest number of connections (800), followed by MG-4 (42) and MG-8 (40). Only one mini-grid in Kenya, MG-3, has an industry connection.

In Rwanda, the mini-grid with the highest number of households connected is MG-10 (1043), followed by MG-11(610) and MG-12 (300). For commercial and businesses, MG-12 has the highest number of connections (100), followed by MG-14 (60). Only one mini-grid in Rwanda (MG-11) has an industry connection.

Table 10: Number of connections by customer type in Kenya and Rwanda.

Country	**Kenya**								
Mini-grid	MG-1	MG-2	MG-3	MG-4	MG-5	MG-6	MG-7	MG-8	MG-9
Households	0	150	5500	570	69	-	150	680	250
Commercial and businesses	1	4	800	42	11	-	4	40	
Industries	0	0	2	0	0	-	0	0	0

Country	**Rwanda**					
Mini-grid	MG-10	MG-11	MG-12	MG-13	MG-14	MG-15
Households	1043	610	300	40	108	246
Commercial and businesses	10	10	100	20	60	18
Industries	0	1	0	0	0	0

4.2 Characterization of mini-grid projects on matrix

4.2.1 Business model evaluation for case studies

In this section, we analyse the case studies using the proposed business model framework.

4.2.1.1 Customer segmentation and anchor load identification

Customer segmentation refers to the process of dividing customers into different groups based on certain characteristics such as income level, location, occupation, and service application. This is a critical aspect of targeting and marketing different customer groups efficiently. By understanding the unique needs and preferences of each group, companies can tailor their products and services to meet those needs, which can help to increase customer satisfaction and loyalty.

According to a survey conducted on mini-grids in both countries, it was found that most mini-grids applied customer segmentation (see Figure 6). This indicates that these companies recognize the importance of understanding their customers and tailoring their offerings accordingly.

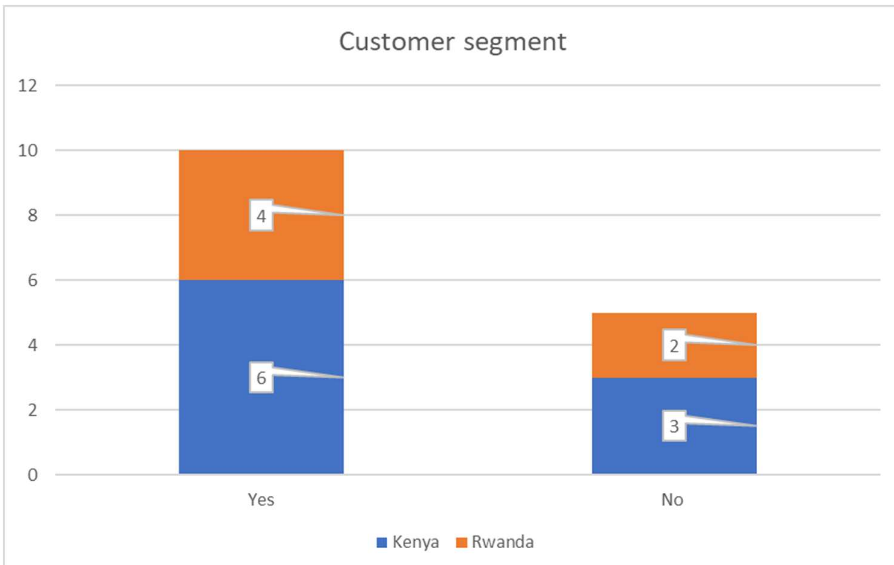

Figure 6: Customer segmentation responds.

In addition, the survey also found that in most of the mini-grids, developers identified an anchor load from institutions that were operating in their community. An anchor load refers to a large consumer of energy in a particular area, such as a hospital or a school. By identifying these anchor loads, mini-grid developers can better understand the energy needs of the community and tailor their offerings accordingly. Table 11 provides the different sectors that provide the anchor load for the mini-grids studied in both countries.

Table 11: Anchor loads in case mini-grids in Kenya and Rwanda.

Country	Mini-grid	Type commercial businesses and industries connected	Sector(s) providing the anchor load
Kenya	MG-1	Utility Provider /KPLC	Commercial business
	MG-2	Posho Mills	Residential household Commercial business, production/manufacturing
	MG-3	Saloon, pharmacy, shops, garages	Hospital, Street lights
	MG-4	Posho Mills, Schools, Restaurants, Shops	Commercial business
	MG-5	Hotels	Commercial business
	MG-6	Cold storage facility, water treatment unit, commercial businesses (hotels, shops)	Commercial business , Production/Manufacturing
	MG-7	Posho Mills	Residential household, Commercial business, Production/Manufacturing
	MG-8	3 NGO offices and small shops	Commercial business
	MG-9	Posho mill	Processing plants
Rwanda	MG-10	Shops, bars, schools, hair cut saloon	Commercial business, school
	MG-11	Carpentry, school, milling machine, egg incubator, tailoring and bar restaurant	Production/Manufacturing , Commercial business
	MG-12	Shops	Commercial business
	MG-13	Small shops	Residential households
	MG-14	Tailer, gusudira, boutique	Commercial business
	MG-15	Milling machines, food processing, cassava processing, welding	Commercial business, Production/Manufacturing

4.2.1.2 Pricing and tariff mechanisms

The appropriate approach to tariff regulation for mini-grids depends on a country's objectives, administrative capacity, availability of subsidies, and legal and policy constraints. Regulators use seven criteria to evaluate their options, including tariff accuracy, risk of monopoly pricing, suitability for rapid expansion of access, time to implement, regulatory capacity needed, compliance cost for developers, and tariff flexibility. Individualized cost-based tariffs ensure high accuracy and low risk of monopoly pricing but require significant time to design and calculate. A light-handed approach to tariff regulation leaves tariff structure choices to the discretion of the developer. Governments mostly consider fiscal and administrative capacity when implementing a uniform national tariff. Subsidies may be necessary to bridge the gap between mini-grids' cost of service and a uniform national tariff [15].

For developers, when it comes to determining tariffs for mini-grids, there are a variety of factors that can come into play, including the type of energy generation units being used, the availability of energy storage, the demand needed, and the type of customers being served. Two common pricing models used in the electric power industry are energy tariffs and power tariffs. Energy tariffs charge customers for the total amount of energy they consume over a given period, while power tariffs charge customers for the maximum power demand they place on the grid at any given time [2].

In the context of mini-grids with energy storage, an energy tariff can have several advantages over a power tariff. For instance, it can reflect actual energy usage, which is particularly important for mini-grids with battery storage where customers may not have a constant demand for power. Additionally, it can encourage energy efficiency, since customers are charged based on the amount of energy they use. This type of tariff can also provide predictable costs, which is essential for small businesses and households that rely on mini-grids for their energy needs. Moreover, it can optimize the use of battery storage to minimize costs by charging the batteries when energy demand is low and discharging them when demand is high.

However, there may be situations where a power tariff is more appropriate for mini-grids. For example, some applications, such as water pumping or milling, require a constant and high level of power rather than energy. In such cases, a power tariff may be more suitable, as it allows customers to pay for the power they need and not for the energy consumed over time. Additionally, for mini-grids with limited battery capacity, a power tariff may be preferred, as it can encourage customers to limit their peak demand and thus avoid exceeding the capacity of the battery storage system. Furthermore, a power tariff can be an effective tool for managing peak demand, which can help mini-grid operators avoid investing in expensive infrastructure upgrades to meet peak demand.

In some cases, mini-grids may need to maintain grid stability by limiting the maximum power demand placed on the system. In such situations, a power tariff can be an effective way to control the power demand and maintain the stability of the grid.

Table 12 shows the different generation and storage options with their corresponding tariff systems. While many factors influence tariff design, hydro mini-grids with no storage options and diesel mini-grids with no energy storage options may focus on power tariffs as the main tariffing method or a hybrid of both systems.

Table 12: Generation and storage unit vs tariff method, in Kenya and Rwanda.

Mini-grid	MG-1	MG-2	MG-3	MG-4	MG-5	MG-6	MG-7	MG-8	MG-9
Country	**Kenya**								
Generation source	Hydro	Solar	Diesel	Diesel	Solar (80), diesel (40)	Solar (50) ,diesel (50)	Solar	Diesel	Solar
Energy storage availability	No	Yes	No	No	Yes	Yes	Yes	No	Yes
tariff method used	Power Tariff	Energy Tariff	Energy Tariff	Energy Tariff	Energy Tariff	Energy Tariff	Energy Tariff	Energy Tariff	Energy Tariff

Mini-grid	MG-10	MG-11	MG-12	MG-13	MG-14	MG-15
Country	**Rwanda**					
Generation source	Solar	Solar	Hydro	Solar	Solar	Hydro
Energy storage availability	Yes	Yes	No	Yes	No	No
Tariff method used	power tariff	Energy tariff	Energy Tariff	Energy Tariff	Power Tariff	Energy Tariff

In addition, pricing mechanisms for energy and power can take different forms, such as fixed rate, consumption-based, or a combination of both. Under a fixed rate pricing structure, customers pay a predetermined rate for their energy and power use, regardless of the actual amount they consume. Conversely, under a consumption-based pricing system, customers are charged based on the measured amount of energy and power they use.

Based on the responses gathered, it was found that in Rwanda, mini-grids MG-13, MG-14, and MG-15 employ a fixed rate pricing mechanism, while in Kenya, most of the mini-grids use a consumption-based pricing system. Additionally, mini-grids MG-10 and MG-11 use a combination of both pricing structures.

It is important to mention that tariffs are determined by various factors, including capital costs, operational costs, cost of finance, and return on investment, in addition to those previously stated. Nevertheless, in the case of rural electrification, it is crucial to strike a balance between financial feasibility and the community's ability to pay, as they are highly sensitive to pricing.

4.2.1.3 Payment channels and mode of payment

Figure 7 shows that prepaid payments are popular in both Rwanda and Kenya. However, while Rwanda mainly relies on prepaid cards, Kenya has a combination of prepaid cards and mobile money transfers. The most prominent mobile money transfer service in Kenya is M-PESA. M-PESA has revolutionized the way transactions are carried out in Kenya, allowing people to send and receive money easily, pay bills, and even access credit. In addition, Figure 8 provides a comparison of the preferred payment methods for electricity services in Kenya and Rwanda. In Kenya, mobile money payments are the most used method, with a total of eight mini-grid respondents choosing this option.

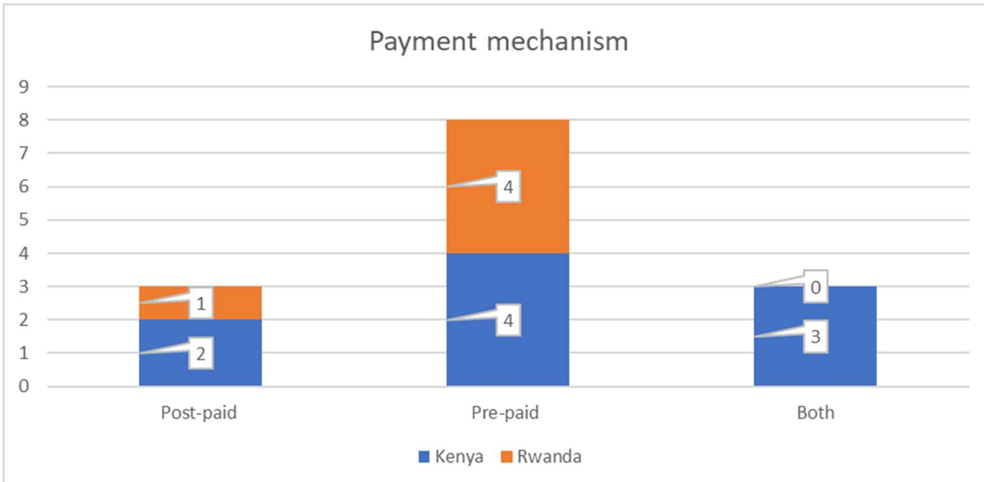

Figure 7: Payment mechanism in Kenya and Rwanda.

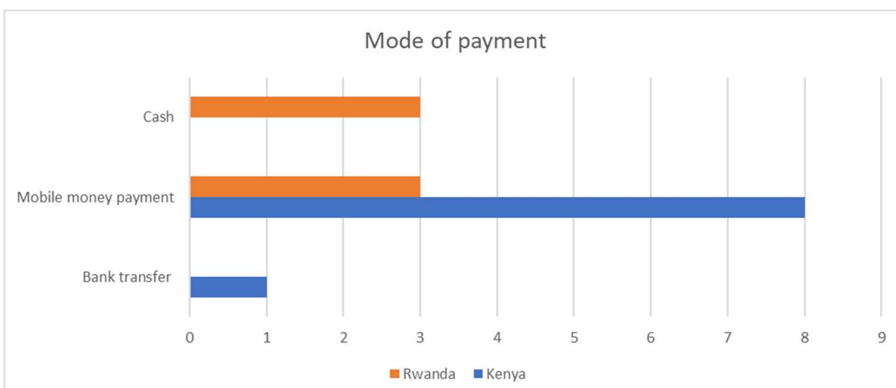

Figure 8: Mode of payment in Kenya and Rwanda.

Out of the participants in mini-grids in Kenya, only one opted for bank transfers as a payment method, making it the least popular option. Similarly, in Rwanda, none of the participants chose bank transfer as their preferred payment method. Cash payments were not preferred by any of the Kenyan mini-grid respondents, whereas in Rwanda, mobile money payments and cash payments were the most popular methods. Notably, none of the Rwandan respondents selected bank transfer as their preferred payment method.

4.2.1.4 Community engagement

According to Figures 9 and 10, mini-grid projects in Kenya and Rwanda have a significant level of community involvement. In particular, a majority of the mini-grids in Kenya reported participating in some type of community engagement program. This suggests that developers in both countries recognize the importance of involving local communities in the establishment of mini-grid infrastructure.

To achieve successful project implementation and long-term sustainability, community engagement theory proposes that community involvement in infrastructure development projects is crucial. Community involvement in mini-grid projects extends beyond the planning and design stages, with programs focusing on educating local communities about the productive use of mini-grids and assessing their electricity requirements being common. Such community engagement initiatives are critical in ensuring that the mini-grid infrastructure meets the specific energy needs of the communities it serves.

In addition, Figure 11 shows the types of community engagement programs for mini-grids in both countries. In Kenya, there are five mini-grids involved in planning, design, and implementation, education on productive use, and evaluation on energy demand. In Rwanda, there is only one mini-grid involved in education on productive use. Additionally, in Rwanda, there is one mini-grid involved in tariff setting, and another mini-grid that has local technicians and sales agents who visit customers on a need basis. Engaging local communities in the planning, design, and implementation of mini-grid projects not only ensures that their energy needs are met but also installs a sense of ownership and responsibility for the infrastructure. This can result in increased community participation and support for the project, thereby enhancing its chances of success.

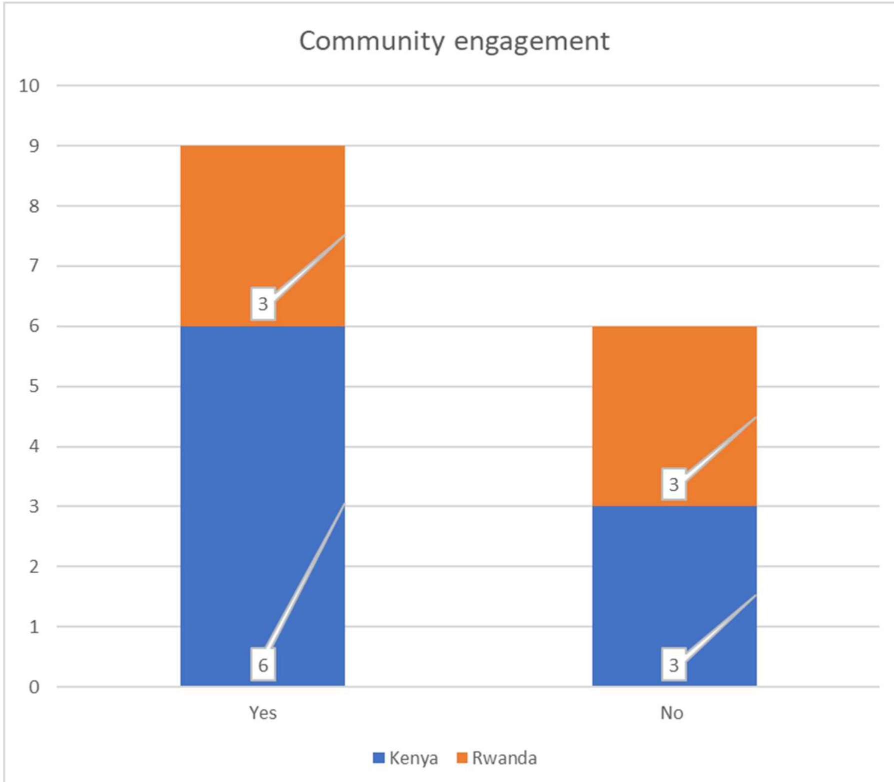

Figure 9: Community engagement in Kenya and Rwanda.

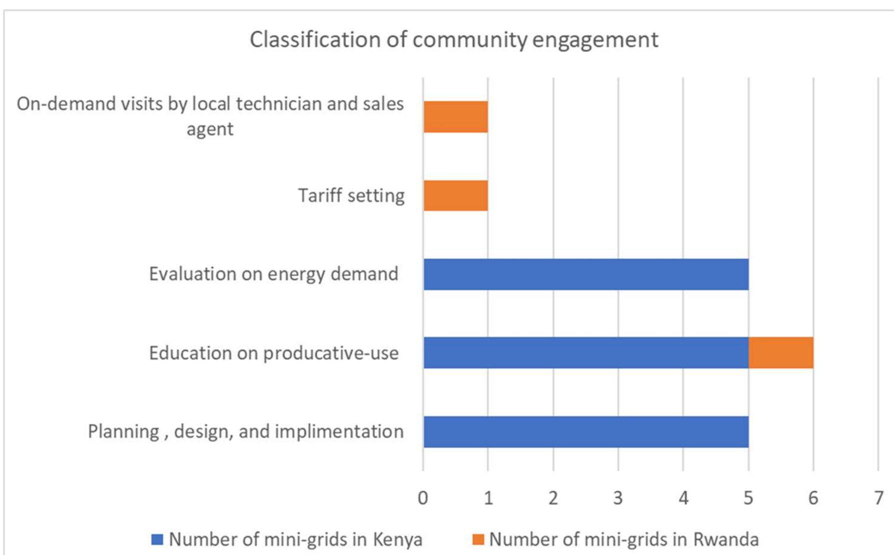

Figure 10: Community engagement types in Kenya and Rwanda.

4.2.1.5 Partnership

Figure 11 illustrates the involvement of partnerships in mini-grids in Kenya and Rwanda. Out of nine mini-grids in Kenya, six of them responded that they were not partnered with any stakeholders, whereas four out of six mini-grids in Rwanda reported that they had partnerships with other stakeholders. Partnership is a critical factor in mini-grid projects as it reflects the collaborative nature of such initiatives, which are usually developed in rural areas that require the pooling of resources, expertise, and funding to establish and sustainably operate mini-grids.

As per the information presented in Figure 12, non-governmental organizations (NGOs) are the most common partners in mini-grid projects. NGOs play diverse roles such as providing productive use equipment, facilitating payment and security platforms, and advocating for community needs. Both countries reported partnerships with payment service facilitators, which provide payment platforms and solutions that allow customers to pay for their electricity consumption. Operation and Maintenance (O&M) partners are responsible for maintaining and repairing mini-grid infrastructure, ensuring that it remains operational and efficient.

Government bodies are another type of partner, which may provide permits, regulations, and subsidies for mini-grid projects. However, there were no government partnerships reported in Rwanda's mini-grid developers.

Figure 11: Portion of involvement of partners in mini-grid projects.

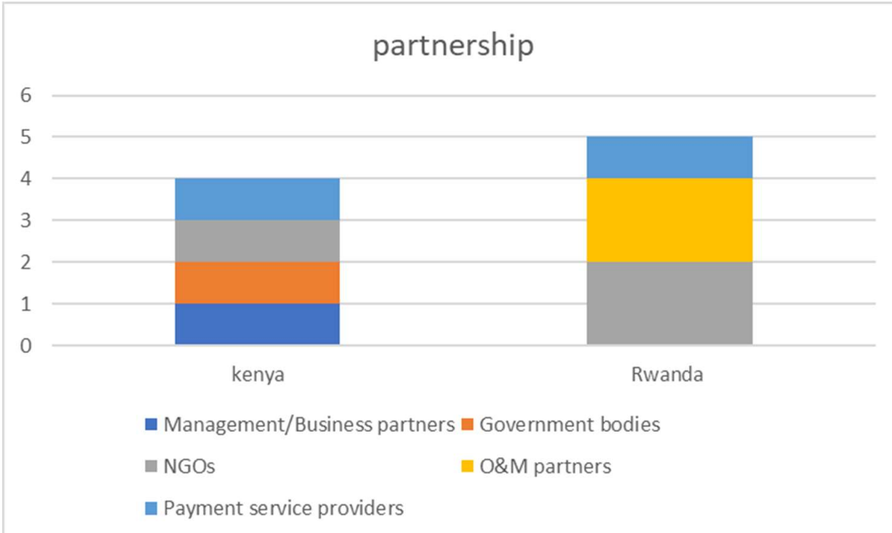

Figure 12: Partnership type and stakeholders in mini-grid projects.

4.2.1.6 Economic inclusivity and poverty alleviation actions

Table 12 provides information on inclusivity and poverty alleviation actions associated with mini-grids in Kenya and Rwanda. The inclusivity and poverty alleviation actions associated with these mini-grids show a focus on supporting local businesses, productive use support, training, and livelihood creation.

In Kenya, MG-1 is associated with training and connecting students to opportunities, while MG-2 and MG-3 are related to productive use support training and enabling an environment for local business creation, respectively. MG-6 is linked to the establishment of Adili Solar Hubs, which has set up water treatment units and cold-chain facilities to be used by the community, providing a ready market for fishers at a rate six times that of dried fish. MG-7 is associated with productive use support training and enabling an environment for local business creation.

In Rwanda, MG-10 is linked to productive use support and enabling an environment for local business creation, while MG-11 is associated with training, productive use support, and livelihood creation. MG-13 and MG-15 are associated with productive use support and training, with the latter also linked to livelihood creation.

Table 12: Poverty alleviation actions.

Country	MG index	Poverty alleviation actions
Kenya	MG-1	Training and connecting students to opportunities
	MG-2	Productive use support training enabling environment for local business creation
	MG-3	Enabling environment for local business creation
	MG-6	Adili Solar Hubs is a productive energy use company that has set up water treatment units and cold-chain facilities to be used by the community. Ready market for the fishers catches at 6 times the rate of dried fish.
	MG-7	Productive use support training enabling environment for local business creation
Rwanda	MG-10	Productive use support enabling environment for local business creation
	MG-11	Training productive use support livelihood creation
	MG-13	Productive use support
	MG-15	Productive use support training livelihood creation

4.2.1.7 Customer service and support

Service calls can provide an important measure of service quality by indicating how well a service is meeting the needs and expectations of its users. When customers have complaints or issues with a service, they are likely to call the service provider to report the problem and seek a solution. Therefore, the number and nature of service calls can offer valuable insights into the quality of service being provided.

Analysing the types and volume of service calls can help service providers identify areas where improvements are needed to enhance overall service quality. For instance, a high number of service calls or complaints can indicate that a service is experiencing issues or that customers are dissatisfied with the quality of service. Conversely, a low number of service calls or complaints may indicate that a service is functioning well and meeting the needs of its users effectively.

Table 13 and 14 provides information on the average number of service calls and complaints received by mini-grids in Kenya and Rwanda over the past 7 and 30 days.

Upon examining the data in the tables for Kenya and Rwanda, it appears that there may be discernible patterns that could aid in pinpointing areas with potential for improvement. However, due to variations in both the number of connections and customer types, drawing definite conclusions is challenging. Additionally, the timeframe of the data may also fluctuate, further complicating the analysis.

Table 13: Number of complaints received from customers (Kenya).

Kenya								
Mini-grid index	MG-1	MG-2	MG-3	MG-4	MG-5	MG-7	MG-8	MG-9
Total users	1	154	6302	612	80	154	720	250
Num. service calls and complaints (past 7 days)	0	5	1	8	7	5	10	6
Num. service calls and complaints (past 30 days)	0	10	4	5	20	10	60	30

Table 14: Number of complaints received from customers (Rwanda).

Rwanda						
Mini-grid index	MG-10	MG-11	MG-12	MG-13	MG-14	MG-15
Total users	1053	621	400	60	178	264
Num. service calls and complaints (past 7 days)	175	3	0	4	3	20
Num. service calls and complaints (past 30 days)	600	12	1	14	12	50

4.2.2 Socio-economic evaluation

This section outlines the socio-economic impacts generated in selected mini-grids. Due to the lack of historical data and lack of monitoring of the evolution of the projects, the impacts are not quantifiable at this stage of analysis. Nonetheless, it is crucial to highlight how different business designs can help mitigate inequalities and promote economic inclusion. A more inclusive and just approach to energy access projects, ultimately would lead to a better development outcome. In Section 4.2.2.1, in Table 15 examples of inclusivity and value-added services that developers offer, both in Kenya and Rwanda, in order to enhance the socio-economic impact in the communities are presented. In many cases, the value-added services are related to productive use programs. More details about specific programs and stakeholders involved are included in Section 4.3. Section 4.2.2.2 presents an analysis of appliances ownership, and energy expenditure of Rwandan users.

4.2.2.1 Socio-economic impact from complementary activities

This sub-section outlines exemplary projects that address different issues besides providing access to electricity only. Some of the challenges that are common in rural areas can be transformed into opportunities, which at the same, can contribute to social value creation. Developers must find the balance between social and economic value creation simultaneously. The success of socially remarkable innovations cannot be measured only with traditional indicators such as customer benefit or economic profit. Attention to societal benefits, problem-solving, or indirect impact should also be evaluated. Table 15 summarizes examples of value-added services offered in different projects with the related socio-economic impacts on the community.

Table 15: Inclusivity and value-added services offered by project developers to enhance the socio-economic impact in the communities in Kenya and Rwanda.

Examples of inclusivity and value-added services	Impact
MG-61) Customer segmentation that favors the poorest. The electricity tariff changes along the day for anchor and higher consumption clients. However, households that consume less keep paying lower prices. Partnership with a local company that sets up a fish processing facility. The installation includes water treatment, an ice machine, and cold storage to be used by the community. Before the cold chain facility, the fisherfolk were forced to dry the fish, reducing the value by 3-4 times compared to fresh fish. Also, the company is in charge of delivering processed products to urban markets. Now, fisherfolk make a higher income for more decent work with lower risks and less activity. A water treatment plant was established to process the fish and impacted the community at large. Now the water is provided to the community at seven times cheaper than before. Furthermore, a water pumping tech provides the neighboring school with water for their water tank. Before, at the beginning of the day, the pupil needed to go to the lake to fetch water every morning, accompanied by the teacher.	• Income generation • Education • Time-saving • Improvement of collective uses • Penetration of electrification • Health
MG-92) Productive use program to provide low-cost appliance leases and business loans combined with enterprise development program—supporting emerging market consumers who cannot afford electrical appliances. The micro-business program provides access to seed funding, financial literacy training, and business planning assistance. One example is the creation of a micro-finance initiative for poultry, where seven chicken brooders have been funded, and 25 brooder houses have been constructed in partnership with the local community. This has resulted in prospects for roughly 130 individuals and the development of an extra revenue source of USD 150-250 per person per month. Those who own brooders are offered continuous training and capital expenditure financing. In addition, the company provided financing for electric pressure cookers and facilitated the rollout of electric mills, motorbikes, and tuk-tuks.	• Income generation • Employment • Time-saving • Improvement of collective uses • Penetration of electrification • Improvement of collective uses
MG-103) Initially, the company conducted community outreach to comprehend the requirements of its customers. It came to light that families who could not pay the upfront expenses for installation and connection fees resorted to	• Penetration of electrification

paying their already-connected neighbors to enable their children to do homework under the illumination. Upon recognizing this situation, the company eliminated the installation and connection fees and started providing all its customers with free light fixtures and power sockets, ensuring accessibility to everyone who wants to get connected. The company also provides (at its own cost) training to female entrepreneurs to ensure benefits of power are equally distributed. Furthermore, the company established a "solar business park" and provides training on entrepreneurship and assistance to community members to set up a business.	• Female empowerment • Employment • Income generation • Firm productivity
MG-11[4)] Combines the delivery of energy services with business incubation and the development of productive uses of energy and clean water. In collaboration with a development agency, the customers are offered business, technical skills, and electrical appliance use training. Small businesses, which often struggle to acquire the necessary funds to buy new equipment, are given access to financing to pursue fresh ideas and opportunities. This enables them to expand into new areas and activities, thereby enhancing the economic and social progress of the entire village through the creation of novel products and services.	• Firm productivity • Income generation • Employment
MG-13[5)] The company expanded to include value-added services in the business model. Those include asset financing services for customers based on "rent-to-own," internet provision, and currently piloting with sale and distribution of TVs. Training of low-skilled local technicians to maintain the mini-grid operations. Furthermore, programs are offered to support village-level micro-entrepreneurs to generate anchor load activities.	• Access to information • Employment • Firms productivity • Income generation
MG-15[6)] Support for productive use activities, empowering community members to engage in entrepreneurial activities that make use of the power. Strong focus on gender and implementing gender sensitization activities across the productive use.	• Employment • Firm productivity • Income generation • Women empowerment

1) https://visionsforeurope.eu/v4e-articles/interview-with-kimani-gichuche-for-sdg-8/

2) https://powerhive.com/power-africa-and-powerhive-boost-solar-energy-consumption-through-appliance-leases-and-business-loans/
2) https://repp.energy/wp-content/uploads/2022/12/Powerhive-2022.pdf

3) https://www.africaoutlookmag.com/company-profiles/1351-arc-power
3) https://www.arcpower.co/stories/articles/arc-power-empowering-villages.html

4) https://www.cirps.it/absolute-energy-with-support-of-endev-successfully-installed-a-solar-hybrid-mini-grid/
4) https://endev.info/wp-content/uploads/2022/02/RBFF-Rwanda-Village-Grid-Project-Closing-Report.pdf
4) https://energy4impact.org/news/big-returns-businesses-rutenderi-thanks-new-mini-grid

5) https://energy4impact.org/news/meshpower-mini-grid-opens-commercial-opportunities-rural-rwanda
5) https://issuu.com/siemensstiftung/docs/sie_casestudies_2201106_ak/s/11296225

6) https://hobuka.com/2022/02/18/mudasomwa-mini-grid-has-been-selected-to-be-in-the-productive-use-of-electricity-program/
6) https://energy4impact.org/news/energy-4-impact-pioneers-innovative-model-mini-grid-development-and-ownership- rwanda

4.2.2.2 Appliance ownership and energy expenditure

This section describes appliance ownership of Rwandan mini-grid users. We use an appliance ownership tier framework to represent different levels of appliances owned adapted from [57]. The tier levels are defined by the appliance cost and the electricity usage, see Table 16. The first tier represents the most basic level of appliance ownership, while Tier 5 represents the highest level. From the customer's data, none of the customers reached tier 5. Appliance ownership among Rwandan users is depicted in Figure 13.

Nonetheless, the higher household income from the available data is 184$ per month. Data from users with higher acquisition levels could provide better insights into understanding adoption of a higher tier of appliances. Since lighting bulbs are present in every house, the bulbs are not accounted as an appliance in Figure 13. Appliances adoption is important because it can derive several benefits to households, such as freeing up additional hours of productive time during the day, which allows for greater market participation or providing services to the homes such as food preparation [58]. Even small appliances may allow (especially) omen to produce new goods and create microenterprises. But also, it is necessary economically in order to increase electricity demand which contributes to enhancing self-sufficiency of the mini-grid projects.

Table 16: Appliances tier.

Tier	Appliance(s)	Cost	Electricity use
0	No appliances		
1	Light bulbs, mobile phone	Very low/ Low	Very low
2	Radio, fan	Low	Low
3	TV, pressure cooker, iron box, electric kettle	Moderate	Low/ moderate
4	Computer	High	Low-moderate
5	Washing machine, refrigerator, electric stove	High	High

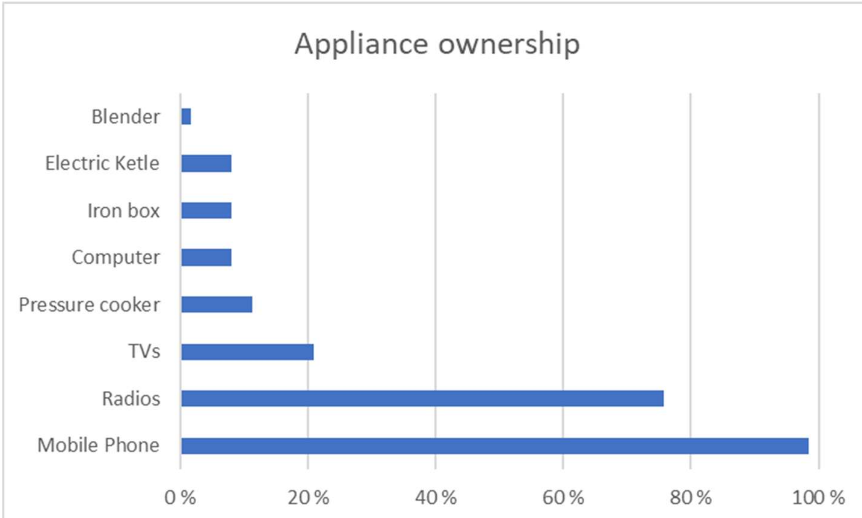

Figure 13: Appliance ownership among Rwandan users.

The results from our analysis are aligned with [59] which shows that information and communication technology (ICT) devices like mobile phones and radios, followed by TVs, are the most likely appliances to be adopted first by households. The next highest probability of ownership devices lies with cooking equipment, showing higher number of different devices for those households with higher income level. The study in [59] determines that middle-income and upper-middle-income households are more likely to adopt welfare appliances such as refrigerators and laundry machines. Our data sample supports again those findings as none of the users own any appliance from tier 5. Promoting the uptake of welfare appliances in low and middle-income households is crucial for enhancing household welfare and well-being. By enabling women to save time on daily household tasks, such appliances can empower them to pursue other activities that contribute to their personal and professional growth.

In Figure 14 it is distinguished the number of devices´ type owned by the households compared to the income. For instance, owning more than one mobile phone, is only accounted for one appliance type. The users owning only one type of appliance includes only mobile phone. Users owning 2 types, normally involves mobile phone plus radio or TV, commonly bought before acquiring any other type of appliance. Figure 15 may provide a better representation of this, as it displays the relationship between appliance tiers and household income.

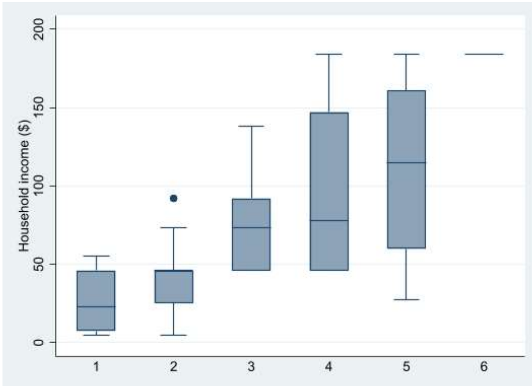

Figure 14: Number of appliances type vs monthly household income.

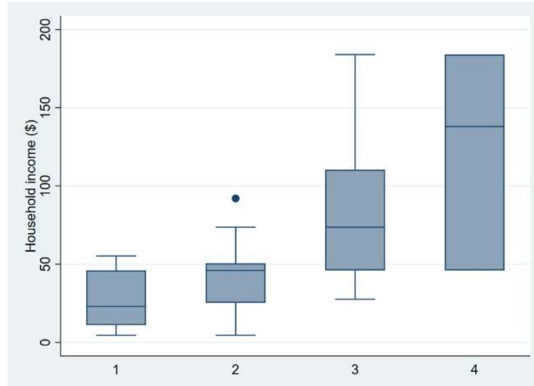

Figure 15: Appliance ownership tier vs household income.

Studies evaluating the impact of electrification over time found that appliances adoption and usage can vary substantially depending on the context. Factors affecting households´ decision-making regarding appliances purchase include household income, financing, preferences and bargaining among household members [60]. Another factor that can affect the appliances purchase can be the connection fee. Results from an evaluation from Tanzania [53] compare effects of low-cost connection fees, showed higher appliance uptake for those with access to low-cost connection fee, compared to control group. Accordingly, several studies show that electricity consumption also varies over time with heterogenous results about the consumption rate growth which is highly context-dependent. Different delivery models can also influence the demand growth rate. For instance, different projects showed consistent demand growth when users are provided with microfinance to buy appliances. Electricity price and low connection fee is also seen as drivers of energy consumption rise.

Figure 16 shows the relation of energy expenditure, which is again, highly correlated with the income level of the household. A more detailed study about impact of electrification on appliance uptake and income growth over time and a bigger sample of participants could provide relevant findings about energy expenditure increase over time.

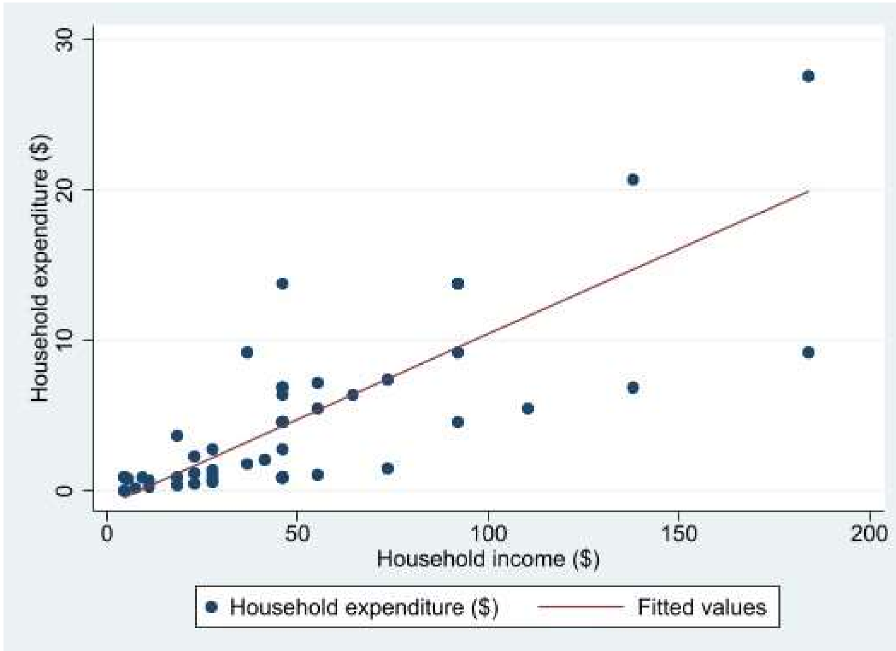

Figure 16: Household income vs household monthly electricity expenditure.

4.2.3 Techno-economic evaluation

A critical step in understanding the effectiveness of mini-grid deployment is the analysis of operational performance and associated techno-economic metrics. To that end, data were collected from 15 mini-grids in Kenya and Rwanda regions, with the objective of understanding the operational performance of the mini-grids, their configuration, size, failure analysis, and smart features used. However, one mini-grid (MG-6) was excluded from the analysis due to insufficient technical information. As such, data from 14 mini-grids were used to identify trends and draw insights about the operational performance of mini-grids.

The analysis included a detailed review of the system configuration, including the types of renewable energy sources used, the size of the system, and the types of energy storage technologies deployed. Additionally, the analysis presents a number of failures experienced by mini-grids. In addition, advanced features such as power quality optimization, data collection, and smart features deployed in the mini-grids were also considered in the analysis.

Figure 17 illustrates the number of the different types of power source, used batteries technologies and grid configurations. As it is seen from the bars, solar generation serve as a power source for most of the mini-grid systems. Diesel generations takes the second place, while hydro powered systems share is the least one. From the second group of bars is seen that half of the systems under observation (7/14) don’t have battery technologies implemented. Li-ion batteries are the most used technology at the considered mini-grids. Twelve out 14 mini-grid systems have 3-phase AC network while 1 phase AC and DC grid configurations are less commonly used.

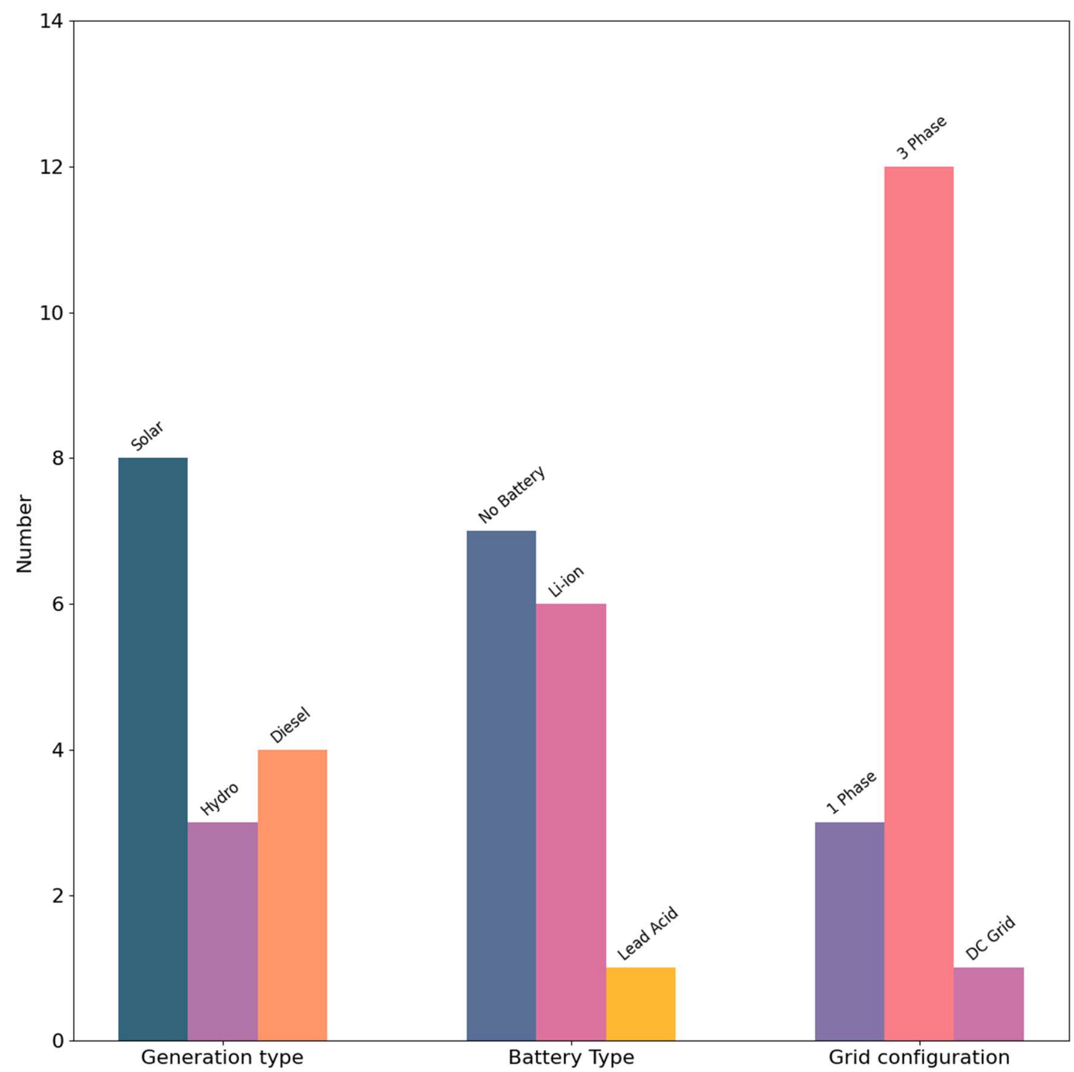

Figure 17: Analysis of mini-grids under study; generation type, battery energy storage, and grid configuration.

Figure 18 shows the length of the distribution lines and the number of customers in a mini-grid. The coloured circles indicate the power sources used in the system. As seen in Figure 18, three of the mini-grids with the greatest number of consumers (6000 and 3000 users) and longest distribution line lengths are supplied with diesel generators. There are also two mid-sized solar mini-grids with around a thousand users. The rest of the mini-grids are mostly hydro and solar-powered. Therefore, it is possible to generalize that renewable energy sources are mostly used for small-scale mini-grids, while large mini-grids are still supplied with fossil fuels.

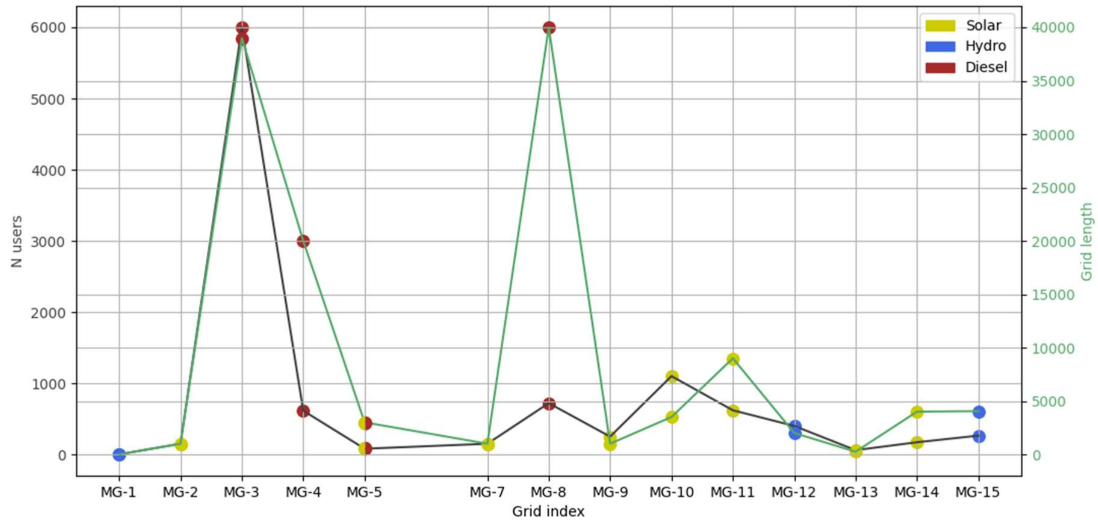

Figure 18: Analysis of mini-grid size.

Figure 19 shows the number of planned and unplanned electricity outages in the system over the last three months. As seen in the illustration, the highest number of outages occurred in the hybrid source mini-grid, where solar generation accounts for 80% of production and diesel generators account for 20%. It should be noted that almost all of these outages were caused by maintenance electricity breaks. The diesel power system had the second highest number of electricity breaks. When considering electricity outages caused by failures in the system, three solar-based and one diesel-based mini-grid had a rate of about 20. The rest of the system worked quite stable, having up to three electricity outages over the last three months.

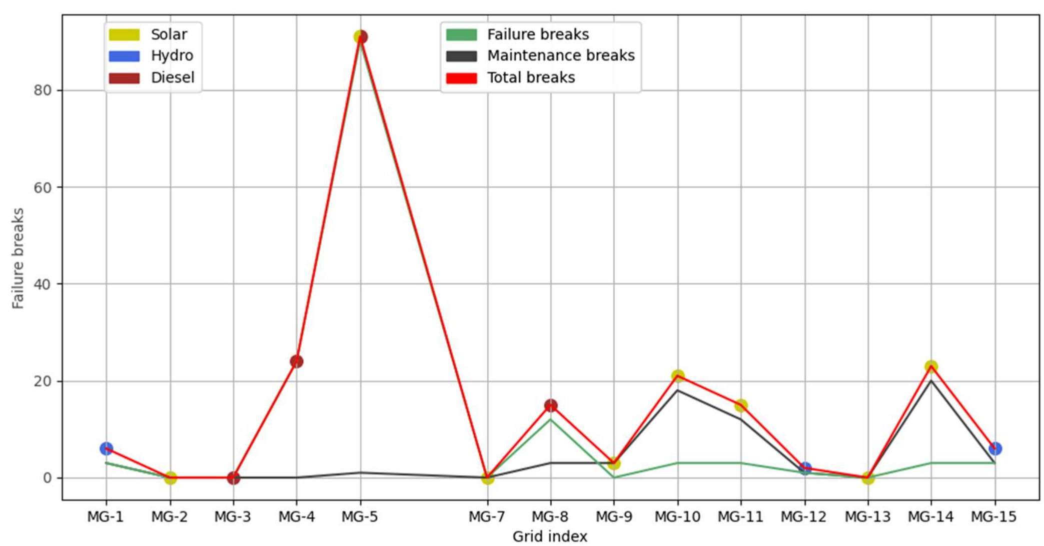

Figure 19: Electricity outage analysis.

Considering the advanced features implemented in the mini-grids, it is possible to define three specific groups: power quality, data collection, and smart features. Half of the mini-grids have voltage optimization and power factor correction, while only two systems also have harmonic filtering. Regarding data collection, 10 out of 14 mini-grids collected data automatically using different software and monitoring devices. Two systems recorded data every half hour on paper, and two systems didn't have any data collection at all. Remote monitoring is available for more than half of the mini-grids.

Based on the information about the recording of personal users' consumption, it can be concluded that all mini-grids with data collection recorded this data. Three mini-grids used smart features such as demand management, blockchain, and image recognition for grid planning. It is worth mentioning that generation optimization based on weather forecasting is not used in the mini-grids under observation, and thus is not shown in Figure 20, illustrating the advanced features used in the observed mini-grids.

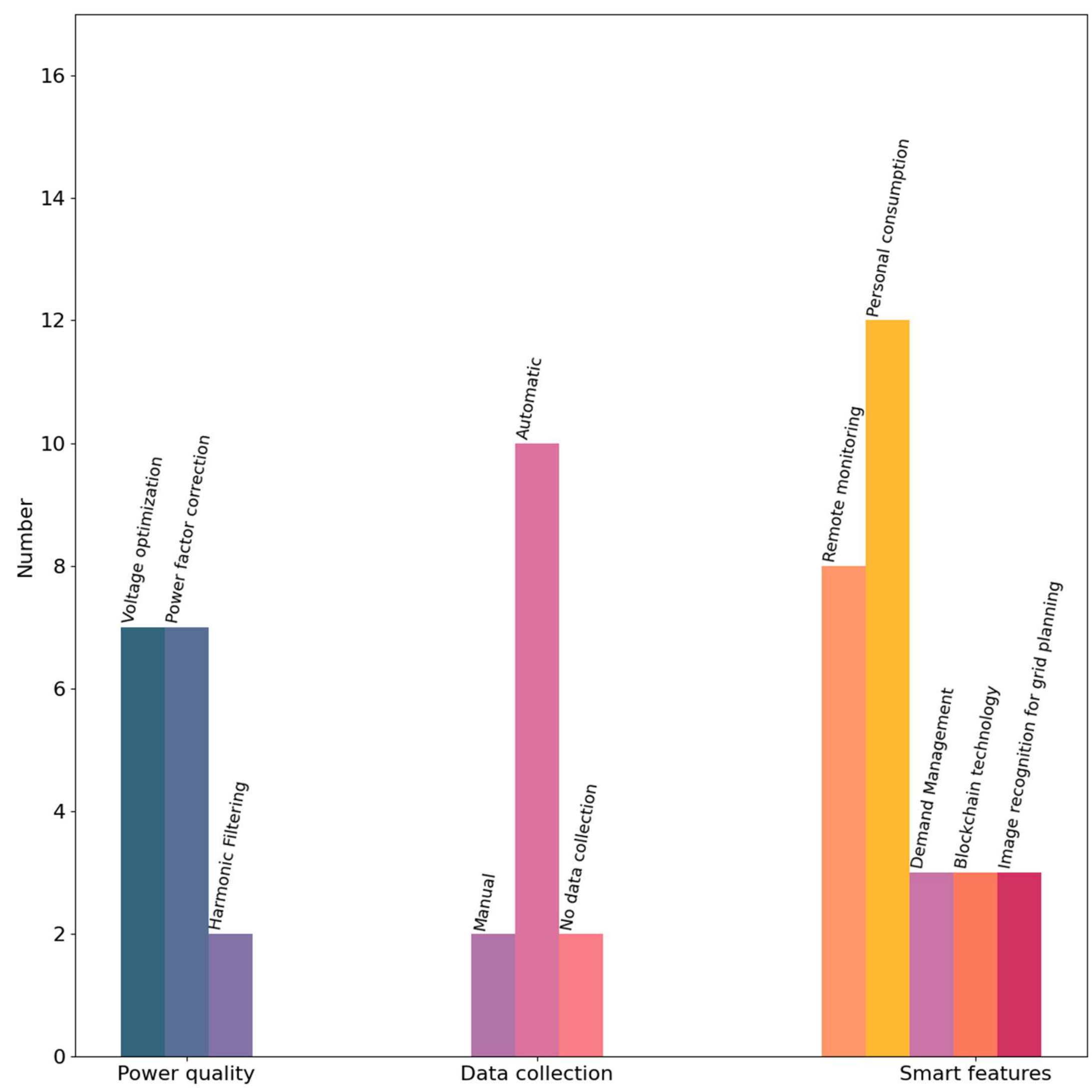

Figure 20: Advanced features of mini-grids under observation.

4.2.4 Stakeholders evaluation

Table 17 maps the most important active stakeholders in both countries with regards to the development of mini-grid projects for rural electrification.

Table 17: Stakeholders in the mini-grid projects and rural electrification development in Kenya and Rwanda.

Stakeholders	Kenya	Rwanda
Private companies	• Private MG developers • MG hardware supplier (technology suppliers) • IT technologies, communication systems) • PU hardware provider (PU equipment, appliances suppliers) • Mobile money integrator, other service providers	
Governmental units	Ministry of Energy (MoE), Rural Electrification and RE corporation (REREC), Energy and Petroleum Regulatory authority (EPRA), Kenya Power and Lighting Company (KPLC)	Ministry of Infrastructure (MININFRA), RURA (Rwanda Utilities Regulatory Authority), Rwanda Energy Group (REG), Energy Development Corportation Limited (as a subsidiary of REG)
Development agencies & NGOs	Green Mini Grid Facility (GMGF), SE4All, USAID	EnDev, E4A, SIDA, USAID , SE4All
Financing Institutions	Energy Access ventures, Green Mini Grid Facility (GMGF), World Bank, African Development Bank (AfDB), EU, European Investment Bank, Agence Française de Développement (AFD), SIDA, UK Department for international Development, GIZ, Netherlands Development Organization (SNV), The rockefeller foundation	Rwanda Development Bank (BRD), World Bank, AfDB, SREP (scaling up RE Program), EnDev, SIDA, E4I, EEP Africa, USADF, Shell Foundation
Funds	SUNREF (AFD), KOSAP, African Enterprise Challenge Fund (AECF), Crossboundary Energy access project, Pro Solar (GIZ), KEMP, SEFA (sustainability energy fund for Africa), Pioneer Energy Investment Initiative, African RE Fund, Efficiency for access, Energy Access Venture Fund, The EnAccess Foundation, EEP Africa	REF (renewable energy fund), SEFA (sustainability energy fund for Africa), CIS (climate Investment fund), RBF, Pioneer Energy Investment Initiative, African RE Fund-SSA, Efficiency for access, Energy Access Venture Fund, The EnAccess Foundation, EEP Africa
Research institutes	Mini Grid Innovation Lab (by crossboundary), Strathmore ERC	UR-Through its Center of Excellence
Industry associations	Kenya Renewable Energy Association (KEREA), AMDA, ARE (alliance for rural electrification), Platform Sustainable Energy Marketplace (by IRENA)	Energy Private Developer´s association (EPD), AMDA, ARE, Platform Sustainable Energy Marketplace (by IRENA)

4.3 Productive uses point of view and stakeholders involved

This section outlines exemplary programs implemented in the mini-grid sites to illustrate how to create and foster opportunities through productive uses of energy and connectivity. In Table 18 different initiatives, including productive uses programs, have been presented in order to showcase how these initiatives support and improve the livelihood of local communities. In this case, the emphasis is on the deployment of productive uses and stakeholders involved in each case. The stakeholders in the studied cases include private companies, NGOs, development agencies, research institutes, and governmental units. Most of the projects provide some form of access to finance to purchase appliances and business and entrepreneurial skills training, either as part of the business model or with the support of external agencies/companies.

MG-6 stands out from the others because it includes a processing plant and distributor for processed agri-food products to reach the regional/national market. From the MG business model point of view, it differs from the Key Maker model from the perspective that the mini-grid developer did not establish the processing plant. Nonetheless, the plant serves as an anchor load, and from the users' perspective, the impact generated may be very similar. Different projects demonstrated that customers who have accessed loans and business funding showed a sustained increase in energy usage.

Table 18: Different productive use initiatives under observation.

PU approach	Stakeholder and role
MG-6	**Adili Solar Hubs**
On this mini-grid site, productive use of energy is accompanied by additional customer support, such as market linkages. Adili Solar Hubs is a pioneer productive energy use company in charge of building, owning, and operating solar-powered cold chain hubs for marginalized fishing communities. The company provides market access to fresh fish, enhancing the value of local enterprises and creating a transparent traceable fish value chain from the fishermen to the end customer. Furthermore, electronic inventory is used, increasing the traceability and collecting data that financial institutions could use to facilitate loans to community members. This is an exemplary case of value creation in the water-food-energy nexus.	• Establishes PU processing facility • Provides access to the market for local products • Establishes a water treatment plant • Serves as an anchor load
MG-9	**USAID**
Implementation of "Kuku poa project": involves running a chicken slaughterhouse. Poultry farmers from the catchment area, who are typically organized as Community-Based Organisations (CBOs), rear poultry, and once mature, they are delivered to the slaughterhouse for dressing ready for the market. The project enables customers to access training and assets for the rearing and marketing of poultry products. Customers pay a small fee	• Grant support • Support to Kuku poa project implementation • The project serves as an anchor load • Access to finance

following their agreement, and in exchange, they get a small flock of chicks every month, a bag of feed, a training course, a brooding kit, and vaccines. This helps offset what would otherwise be a somewhat-expensive production process – at least until the chicks are old enough to scavenge for food (around one month). The approach is appreciated by participants who can earn a profit without many of the barriers associated with a larger enterprise. Another example from the same developer (in MG-2) is the "Dudu poa project," which involves rearing Black Soldier Flies (BSF) using the organic waste collected from the nearby municipal markets. The BSF is reared and sold to the farmers once dried as chicken and pig feed. The pilot demonstrated that customers who accessed loans and business funding showed a sustained increase in energy usage.	• Access to assets • Training
MG-10 Implementing a "Solar business park" next to generation units supports the development of new businesses. The community members are facilitated access to loans for electric appliances, and entrepreneurs pay for the power used and the space occupied at the business park. Examples of businesses are bakeries, tailors, milling stations, welding shops, and honey farming cooperatives. The park also serves as a house for battery swapping stations for electric vehicles. It is done in partnership with a local company, "Empowering Villages". After the first successful project, the company aims to build a solar business park at each MG site.	**Empowering Villages** • Basic business and entrepreneurial skills training • Undertake business planning • Access loans for electric appliances
MG-11 Energy 4 Impact funded 70% of the appliance costs through SOGER (Scaling Up Off Grid Energy in Rwanda) grants, with the remaining 30% being funded by the micro-enterprises themselves through their own savings or loans from local Savings and Credit Cooperative Organizations. Energy 4 Impact provides services around three main pillars: - Value chain analysis to assess how value can be added to products and services as a result of having an electricity supply - Development and training to help build businesses and training to select and use electric appliances - Access to finance for small businesses to purchase new equipment	**Energy 4 Impact, Interuniversity Centre for Sustainable Development – University of Rome "Sapienza" and AVSI Foundation** • Value chain analysis • Training for businesses • Assistance for appliances use • Access to finance
MG-13 Establishment of programs to support village-level micro-entrepreneurs with the support of Energy 4 Impact (through the SOGER Program) and DOEN Foundation. Engaging with welders, tailors, hairdressers etc., and helping them develop their capacity to use electricity to increase their productivity and profitability. Appliance financing with payment terms ranging from three to 12 months is offered as a part of the mini-grid business model. Furthermore, this developer is piloting a new internet access service in a different mini-grid site.	**Energy 4 Impact** • PU promotion **DOEN Foundation** • Access to finance for electric appliances **Microsoft** • Finance for an internet service provider
MG-15 The Association of Volunteers in International Service (AVSI) Foundation, in partnership with GiZ, initiated the promotion of the	**Association of Volunteers in International Service (AVSI) foundation, GiZ,**

productive use of electricity. The process included different field visits for awareness activities and training beneficiaries on the use of productive use equipment; the successful compliant beneficiaries were awarded different appliances for their businesses. Existing businesses were advised and given technical assistance; other newly opened business owners were trained. The support includes advice on markets and supply chains, the economics of their business case, and accessing capital to acquire electrically powered equipment. Assistance and creation and registration of the community cooperatives were also provided.	**Energy 4 Impact, Rwanda Energy Group (REG)** • Engagement with local authorities • Mechanisms to establish legal agreements between community and developers • Promotion of PU • Training

Figure 21 shows a classification of the mini-grid sample according to the services provided. In this classification, we consider all the services provided to the users without distinction regarding whether those services are included in the business model design or if they are offered through a partnership with other organizations. Information about the implementation and stakeholders involved in the provision of services is provided in Table 18.

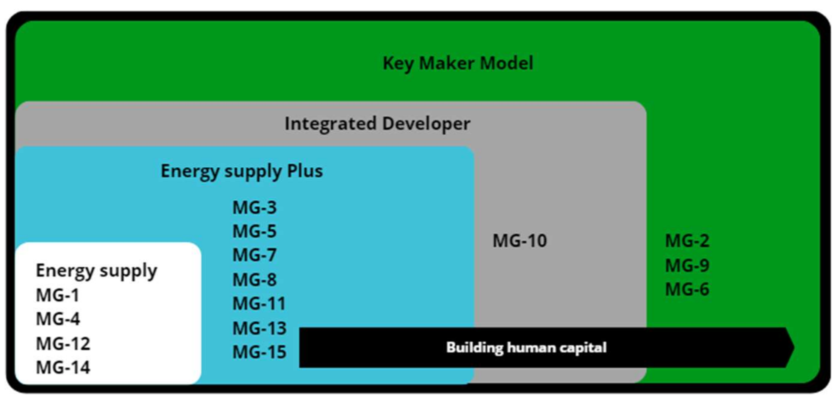

Figure 21: Classification of business model based on value added services.

4.4Key takeaways

4.4.1 Summary matrix

Table 19 summarizes the main characteristics of the mini-grid projects studied in this report based on the defined indicators and presented in a matrix format. Each of the four dimensions: business model, socio-economic, technology, and stakeholders, have been described thoroughly in this report. However, the purpose of this matrix is to recap and display in an organized manner the primary attributes of each project. In the matrix, each dimension is divided into main indicators, as defined in Section 3.1; the indicators are then divided into sub-indicators that cover the diverse possibilities the project can incorporate. The subsections following the matrix describe key takeaways of the overall analysis.

Table 19: Evaluation matrix, with the main characteristics with the defined indicators of the mini-grid projects used in the study.

		MG index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Business model	Customer segmentation: Anchor load	Commercial															
		Residential															
		Processing plants, manufacturing															
		Public institutions															
	Commercial customers	>30% 10-30% <10%															
	Residential customers	>90% 80-90% 65-79%															
	Payment mechanism	Mobile money															
		Cash															
	Pricing mechanism	Energy Consumption															
		Power tariff															
		Fixed rate															
	Mode of payment	Post paid															
		Pre paid															
	Demand growth	Yes															
	Inclusivity: Poverty alleviation actions	Skills training															
		PU program															
		Local business facilitator															
		Access to credit															
	Inclusivity: Community engagement and participation	Planning, design, implementation															
		Tariff setting or local technicians															
		Evaluation electicity needs															
Socio-economic	Impacts derived from specific poverty alleviation actions	Income gen. /employment/firm productivity															
		Education/access to information															
		Female-empowerment															
		Time-saving															
		Penetration of electrification															
		Improvement of collective uses															
Technology	Generation capacity (KW)	1000-1200 150-999 50-149 13-49 <12															
	Energy generation source	Hydro															
		Solar															
		Diesel															
	RE share	0% 50-60% 100 %															
	Storage system type	Lithium-ion															
		Lead Acid															
		Capacity bank															
	Monitoring systems and data storage	SCADA and HMI															
		Smart meter															
		Excel / Log sheet															
	Reliability: Blackouts 3 months	0 0-5 6-15 16-25 >25															
	Reliability: Blackout reasons	O&M or lack of sparte parts															
		Overload/low generaton/battery issues															
		Payment fault															
		Line fault and other accidents															
Stakeholders	Ownership	Private															
		Public															
	Funding	Local															
		International															
	Partnership	NGO / development agencies															
		O&M, payment facilitators, other private firms															

4.4.2 Anchor load

The establishment of anchor projects guarantees the predictable use of electricity, which is necessary for the economic viability and sustainability of the electricity system. Anchor loads here are considered to be a customer or group of customers that consume at least 60% of the energy generated in the mini-grid. In all the studied projects, residential customers represent at least 65% of all users. However, residential customers' consumption is much lower compared to other sectors. Commercial and processing plants are usually the biggest energy consumer group, although they account for only a few consumers. For instance, in MG-4 and MG-8, more than 90% of users are from the residential sector, but commercial activities alone account for more than 60% of electricity consumption. The same occurs in the case of MG-9, in which processing plants and manufacturing industries are the anchor load. The availability of electricity can enhance the productivity of the anchor load and stimulate economic activities in the surrounding area, thereby creating additional demand for electricity and contributing to the sustainable development of the local economy. Finding an appropriate anchor load can contribute to the sustainable development of the local economy.

4.4.3 Payment and pricing mechanisms

Regarding payment and pricing mechanisms, Kenyan mini-grids are more uniform, being mobile money and energy consumption tariff the typical approach. In Kenya, in the public mini-grids, electricity prices are lower than the private ones, as the price equals the national electricity tariff, which is about 0,17$/kWh. In contrast, the price from private mini-grids can go up to 0,6$/kWh. In some cases, i.e., in MG-6, price is differentiated according to customer type and time. In contrast, Rwandan mini-grids show more diversity in several sites, and different payment options are provided based on customer type. It is common to apply a fixed rate among the poorest households. In several sites, low-energy consumption houses pay less than 3$ per month. Examples of payment flexibility are presented in MG-13, which has price flexibility based on seasonal variation, and MG-10, which applies special tariffs to customers using certain productive use equipment. As demonstrated, there are many possibilities for payment structures; nonetheless, the impact that different payment and tariff structures have on the business sustainability, users, or demand growth, remains still uncertain and would require deeper evaluation in order to provide generalized conclusions.

4.4.4 Demand growth

Most of the mini-grids reported demand growth over the years, being the main reasons an increase in the area population, partly motivated by the availability of electricity, growth in commercial activities, and productive use initiatives. Furthermore, one mini-grid reported customer growth due to the reduction of power connections. Two mini-grids did not experience demand growth; deeper analysis would be required to understand better the factors; however, no complementary activities, such as the poverty alleviation actions described in Table 18, were implemented, which suggests, that the implementation of these complementary activities might have an essential role in promoting electricity demand. Most of the complementary activities have been supported by NGOs and development agencies, which highlights the importance that diverse partnerships and stakeholders play in enhancing inclusivity, value creation and livelihood improvement within the community.

4.4.5 Reliability

The causes of blackouts vary widely among mini-grids, nonetheless, the lack of available spare parts and operation and maintenance activities have lead to high number of blackouts in two-thirds of the studied cases. This is followed by overload and battery energy storage system issues. Measures to enhance system efficiency and reliability, such as smart grid, peak demand pricing or demand-side management, could be evaluated to distil and quantify its impacts on grid reliability and, ultimately on the customers. Furthermore, providing training to technicians in the local area to repair and maintain the mini-grid equipment have been recorded as crucial for continued success, and keeping spare technical components readily accessible has been found beneficial for uninterrupted operations.

4.4.6 Summary for business model activities

Private sector involvement has been found to play a crucial role in the success of mini-grid projects by increasing the efficiency and quality of energy service delivery. However, government control is also necessary to ensure tariff control, regulation, and subsidies are properly managed. To ensure that the mini-grid projects are sustainable and inclusive, it is important to involve local communities in the value creation and capture of the mini-grid ecosystem. This can be achieved through various means, including productive use of energy, which can promote the local economy and improve energy demand.

To roll out mini-grids efficiently and cooperatively, several delivery models are available that describe the installation, operation, and ownership aspects of a mini-grid. Public-private partnerships are encouraged for better delivery model design, which can enhance the inclusivity of local communities and promote economic opportunities. One of the key aspects of inclusive action in mini-grids is the productive use of energy. By integrating the nexus of energy, agriculture, and water in rural developing regions, productive use of energy can help create sustainable and resilient communities

Customer service is a key indicator of mini-grid business success, and analyzing service calls can help identify areas for improvement. Additionally, the appropriate approach to tariff regulation depends on a country's objectives, administrative capacity, availability of subsidies, and legal and policy constraints. The survey conducted on mini-grids in Kenya and Rwanda revealed that most mini-grids applied customer segmentation and identified anchor loads from institutions operating in their community. Mini-grid projects in both countries have a significant level of community involvement, but there is a lack of partnership in some mini-grids; incorporating a more diverse set of stakeholders involved the projects could provide higher value for users and foster greater impact on the whole rural value chain, thus enhancing the sustainability of mini-grid projects. Therefore, it is crucial for developers and stakeholders to recognize the importance of partnerships and collaboration in establishing and operating mini-grids.

4.4.7 Future research needs

In order to understand better the intermediate channels and mechanisms that lead to the different desired outcomes related to business and socio-economic impact, it is recommended that future research includes performing quantitative analysis about the effectiveness of different input activities. Some suggestions are to evaluate different approaches to tariff structures and payment mechanisms, the influence of different programs (i.e., access to finance), measures to enhance system efficiency, or promotion of energy efficiency (i.e., subsidies for efficient units, information campaigns, support to companies offering energy efficiency services).

5. Discussion and observation of best practices

The technological impact of mini-grids extends beyond energy production and storage. Mini-grid deployment also requires the development of critical infrastructure, such as roads, communications, and supply chains. The implementation of these essential elements can have a transformative effect on the surrounding communities, creating new opportunities for economic growth and development. Moreover, the deployment of mini-grids also provides access to modern technologies, such as the internet and mobile phones. This technological advancement can help to bridge the digital divide in remote and under-served areas, enabling greater access to education and other social services. Therefore, the deployment of mini-grids has significant techno-economic impacts on the region. It is important to note that the deployment of mini-grids provides access to electricity in areas where it was previously impossible or economically unfeasible with the utility grid. With mini-grids, communities in remote and under-served areas can access reliable and affordable electricity, allowing for the stimulation of economic growth and development.

Residential sector consumption, although including the highest number of users, is much lower than commercial or industrial sector. To ensure a steadier and consistent electricity demand, finding appropriate anchor loads is important. It requires careful consideration of the specific needs and characteristics of each community. It is recommended to start engaging the local community at the very early stages so that the input from the beneficiaries can be incorporated in the planning design. Engaging with the local community to understand the needs and priorities is required to identify potential anchor loads. At the beginning of the project, developers may consider reaching out to local organizations to discuss potential partnerships. Local businesses, organizations, or public institutions should be considered. Other potential anchor loads can be companies specializing in productive uses for rural communities, those companies are an emerging trend in different African countries.

Pilot projects in which customers were provided with access to finance to buy appliances or start businesses have proven to ensure a sustained increase in energy usage; thus, mechanisms to ensure access to microfinance or loans can benefit developers and users. Developers can approach it as part of their business model or by partnering with microfinance institutions or appliance providers.

The absence of local maintenance capacity is a major issue. Training local technicians and having available spare technical components can significantly minimize downtime, allowing the system to return to normal operation quickly. It can also contribute to cost savings due to reduced transportation costs and components price when ordering spare parts in bulk. On the other side, the potential that digital technologies can offer to the mini-grids has been recognized by many developers. One of the most appreciated applications is monitoring solutions and troubleshooting issues remotely, increasing the mini-grid system performance. From a technological perspective, mini-grids provide access to renewable energy sources, energy storage, and smart technologies, which enhance energy efficiency and facilitate effective energy management. The implementation of these technologies promotes sustainability and reduces energy costs for consumers.

The development of infrastructure that comes with mini-grid deployment, along with the advancement of digital technologies, provides new opportunities for economic growth and development in underserved areas. With the provision of reliable and affordable electricity, mini-grids have the potential to stimulate economic growth, create new opportunities for income generation, and promote entrepreneurship. Furthermore, the deployment of renewable-based mini-grids also plays an important role in reducing carbon emissions and promoting sustainability, making it a vital component in the transition to a more sustainable energy future.

Overall, the report provides valuable insights into mini-grid development and operation in Kenya and Rwanda, based on the four dimensions. However, there are limitations to the analysis presented, including the quality of data and the survey's focus on developers rather than facilitators. Nevertheless, stakeholders can work together to create sustainable and inclusive mini-grid projects by leveraging the insights provided in this report.

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