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MASTER THESIS

Speciality: Economics/Policies/Infrastructures and Green Hydrogen Technology

Topic:

Designing a Sustainable Business Model for Solar Mini-Grids to Enhance Rural Electrification in Guinea-Bissau

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ABSTRACT

West Africa faces persistent challenges of sub-electrification, and Guinea-Bissau ranks among the least electrified countries, with a national rate of just 35.7% and rural electrification lagging at only 7%. This highlights the urgent need to accelerate access. In such contexts, solar mini-grid sustainable business models become crucial for enabling viable and inclusive electrification, particularly where established markets are absent and household incomes remain low.

This thesis examines the design of a sustainable business model for solar mini-grids to enhance rural electrification in Guinea-Bissau, where the sector is still in its infancy with only four projects implemented. Drawing on the Triple Bottom Line (TBL) framework and SWOT analysis, the research evaluates the economic, social, and environmental dimensions of the solar mini-grid business model currently applied in Bissora.

Findings show that, while projected revenues (€30,696) initially suggest a positive margin over annual costs (€23,976), including replacement obligations (€32,032 annually) reveals a structural deficit of €25,312 per year, rendering the model financially unsustainable. On the social side, the model falls short in addressing community needs, as frequent power outages, exclusion of potential users, and limited support for productive use undermine the developmental benefits of electricity access. Environmentally, the mini-grid contributes to emission reduction by displacing diesel but faces setbacks from ongoing deforestation pressures and the absence of equipment recycling or end-of-life strategies.

To address these gaps, the thesis proposes a sustainable business model based on the Triple Layered Business Model Canvas (TLBMC). The model integrates reliable electricity provision, productive-use promotion, community engagement, and material lifecycle management. It is supported by strategic partnerships, circular economy practices, and inclusive financing mechanisms.

Policy recommendations emphasize the importance of fostering multi-sectoral partnerships, mobilizing climate finance, and adopting adaptive planning to enable future grid integration.

Keywords: Solar mini-grids, rural electrification, sustainable business model, Triple Bottom Line, Triple Layered Business Model Canvas

RESUME

L'Afrique de l'Ouest fait face à des défis persistants liés à la sous-électrification, et la Guinée-Bissau figure parmi les pays les moins électrifiés, avec un taux national de seulement 35,7 % et un taux d'électrification rurale limité à 7 %. Cela souligne l'urgence d'accélérer l'accès à l'électricité. Dans un tel contexte, des modèles économiques durables deviennent essentiels pour permettre une électrification viable et inclusive, notamment dans les zones où les marchés sont inexistants et où les revenus des ménages restent faibles.

Ce mémoire examine la conception d'un modèle économique durable pour les mini-réseaux solaires afin de renforcer l'électrification rurale en Guinée-Bissau, où le secteur reste embryonnaire avec seulement quatre projets mis en œuvre. En s'appuyant sur le cadre du Triple Bottom Line (TBL) et l'analyse SWOT, la recherche évalue les dimensions économiques, sociales et environnementales du modèle actuellement appliqué à Bissora.

Les résultats montrent que, bien que les revenus projetés (30 696 €) suggèrent initialement une marge positive par rapport aux coûts annuels (23 976 €), l'inclusion des obligations de remplacement (32 032 € par an) révèle un déficit structurel de 25 312 € par an, rendant le modèle financièrement non viable. Sur le plan social, le modèle ne répond pas pleinement aux besoins de la communauté : pannes fréquentes, exclusion de clients potentiels et faible soutien aux usages productifs limitent les bénéfices du développement liés à l'accès à l'électricité. Sur le plan environnemental, le mini-réseau contribue à la réduction des émissions en remplaçant le diesel, mais reste freiné par la pression de la déforestation et l'absence de stratégies de recyclage ou de gestion de fin de vie des équipements.

Pour combler ces lacunes, ce mémoire propose un modèle économique durable basé sur le Triple Layered Business Model Canvas (TLBMC). Ce modèle intègre : la fourniture fiable d'électricité, la promotion des usages productifs, l'implication communautaire et la gestion du cycle de vie des matériaux. Il s'appuie sur des partenariats stratégiques, des pratiques d'économie circulaire et des mécanismes de financement inclusifs.

Les recommandations politiques soulignent l'importance de promouvoir des partenariats multisectoriels, de mobiliser les financements climatiques et d'adopter une planification adaptative afin de permettre l'intégration future au réseau.

Mots-clés : mini-réseaux solaires, électrification rurale, modèle économique durable, Triple Bottom Line, Triple Layered Business Model Canvas

ACRONYMS AND ABBREVIATIONS

ACDB	Bambadinca Community Development Association
DIVUTEC	Study and Release of Appropriate Technologies
DCR	Design Science Research
SBM	Sustainable business model
SDG	Sustainable Development Goals
SMG	Solar Mini-Grid
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TBLC	Triple Bottom Line Canvas
TLBMC	Triple Layered Business Model Canvas
UEMOA	West African Economic and Monetary Union

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CHAPTER 1: Introduction

According to the International Energy Agency (IEA, 2021), achieving Sustainable Development Goal 7 (SDG7), which aims to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030, in West Africa remains highly challenging, as the 2019 electrification rate was below 50%, leaving over 170 million people without access to electricity. Particularly, in Guinea-Bissau, the electrification rate was only 35.7% in 2024 (IRENA, 2024). According to Antonanzas-Torres et al. (2021), the country is one of the least-electrified in the region, and the gap between urban and rural areas is very large: about 56% of people in the capital, Bissau, have electricity, but in rural areas it is 7%. A table of comparative statistics on electrification in West African countries is presented in Appendix A.

Significant efforts are urgently needed to accelerate and expand electrification access in rural areas to meet SDG7. Guinea-Bissau is at an early stage of adopting solar mini-grids (SMG) for rural communities, with four projects implemented so far (AMAP, 2025). The SMG in Bissora, like its predecessor in Bambadinca, faces various challenges, including technical issues linked to financial unsustainability, which undermine its ability to provide reliable services. These challenges negatively affect the communities they were intended to support, constrain local economic activities, reduce social well-being, and limit the delivery of the expected environmental benefits.

The core cause of these challenges is that in Guinea-Bissau the business models of SMG projects are often unclear, making effective management difficult for operators. Moreover, there is a lack of research on sustainable business models (SBM), which are a core factor for the success of SMG in rural areas. As Eales et al. (2024) note, existing business models, by focusing only on economic viability, often fail to achieve not only economic sustainability itself but also broader social sustainability, while Mukoro et al. (2022) emphasize the importance of integrating environmental considerations to ensure holistic sustainability. Therefore, SBM is crucial for SMG to be successfully implemented and sustained in the rural context, ensuring economic viability, social well-being, and environmental care in the long run.

To address this, the research is guided by the following questions:
RQ1: What are the existing business models for SMGs in developing countries, and what are their respective strengths and limitations from a sustainability perspective?
RQ2: How can a SMG business model be designed to effectively address economic, social, and environmental aspects in Guinea-Bissau?

The main objective of this research is to propose a SBM for SMGs in rural areas. This will be achieved through the following specific objectives:

1. To assess the sustainability of a traditional SMG business model.
2. To propose a SBM by addressing identified gaps and incorporating best practices from comparable international contexts.

This thesis is organized as follows:

- Chapter 2: Literature Review – Presents key theoretical foundation, reviews existing business models for SMGs, international experiences and projects implemented in Guinea-Bissau.
- Chapter 3: Methodology – Details the conceptual framework, research process, and explains the steps undertaken in the study. It discusses data collection, the TBLC, and SWOT analysis used to evaluate business model performance, as well as the TLBMC as the approach to designing the proposed business model.
- Chapter 4: Results and Discussion – Presents the evaluation of existing business models based on collected data, followed by the design of a SBM aimed at enhancing rural electrification. The chapter also discusses strategic planning for the adoption of the proposed SBM to ensure SMG viability.
- Conclusion – Summarizes the main findings, proposes actionable recommendations, and suggests directions for future research.

CHAPTER 2: Literature review

2.1. Theoretical framework

This research is based on two essential theories that guide both the evaluation of existing business models and the design of a SBM for SMGs: the Triple Bottom Line (TBL) and Stakeholder Theory.

The TBL framework, introduced by Elkington (1997), emphasizes that sustainability rests on three interconnected pillars: economic performance, social responsibility, and environmental protection, often summarized as "people, planet, profit." Earlier work in sustainability accounting (Lamberton, 2005) contributed to this approach, but Elkington's formulation established the TBL as a widely used model in both academia and practice. In parallel, sustainability became increasingly conceptualized through a tripartite model consisting of economic, environmental, and social pillars or goals (Basiago, 1999; Purvis et al., 2019). Nevertheless, debates emerged around the extent to which sustainability assessments added new insights. Some scholars argue that socio-economic aspects were already embedded in decision-making and that sustainability assessment risks duplicating efforts while excluding environmental considerations (Morrison-Saunders & Fischer, 2006).

The second theoretical foundation, Stakeholder Theory, was proposed by Freeman (1984). It argues that businesses achieve long-term success when they consider the needs and interests of all parties affected by their activities. In the context of SMGs, this includes end-users, local communities, suppliers, employees, and investors. Donaldson and Preston (1995) expanded on Freeman's work, arguing that companies possess a moral obligation to consider the interests of all stakeholders. Furthermore, stakeholder theory posits that stakeholders are interdependent, and creating value for one stakeholder creates value for the others (Parmar et al., 2010). This is the case, because if a stakeholder is not adequately considered, he or she will turn against the company (e.g., union strikes and consumer boycotts) and thereby harm profits (Jensen, 2001).

2.2. SMG business models in developing countries

Chaudhary (2019) pointed out that mini-grid business models in Africa remain largely unproven, despite encouraging developments in some countries like Kenya, Tanzania, and Nigeria. Therefore, this section highlights practical examples of SMG business models of these countries with more established experience in mini-grid deployment in Africa.

In Nigeria, a KeyStarter business model has been successful in providing support at the earliest stages of the agricultural cycle, including investments in seeds, equipment, training, extension services, and credit for smallholder farmers (Sesan et al., 2024). Another studied case is an operator in Kenya that decided to reach back even further in the value chain by partnering with another company on an initiative focused on improving the quality of poultry feed used by its contract farmers, and later integrating e-mobility services into its business model by introducing mini grid-powered bicycles and tricycles for hire by local motorcycle taxi operators (Sesan et al., 2024a). Both cases went through challenges, but in the end, the innovation brought evident benefit in a socio-economic perspective for both the operators and the communities they serve. This is because, as Cabanero et al. (2020) stated, the understanding of electricity should be as a means rather than merely an end in itself.

Eales et al. (2024) evaluated the performance of the Mthembanji SMG mini-grid in Malawi. As a result, the study highlights notable social impacts, particularly in terms of gender inclusion and overall community well-being, suggesting that such projects contribute to more than just energy access. However, economic sustainability remains a key area requiring improvement, given high capital ($ 101 995) and operational costs ($3796.8 annually) while the income (from 180 to516 USD/month) only covers the monthly OPEX costs, and provides no support for additional staff costs, transport, or wider business costs (Eales et al., 2024). Yet mini-grid experiences across West Africa suggest that balancing affordable service provision with acceptable cost recovery remains difficult to achieve (Bhattacharyya, 2018).

While paying attention to guaranteeing financial viability, in Tanzania private-led business model was challenged given the fact that some of the key promises that PowerGen made to potential consumers before implementing SMG just failed, which led to complaints and reduced satisfaction at the Kalenge community level (Ogeya et al., 2021). However, business models that account for high transaction costs in rural areas and that are based on realistic demand forecasts could considerably increase the commercial viability of mini-grids (Peters et al., 2019).

Therefore, this study (Ogeya et al., 2021), on its way to maximise positive user experiences, offers some insights:

- The business model needs to be redesigned to meet the needs of heavy-load users to go beyond improved living standards and small-scale business opportunities to support greater income generation and productive use.

- Creating realistic expectations and moderating unrealistic ones is crucial to avoid disappointment and dissatisfaction amongst users after the mini-grid is up and running.
- Continuous engagement to improve the user experience at the continued use stage could mitigate the risk of reverting to sources of energy used before the mini-grid.

Study done by Kapole et al. (2023) critically assess the 5 major SMG in Zambia giving very interesting inshights on economic, social and environmental sustainability. The following are the key findings:

- Economic sustainability - Community-owned SMGs such as Chibwika, Katamanda, and Magodi proved financially unsustainable due to low tariffs, weak revenues, and lack of clear business models. Privately managed plants showed slightly better results: Chitandika achieved partial sustainability through prepaid bundles but faced a long payback period, while Sinda underperformed because of low connections, though full utilization could make it viable (Kapole et al., 2023).
- Social sustainability - Despite weaknesses, the five SMGs were largely socially sustainable (Kapole et al., 2023). Affordability was achieved through fixed tariffs, and most plants provided reliable electricity, improving social connectedness, business hours, and education through extended study time. Rural health centers benefited from lighting and services at night, while communities reported reduced crime.
- Environmental sustainability - All SMGs reduced diesel use and greenhouse gas emissions, improving community health and environmental sustainability (Kapole et al., 2023). For example, Chitandika replaced diesel in hammer mills and welding shops. Studies estimate SMGs can displace 120,000 - 180,000 t CO2 eq. over 20 years (Moner-Girona et al., 2018), although hybrid systems with diesel backup can still emit significantly if solar generation is underutilized (Huber et al., 2021).

Still, from an environmental perspective in The Gambia, the installed PV system supplies electricity to the same rural community in Kaur previously served by the diesel units (DRAECK, 2017). However, Mukoro et al. (2022a) conclude that the environmental impacts of SMGs are generally higher in traditional than in circular business models, which include equipment end-of-life responsibility, while comparing these business models in Kenya.

2.3. SMG business models in Guinea-Bissau

The Bambadinca SMG became operational in 2015 and now serves over 650 customers, including households, businesses, and institutions, demonstrating the potential of such systems to extend access to clean electricity in off-grid areas of Guinea-Bissau (Business Models and Financing Instruments in the Solar Energy Sector, 2023). One of the key strengths of the Bambadinca model lies in its deep community participation from the outset. This approach fostered acceptance and reduced the use of traditional energy sources like candles and batteries by 50% (DRAECK, 2017). Prior to the project, in 2011, 96% of Bambadinca's population relied on candles and batteries, and only 60 of 1,000 households could access electricity with a diesel generator, which operated for five hours every day (International et al., 2024). At that time, households spent nearly 24% of their monthly income on energy. The mini-grid project has increased the number of households and institutions with electricity access from 5% to over 85% and reduced household expenditure by 14% on average. The report (International et al., 2024) concludes that the mini-grid provides a clean, efficient energy source to the community and has reduced emissions and reliance on polluting energy sources such as diesel generators.

The implemented SMG in 2017 in Contuboel, financed by the OPEC Fund for International Development (OFID) and the European Union, consists of a 100-kW solar plant with an estimated annual production of 200 MWh (ALER, n.d.). On the one hand, Sema (2020) questions whether the Contuboel mini-grid's business model is genuinely profitable given the large subsidies it received; on the other hand, Bukari et al. (2021) emphasize that a lack of funding can undermine business models altogether, highlighting the critical role of financial structures in mini-grid adoption.

In addition to the Contuboel and Bambadinca projects, another relevant case of a SMG in Guinea-Bissau is located in Bissora.

Unlike the approach adopted in Bambadinca, where a comprehensive stakeholder engagement process ensured community involvement throughout the project cycle, this 500 kWp SMG planning phase lacked effective consultation with local beneficiaries. According to Sema (2020), this lack of community participation was a major oversight and posed a serious threat to the long-term sustainability of the initiative.

CHAPTER 3: Methodology

This chapter describes the research approach and procedures used to carry out this study.

The methodology is structured into five main components: conceptual framework, case study method, process description, data collection, and data analysis.

3.1. Conceptual framework

Dibaba et al. (2023) emphasize the importance of continuously evaluating current mini-grid business models to ensure alignment with the unique needs of rural Sub-Saharan African (SSA) settings. Similarly, Ogeya et al. (2025) underscore the role of business model innovation in ensuring economic, social, and environmental sustainability.

Economic Sustainability

Commercial viability is widely recognized as the foremost challenge in expanding mini-grids in SSA (Bandi et al., 2022). Financial sustainability is primarily driven by tariff structures, as revenue generated must enable developers to recover capital and operational expenditures while ensuring a return on investment (Chaudhary, 2019). Even when capital expenditures (CAPEX) are partially or fully supported by donors, tariffs are still expected to cover operational and maintenance (O&M) costs (Antonanzas-Torres et al., 2021).

For this reason, we select CAPEX and OPEX coverage over the lifetime of the mini-grid as our primary benchmark for economic sustainability. For grant-financed projects, only OPEX coverage is considered. This criterion is evaluated using the Net Present Value (NPV), defined as the difference between the present value of cash inflows and the present value of cash outflows over the lifetime of the project (Ross et al., 2019). A non-negative NPV ($NPV \geq 0$) is used as a qualitative indicator of economic sustainability, demonstrating the model's ability to recover key costs during its operational life.

Social Sustainability

Affordability remains a significant barrier to achieving energy equity and retaining customers (Erdiwansyah et al., 2023). From Burkina Faso and Uganda to Zambia and South Africa, research reveals the persistent difficulty of operating mini-grids in areas where household incomes are substantially lower than the cost of electricity provision (Kapole et al., 2023).

Following Peters (2017), affordability is assessed by comparing the cost of a basic electricity package (1 kWh/day or 365 kWh/year) with household expenditure. If the cost exceeds 5% of household income, the service is deemed unaffordable.

Reliability is another essential component, defined by Bhatia and Angelou (2015) as the consistency of electricity supply, measured by the frequency and duration of unplanned outages. Reliable electricity enhances customers' willingness to pay, by reinforcing perceptions of fairness and value for money. Studies show that while energy access through mini-grids can support societal needs, such as education, health, and gender equity, these models alone are not sufficient to guarantee broader social development (Mukoro et al., 2022b). However, when affordability and reliability are met, indirect social benefits often follow. These include reduced time spent on household chores for women, increased capacity for nighttime study, enhanced services at local institutions, and improved communication through phone charging and access to news.

Environmental Sustainability

While the original methodologies emphasize a broad set of steps for creating circular business models (Mukoro et al., 2022), the adapted approach used here focuses specifically on identifying environmental "hotspots" within existing business models, evaluating their consequences, redesigning the model to address these impact.

In the context of SMG, the environmental evaluation centers on the impact of greenhouse gas (GHG) emissions, particularly CO_2. SMGs have strong potential to mitigate environmental costs by displacing kerosene and fossil-diesel fuels. Mukoro et al. (2022a) highlight that such displacement yields substantial emission reduction. Nevertheless, many mini-grids operate as hybrid systems with diesel backup generators, which can significantly contribute to emissions when solar penetration is low (Huber et al., 2021). Although PV/hybrid mini-grids result in lower carbon emissions than fossil-fuel based generation (Moner-Girona et al., 2018).

The environmental framework also incorporates circular economy considerations. At the baseline, low recycling rates shift the environmental burden upstream, as unrecovered materials place greater demand on resource extraction. This is a common feature of traditional, linear business models (Mukoro et al., 2022a).

3.2. Process description

A number of methodological approaches have been proposed in the literature for evaluating and designing business models. For instance, Zhang et al. (2019) developed the Rural Market Evaluation framework, specifically tailored for assessing business models in rural contexts. In terms of business model design tools, Osterwalder and Pigneur (2010) introduced the widely used Business Model Canvas (BMC), which primarily focuses on economic value creation.

While useful, both frameworks do not capture all critical variables within a comprehensive sustainability concept. In particular, they offer limited consideration of social and environmental dimensions, thereby falling short of aligning with broader sustainability goals.

This thesis adopts a predominantly qualitative mixed-method and design science research paradigm, integrating a single case study, two-steps business model evaluation and SWOT-based design. Such an approach aligns with Hevner, March, Park & Ram (2004) who define DSR as extending human capabilities by creating innovative artifacts and contributing knowledge through rigorous evaluation. Through semi-structured interviews and survey, serves as the primary means to understand the current business model and to design SBM.

The evaluation of the existing business model is conducted using the TBLC, which assesses business performance across economic, social, and environmental dimensions, helping to identify key gaps, particularly in the social and environmental domains.

A SWOT analysis is used as an intermediary diagnostic tool to identify strategic opportunities and threats that inform the redesign process, consistent with its application in renewable energy and rural electrification contexts (Kumar et al., 2017). Furthermore, Osterwalder and Pigneur (2010) consider SWOT as suitable transitioning from evaluation to design of business models.

The design of the proposed SBM employs the TLBMC, which extends the original Business Model Canvas by adding environmental and social layers to the economic layer. The TLBMC provides a concise framework to support visualization, communication and collaboration around innovating more SBMs (Joyce & Paquin, 2016).

3.3. Case study

A case study represents a methodological research approach that provides an in-depth understanding of contemporary phenomena within their real-world contexts (Bromley, 1986). This approach involves comprehensive investigation of individuals, groups, or events to examine complex phenomena in authentic settings (Ellinger & McWhorter, 2023).

This thesis employs a single case study approach to evaluate and redesign the business model of the Bissora SMG in Guinea-Bissau.

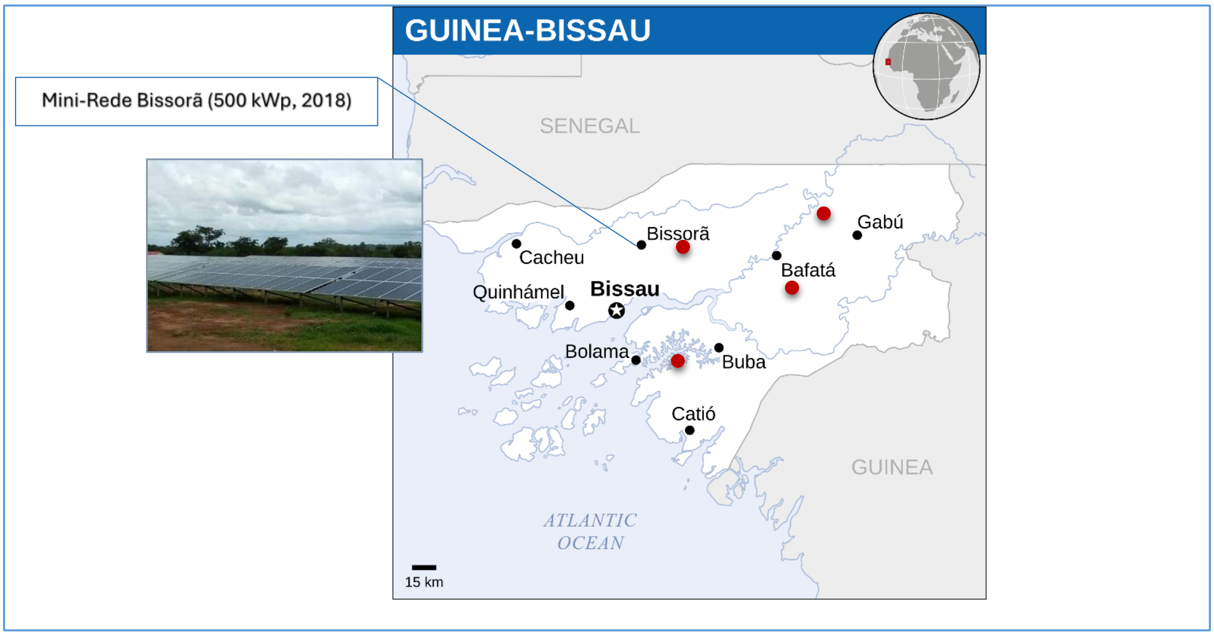

Figure 1 - Bissora Solar Mini-Grid

Source: (AMAP, 2025)

Following Creswell and Poth's (2018) framework for instrumental case studies, this research focuses on a specific issue, SBM development, through examination of a single case that exemplifies the challenges and opportunities in rural electrification. The Bissora mini-grid was selected based on three key factors:

1. Its location in Guinea-Bissau's rural context
2. The absence of prior business model analyses for this specific installation
3. Its seven-year operational history since establishment in 2018 (Sema, 2020), which provides sufficient stakeholder experience to assess the current model's impacts

3.4. Data collection

To map the existing business model from the operator's economic perspective, semi-structured interviews were conducted with two key representatives of the government entity that owns and operates the mini-grid: the management staff responsible for operations and the Director of Rural Electrification in Guinea-Bissau. Semi-structured interviews were chosen because they allow the researcher to explore specific themes while maintaining flexibility to follow up on relevant issues that arise during the discussion (Kallio et al., 2016).

In addition, a customer-oriented survey was conducted in person by trained enumerators within the geographical jurisdiction of the case study. The survey aimed to capture insights into the social and environmental impacts of the existing business model, complementing the economic perspective obtained from the interviews.

A stratified sampling approach was used to ensure proportional representation of households, businesses, and public services. Respondents included small business owners, households with and without electricity access, and public institutions. This method was selected because it improves the accuracy and representativeness of survey results by ensuring that important subgroups within the population are adequately included (Etikan & Bala, 2017).

3.5. Data analysis

Survey data were processed using Microsoft Excel to generate descriptive statistics, tables, and graphs for clear interpretation of patterns and trends. The survey results focus on economic, social and environmental dimensions of the existing business model, reflecting the perspectives of proportionally represented households, businesses, and public services in the study area.

Interview responses from government representatives responsible for the operation of the mini-grid (the Bissora SMG management responsible and the Director of Rural Electrification) were transcribed and subjected to thematic analysis. This method was chosen to identify recurring patterns, strategic issues, and operational insights that may not be fully captured by quantitative metrics (Braun & Clarke, 2006).

The overall results from the survey and interviews were synthesized using TBLC as an impact-oriented framework. The TBLC was applied to evaluate the Bissora SMG business model in relation to economic, social, and environmental sustainability. Following Osterwalder et al. (2012), TBLC includes nine core components that are described further in detail in subsection 3.5.1., given the fact that these blocks are inherent to the economic layer of TLBMC. The TBLC extends this by including two additional components, social and environmental costs, and social and environmental benefits, which enable the assessment of how well the model minimizes negative impacts and maximizes positive contributions to sustainable development (Wit & Pylak, 2020).

The current business model was then examined using a SWOT (Strengths, Weaknesses, Opportunities, and Threats) framework. This approach provides a structured means of identifying internal strengths and weaknesses, as well as external opportunities and threats (Tafida & Fiagbomeh, 2021). Identifying internal and external factors and matching them allows for the development of four sets of strategies in the SWOT matrix, in this case, towards business model innovation.

3.5.1. Triple Layer Business Model Canvas

Based on the SWOT outcomes, a new SBM was designed using the TLBMC. The TLBMC extends the original economic layer of the BMC by adding an environmental layer and a social layer (Joyce & Paquin, 2016).

Economic Layer

The Customer Segments block defines the different groups of people or organizations an enterprise aims to reach and serve. The Value Proposition represents the reason why customers choose one company over another, as it solves customer problems or satisfies customer needs. Communication, distribution, and sales Channels comprise a company's interface with customers, serving as touchpoints that play important roles in the customer experience. These channels perform several functions, including raising awareness about a company's products and services.

Customer Relationships describe the types of connections a company establishes with Customer Segments, which may be driven by various motivations:

- Customer acquisition
- Customer retention
- Boosting sales (upselling)

The Revenue Streams represent the cash a company generates from each customer segment. Key Resources are the assets required to offer and deliver necessary activities to ensure the Value Proposition. Key Activities are performed to maintain operations. Key Partnerships occur when some activities are outsourced or when resources are acquired outside the enterprise. The Cost Structure describes all expenses incurred to operate a business model successfully for customers.

Social Layer

This layer captures mutual influences between stakeholders and the organization, along with key social impacts deriving from these relationships.

Social value reflects the aspect of an organization's mission focused on creating benefits for stakeholders and society broadly. The employee's component examines their role as core stakeholders, including elements like workforce composition, demographics (pay, gender, ethnicity, education), and other relevant characteristics.

Governance captures organizational structure and decision-making policies. While economic relationships exist with business partners, social relationships develop with suppliers and local communities. These stakeholders converge as communities when aligning the three TBLMC layers. Successful community interactions often depend on developing and maintaining mutually beneficial relationships.

The societal culture component recognizes an organization's potential impact on society, leveraging the concept of sustainable value (Laszlo, 2008; Joyce & Paquin, 2016) to acknowledge how organizational actions can positively influence society (Steurer et al., 2005; Joyce & Paquin, 2016).

Scale of outreach describes the depth and breadth of stakeholder relationships developed over time, including long-term integrative relationships and geographic impact scope (local, regional, global). It also addresses how organizations navigate societal differences across cultures and countries.

The end-users are potential beneficiaries from the value proposition. Notably, the end-user may differ from the economic layer's customer definition. This component examines how the value proposition addresses user needs and contributes to quality of life, with segmentation typically based on demographics (age, income, ethnicity, education).

"Social impacts" means social costs that involved stakeholders can undergo concerning a given project, complementing the financial costs (economic layer) and biophysical impacts (environmental layer). Social benefits represent positive social value creation, providing explicit consideration of beneficial organizational actions.

Environmental Layer

The environmental layer of the TLBMC builds on a life cycle perspective of environmental impact, drawing from research and practice on Life Cycle Assessments (LCA). LCA and the canvas can be paired to analyse the impacts of traditional and propose strategies towards circular business models (Mukoro et al., 2022). Although such combinations are scarce in the literature (Kjaer et al., 2018).

The functional value describes the focal outputs of a service (or product) by the organization under examination. It emulates the functional unit in a life cycle assessment, providing a quantitative description of either the service performance or the needs fulfilled in the investigated product system (Rebitzer et al., 2004).

The materials component extends the key resources concept from the original business model canvas to the environmental dimension. The production component similarly extends the key activities element, capturing the actions the organization undertakes to create value. Supplies and outsourcing represent all other material and production activities necessary for functional value but not considered 'core' to the organization. Similar to the original business model canvas, this distinguishes between core versus non-core elements supporting value creation.

Distribution involves the transportation of goods. For service providers or manufacturers, distribution represents the physical means ensuring access to functional value. The use phase focuses on impacts during client engagement with the core service/product, including maintenance, repair, and consideration of client resource/energy requirements. And End-of-life occurs when an operator stops using a product, raising issues of reuse, recycling, or disposal.

The environmental impacts component addresses ecological costs of organizational actions, extending beyond traditional financial cost assessments. Environmental benefits expand value creation beyond financial measures to include ecological value through impact reductions and positive ecological contributions. This component enables organizations to explicitly explore innovations that may reduce negative or increase positive environmental impacts.

CHAPTER 4: Results and discussion

4.1. Evaluation of the Bissora mini-grid's current business model

To understand the current situation of the Bissora model, it is also essential to discuss the causes and effects behind the results. This helps to identify the main challenges of the model clearly and supports the design of a more sustainable and inclusive business model.

4.1.1. Data collection and sampling approach

According to projections by Sema (2020), the population of Bissora, estimated at 14,280 inhabitants (1,350 households) at the time of the SMG commissioning in 2018, has remained relatively stable and is expected to do so through year ten (2028). In this context, households represent approximately 55% of the population, small businesses 40%, and institutions 6%, with the mini-grid designed to operate at full capacity to meet this demand.

However, the current situation falls short of this expectation, with only 98 total connections recorded. The vast majority of these are households, alongside a smaller number of small businesses and a few institutions. This trend is consistent with Sema (2020), though the actual number of connections remains significantly below projections.

The survey ultimately included 86 respondents, of whom 85 consented to participate. As shown in Figure 2, among these 85 respondents, 57 (66%) represent households, 25 (29%) are small businesses, and 3 (4%) are institutions, including a school, health centre, and police station. Overall, 55% of respondents are connected to the mini-grid, while 44% are not, representing both actual and potential customer segments.

An important dimension of the data collection involved consideration of the geographical distribution of current and potential customers. Surveys were conducted across various neighborhoods in Bissora, including well-connected areas such as Joaquim Ncom and Braga, as well as zones with fewer connections or mostly unconnected potential customers, such as Praça, Ga-Semitério, and Mercado Central.

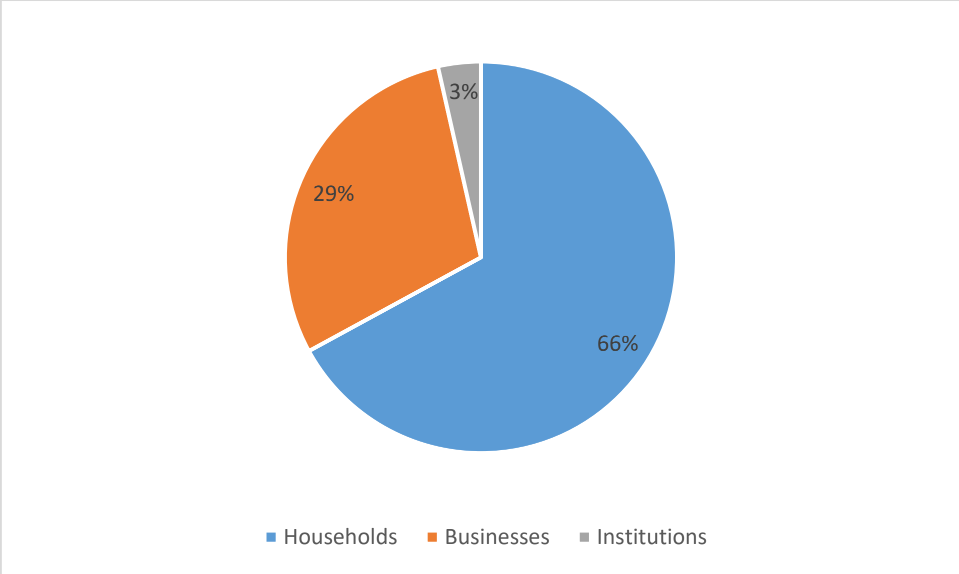

Figure 2 - Survey participation (85)

4.1.2. Mapping existing business model

In mapping the existing business model using the TBLC framework, we identified its key features across the different dimensions of the model.

Value proposition

According to mini-grid management, the solar home system was the standard for electricity generation in the community before the mini-grid, as it provided low-quality electricity:

"Currently, the only viable alternative for electricity access in Bissora outside the mini-grid is through Solar Home Systems (SHS). However, the mini-grid provides a higher quality and more reliable electricity supply, capable of powering household and commercial appliances that SHS units cannot support."

Therefore, customers recognize among a couple of benefits that the proposed value is noticeable, responding that the mini-grid electricity ensures better lighting and more reliable appliance operation compared to their diesel generation or solar home systems (see Figure 3). Nevertheless, the business model's value proposition can be compromised in this case if the electricity provided is unreliable. The appliances that consumers may have would not be beneficial to them with constant and lengthy interruptions. The management stated, "*Due to the technical problems we are facing, we can provide electricity during the day while sunlight is available*."

Beyond electricity provision, the Bissora mini-grid operator also decided to support community water access by powering water pumping systems. This initiative represents a contextually significant expansion of the value proposition, especially considering that most mini-grid operators focus exclusively on electricity generation and distribution.

For instance, in the Kenjya study, the value proposition across five mini-grid cases was primarily limited to electricity supply to end-users (Ogeya et al., 2025). By contrast, the inclusion of water pumping in Bissora illustrates a broader socio-economic value, addressing a critical local need and enhancing the relevance of the mini-grid within the community.

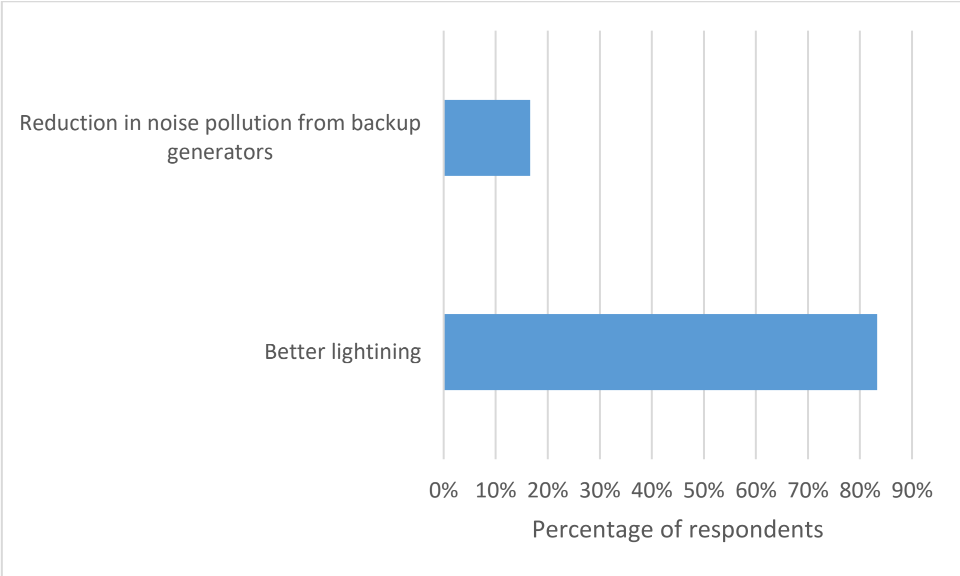

Figure 3 - The mini-grid differential benefits

Costumer segments

The SMG in Bissora serves three primary customer segments: households, small businesses, and institutions. These segments are commonly targeted by mini-grid developers. As Ogeya et al. (2025) emphasize, the main customer segments for private mini-grid developers typically include residential, commercial, and institutional users, with institutions such as schools, hospitals, and churches being particularly common targets. However, reliance on these segments for financial sustainability poses challenges, especially when electricity demand remains low or unstable.

In the case of the Bissora mini-grid, households constitute the majority of connected users, followed by small businesses. This reflects a common trend in rural electrification, where residential users dominate due to the demographic structure of rural communities.

Rather than assuming that profitability will come solely from high-load customers such as businesses or institutions, the focus should also include residential users as a key customer base

(Erdiwansyah et al., 2023), it is crucial to empower residential users to increase their electricity usage, particularly through access to electric appliances that enhance their daily lives and encourage higher, more consistent demand.

Currently, the number of active customers is below 100, whereas in the past it ranged between 500 and 600 connections. According to the mini-grid management, there are currently 98 active consumers. They noted that, despite relatively high tariffs, many potential customers still express interest in connecting. However, they attribute the reduction in connections to technical limitations, which led them to stop supplying power to heavy-load users and to scale down connections to households and small businesses.

In contrast, potential customers offered a different perspective. Many stated that they have not connected to the mini-grid primarily due to the unreliability of the electricity supply, rather than technical restrictions or tariffs. This perception is reflected in Figure 4, which summarizes the main reasons cited by those who remain unconnected.

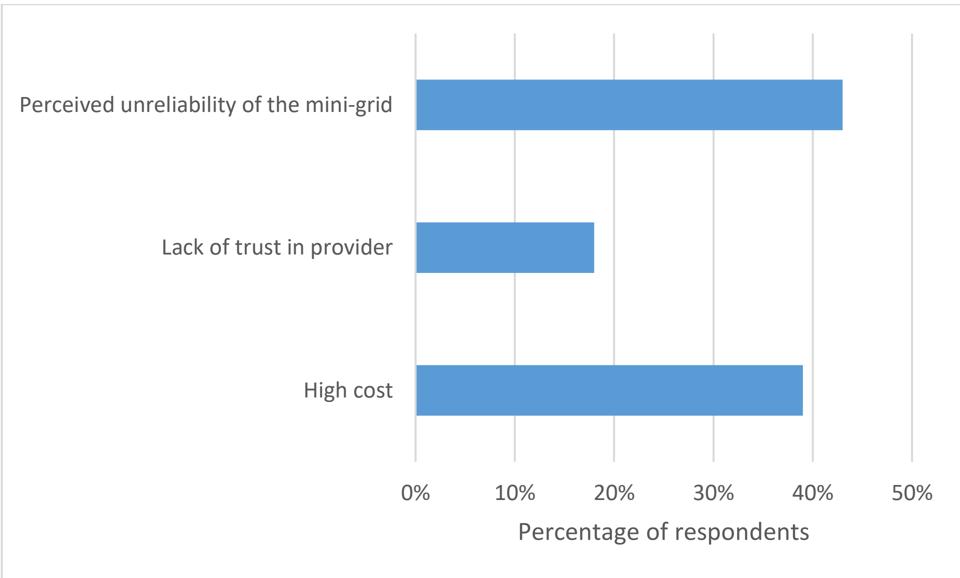

Figure 4 - Reasons for Not Being Connected to the Mini-Grid

Key partners

Partnerships are essential to the success of any business model, particularly when the project owner is not fully integrated or self-sufficient in meeting all the sector's requirements. In the case of the Bissora mini-grid, the only identified partner is the project's funder, the West African Economic and Monetary Union (UEMOA), through the African Biofuel and Renewable Energy Company (SABER/ABREC). The limited partnership structure makes the current business model less flexible and poorly equipped to respond to ongoing challenges, particularly those requiring technical, managerial, or operational support beyond the scope of the funder. Director of Rural Electrification:

"*The only official partner involved in the project is UEMOA, which financed the SMG. UEMOA is also expected to participate in future rehabilitation or maintenance work on the infrastructure, which may happen soon. It is essential to note that no maintenance has been performed since the system's commissioning, and it currently faces numerous technical issues.*"

Strengthening and expanding such collaborations is key to enhancing the sustainability and scalability of the SMG business model (Ogeya et al., 2025).

Key activities & Key resources

The current operational activities focus on technical management, accounting, security, backup power, and water pumping. However, a critical gap exists in the preventive and regular maintenance of the SMG equipment, which is essential for long-term system efficiency and reliability.

The key resources of the Bissora SMG include a 32-person workforce responsible for day-to-day operations. However, the current organizational structure could be improved by better integrating maintenance responsibilities into staff roles. While the mini-grid offers important opportunities for local employment, most of the jobs created are precarious in nature, such as those in security and cleaning services, with limited skill development or career progression. In contrast, PowerGen in Tanzania has adopted a more integrated staffing model by employing local technicians and a local sales agent, thereby enhancing both the sustainability of operations and the development of local human capital (Ogeya et al., 2021).

The water pumping system serves as both a maintenance resource (for panel cleaning to preserve energy output) and a revenue stream when excess water is sold. While backup generation was initially implemented to ensure a continuous nighttime power supply, this function has proven unreliable due to persistent system failures, indicating a need for improved maintenance protocols.

Customer relationships

The customer relationship is currently defined by a reactive cycle of complaints and troubleshooting. Management reports receiving approximately 10 complaints daily, predominantly about unexpected power outages. In response, they explain the technical constraints: the system's complete dependence on solar energy makes it vulnerable to weather conditions, while aging batteries (now in their tenth and final year of operation) and the absence of climate control in the battery storage room further compromise reliability. For issues identified as customer-side faults, technicians are typically deployed within one to two days. The management stated:

We explain to customers that our system relies entirely on solar energy, and when sunlight is insufficient, generation drops. The battery capacity has deteriorated — they are in their final year of a 10-year lifespan, and the battery room lacks air conditioning, which is essential for maintaining equipment performance. If the issue is on the customer's side, we arrange for a technician to visit within 1–2 days.

Consolidating this relationship would require a reliable system, alongside more transparent communication about system capabilities and maintenance schedules.

Channel

As noted previously, the customer relationship remains physical mainly in nature. While some communication channels are utilized, primarily for service warnings or gathering user feedback to improve operations, the interaction stays predominantly in-person.

In the event of service interruptions, we try to notify customers in advance using a megaphone… Payments are made in cash at the mini-grid's accounting office… Customers occasionally call or visit the administration office to report issues or share feedback… Recently, we established a WhatsApp chat group to facilitate closer interaction and enhance communication with our users.

Economic cost & revenue

The SMG business model demonstrates basic economic sustainability under current operating conditions. The current business model only covers operational costs, and even these remain difficult to sustain. This fragile financial state results from two key issues: an unclear business strategy and inadequate technical management. The consequences became evident when the mini-grid nearly collapsed, experiencing a sharp decline in connections, followed by a tariff increase from 5,000 XOF (~8 €) to 15,000 XOF (~23 €):

"*We recently increased the monthly tariff from 5,000 XOF (~8 €) to 15,000 XOF (~23 €) to reduce (discourage) demand due to technical constraints — we couldn't meet demand at the lower price...*"

For our evaluation of economic sustainability, we examine annual revenue streams against operational expenditures. In this analysis, we consider only overhead costs as regular maintenance expenses are not accounted for in current operations. Capital expenditures (CAPEX) are excluded from our calculations as the mini-grid infrastructure was provided to the government as a donation.

The Bissora SMG currently supplies power to 98 connected entities, comprising predominantly households along with several businesses and institutional customers. The system employs a uniform pricing structure, charging all customer segments a fixed monthly tariff of €23, which generates a maximum potential revenue of €2,254 per month from electricity sales. Beyond electricity provision, the mini-grid produces additional income through water pumping services, serving 22 community customers at a rate of €0.92 per 1,000 liters. With an average monthly water volume of 330,750 liters, this translates to €304 in monthly water revenue. When combined, these two revenue streams yield a total monthly income of €2,558 for the mini-grid management. Under ideal operating conditions with full payment compliance and uninterrupted service delivery, this translates to an annual revenue potential of €30,696. The current operational expenditure structure[1], which excludes maintenance costs, is detailed in the accompanying financial Tables 1 and 2.

[1] The West African CFA franc (XOF) is pegged to the euro at a fixed exchange rate of 1 EUR = 655.957 XOF (IMF, n.d.).

Table 1- Staff expenses

Role	Salary (XOF)	Salary (€ EUR)	Quantity	Total (XOF)	Total (€ EUR)
Delegate / Assistant Delegate / Deputy	50,000	€76	3	150,000	€228
Secretary / Treasurer	30,000	€46	2	60,000	€92
Main Administrator	45,000	€69	1	45,000	€69
Deputy Administrator	40,000	€61	1	40,000	€61
Head Technician of the Power Plant	75,000	€114	1	75,000	€114
Assistant Technician of the Power Plant	65,000	€99	1	65,000	€99
Plant Inspection Team (3 positions)	40,000	€61	3	120,000	€183
Head / Deputy Head of Power Network	30,000	€46	2	60,000	€92
Electricians	30,000	€46	4	120,000	€183
Head / Deputy Head of Plumbing Network	30,000	€46	2	60,000	€92
Plumbers	30,000	€46	4	120,000	€183
Cleaner	30,000	€46	1	30,000	€46
Security Staff (responsible & night shift)	30,000	€46	5	150,000	€228
Security Staff	28,000	€43	3	84,000	€129
TOTAL			**33**	**1,179,000**	**€1,799**

Source: Recorded dataset from Bissora SMG (field data)

Table 2 - Estimated overhead costs for Bissora SMG

Cost designation	Monthly cost (€)	Annual cost (€)
Staff cost	1,798	21,576
Logistics cost for water delivery	200	2,400
Total	**1,998**	**23,976**

Source: Recorded dataset from Bissora SMG (field data) and own calculations

The comparative analysis of annual costs (€23,976) versus projected revenues (€30,696) suggests a nominal gross margin of €6,720. While this positive differential initially indicates financial viability, several critical considerations undermine this conclusion. First, the current cost framework excludes potentially significant operational contingencies that could substantially erode the apparent surplus. Second, the revenue projections assume ideal operating conditions with full payment compliance, an optimistic scenario that may not accurately reflect reality due to eventual lower willingness to pay inherent to a high imposed tariff and unreliable service.

A more realistic assessment must account for the annualized replacement costs of key components over the system's lifetime. As shown in Table 3, the total cost of material replacements over 25 years amounts to €800,811.9, equivalent to €32,032.48 annually. When this figure is compared to the gross margin of €6,720, the result is a deficit of €25,312.48 per year. This structural imbalance indicates that, rather than generating sustainable surpluses, the project would operate with persistent negative cash flow once replacement obligations are incorporated. Such a financial trajectory strongly suggests either (i) the gradual deterioration and premature collapse of the mini-grid due to underfunded maintenance, or (ii) the need for external subsidies, tariff adjustments, or cross-subsidization mechanisms to ensure continuity of service.

Table 3 - Costs of Maintenance (Material Replacements)

Component	**Quantity**	**Unit cost (€)**	**Cost per renewal (€)**	**Lifetime (years)**	**Renewals (25 years)**	**Total cost over 25 years (€)**	**Annualized cost (€)**
Batteries	432	604	260,928	7	2	521,856	20,874.24
Grid inverters	18	3,803	68,454	10	1	68,454	2,738.16
Battery inverters	54	3,192	172,368	11	1	172,368	6,894.72
Miscellaneous	–	–	–	–	–	38,133.9	1,525.36
Total	–	–	–	–	–	**800,811.9**	**32,032.48**

Source: Recorded dataset from Bissora SMG (field data) and own calculations

Consequently, while the mini-grid demonstrates basic operational sustainability in the short term, its current financial model lacks the necessary resilience to ensure viability across the project's lifecycle.

Social costs & benefits

The current pricing structure reveals significant challenges in striking a balance between affordability and sustainability. At a fixed tariff of €23 per month, representing approximately 33% of average monthly income for households and small businesses (typically under €70), the electricity costs already impose a substantial burden on customers. The mini-grid's reliability issues force customers to maintain parallel energy expenditures. Frequent and prolonged outages compel users to spend nearly equivalent amounts (approximately €23 monthly) on supplemental energy sources, effectively doubling their energy costs.

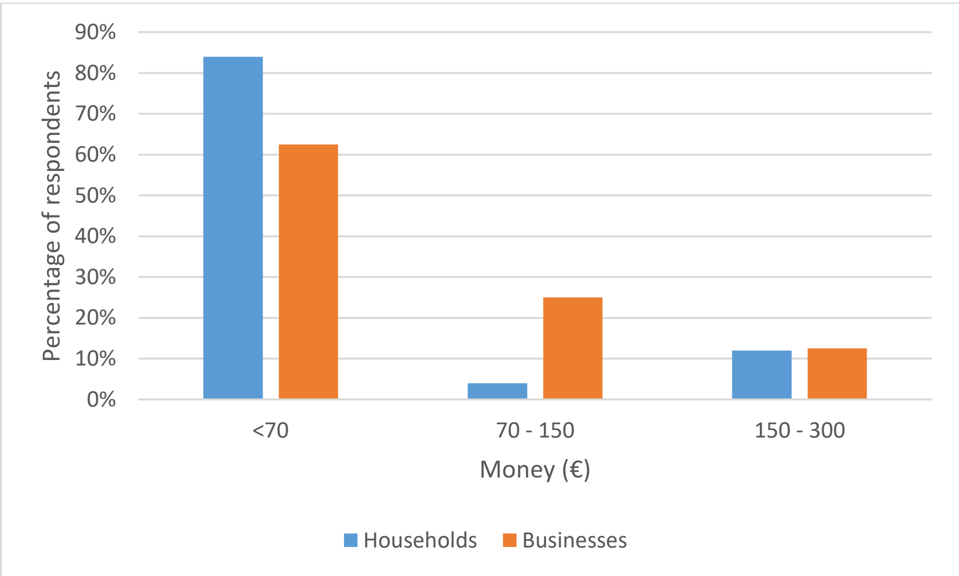

Figure 5 - Monthly income level of connected households and businesses

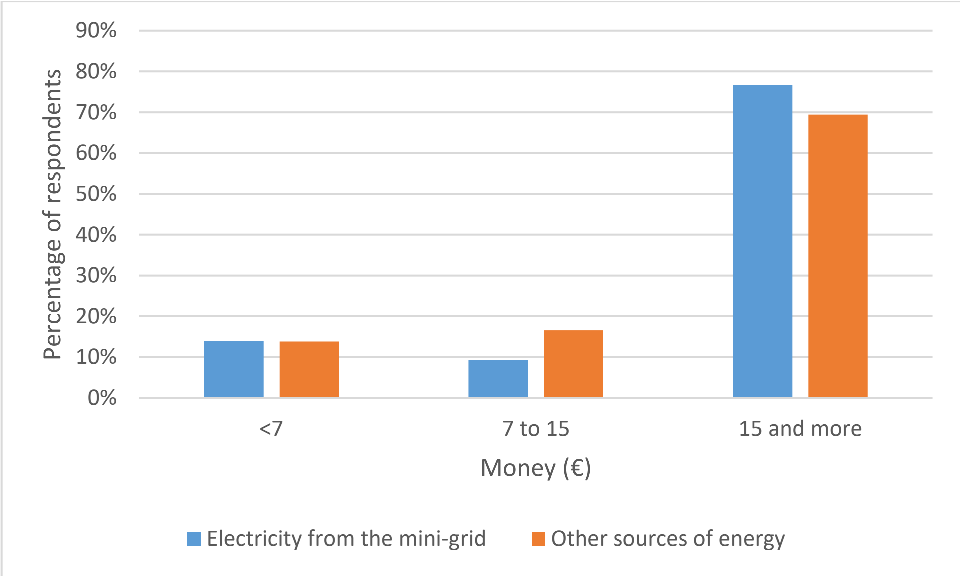

Figure 6 - Monthly energy expenditure distribution

The mini-grid's performance in delivering its promised socioeconomic benefits, including livelihood improvement, educational enhancement, healthcare access, and income generation, reveals significant shortcomings.

When examining the mini-grid's effect on home study conditions, no respondents reported improvements. Users universally noted that frequent nighttime outages force students to continue studying by candlelight – an inefficient method that poses health risks to vision. This represents a clear failure to deliver one of electrification's most fundamental educational benefits.

The project has similarly failed to reduce women's domestic labor burdens. Most households report no decrease in cooking time, primarily because they cannot afford or access electric cooking appliances. This maintenance of the status quo contradicts one of rural electrification's key gender equity objectives.

Overall, multiple users report that their living conditions have actually worsened relative to their pre-connection situation. This regression suggests the mini-grid may be creating new burdens rather than alleviating existing challenges. The high tariff further contributes to a negative perception of value for money, especially when electricity availability is inconsistent.

In contrast, experiences from five rural SMGs in Zambia revealed a more positive outlook. Despite facing certain social challenges, those projects were associated with improvements in community well-being, including better education and healthcare delivery, reduced crime rates, extended business operating hours, and increased access to entertainment (Kapole et al., 2023). In that context, social sustainability was understood as a combination of affordable tariffs and the availability of electricity on a 24/7 basis.

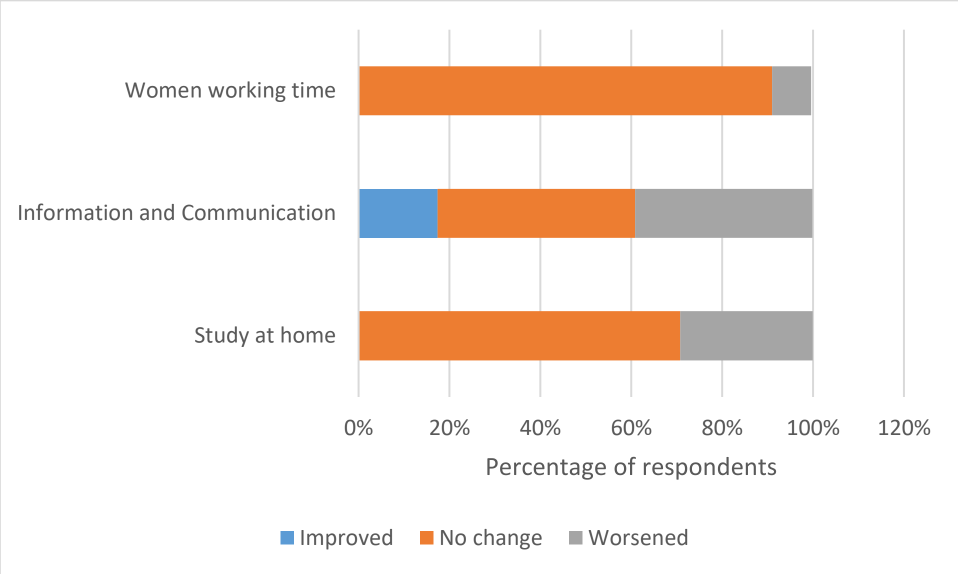

Figure 7 - Mini-grid impact on households

The mini-grid's contribution to income generation among households and small businesses reveals a pattern of underperformance. While a minority of respondents report positive impacts, the overwhelming majority describe either neutral or negative outcomes, with many enterprises experiencing financial losses directly attributable to the power supply's limitations.

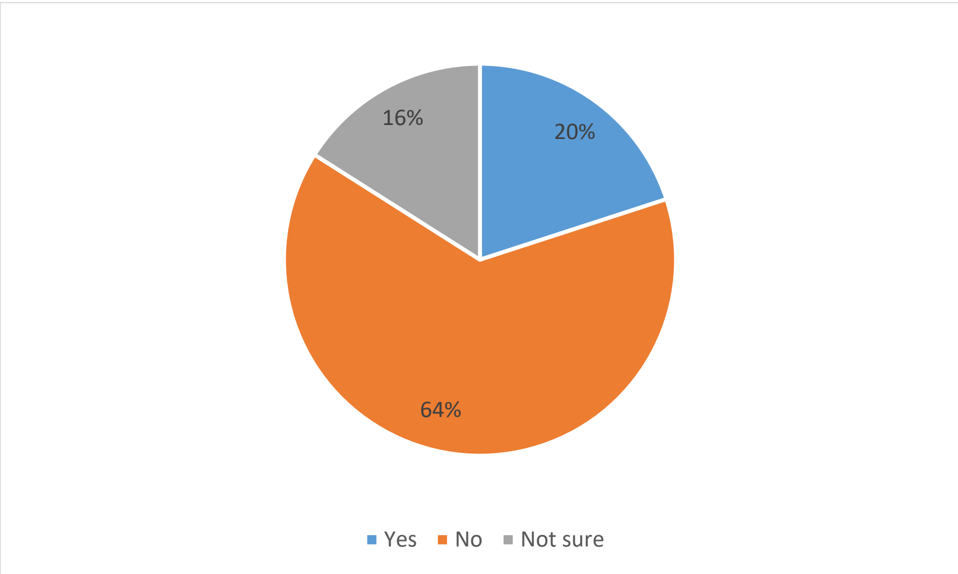

Figure 8 - Mini-grid opportunities for households to earn extra income

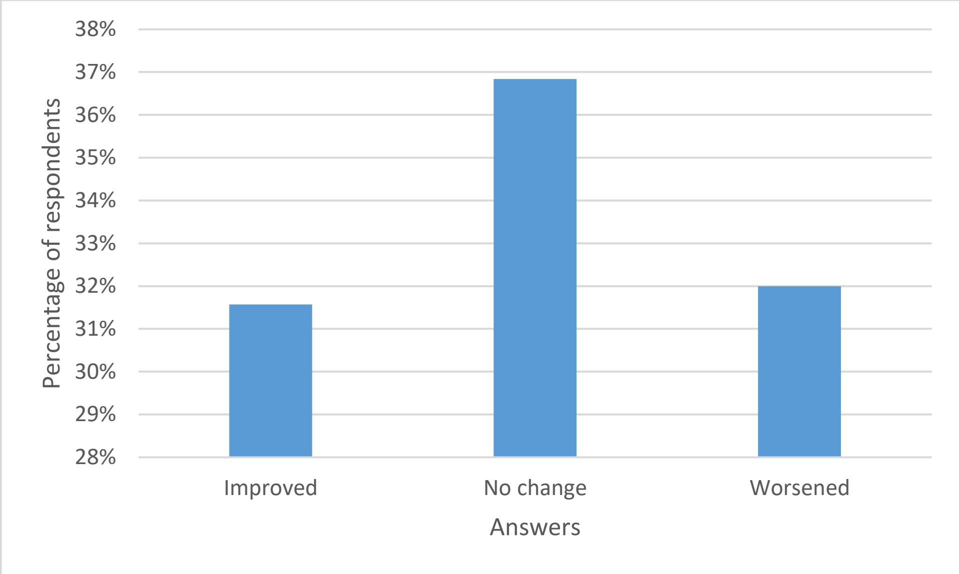

Figure 9 - The mini-grid effect on business income

Institutional users reported similarly poor or even worse outcomes, with none perceiving any improvement in their service delivery capabilities as shown in Figure 10.

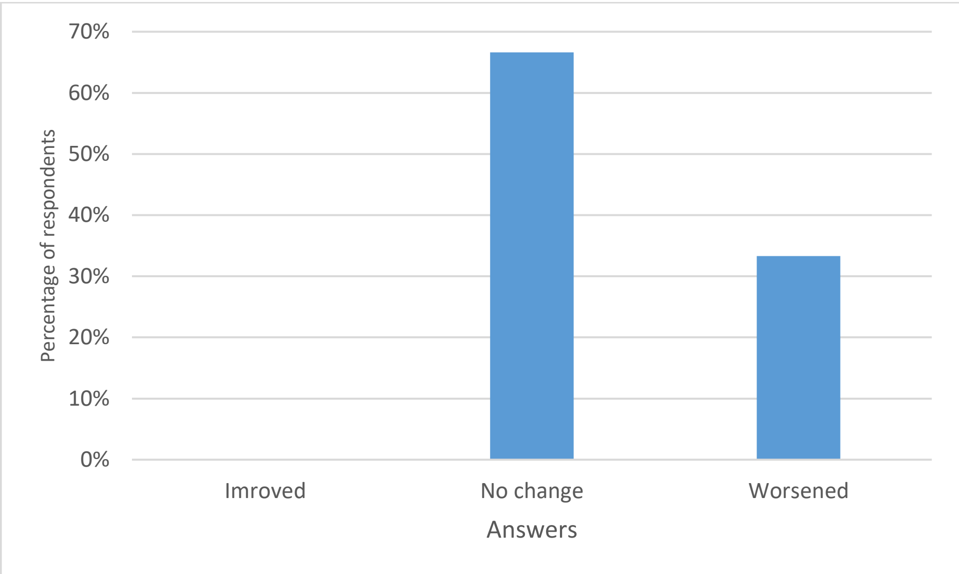

Figure 10 - The mini-grid effect on institutions' ability to deliver services

The data suggests that for most commercial users and institutions, the mini-grid currently functions as a supplemental rather than primary power source, undermining its potential as a catalyst for local economic development.

Environmental costs & benefits

Deforestation is the primary environmental cost for the local community and the broader ecosystem. Trees play a crucial role in absorbing greenhouse gas emissions, with one hectare capable of sequestering between 25 and 30 tons of CO_2 annually (Grow Billion Trees, n.d.). The mini-grid system occupies approximately 17,500 m² (Sema, 2020), which is equivalent to 1.75 hectares, potentially reducing the land's carbon absorption capacity by up to 52.5 tons of CO_2 each year. Director of rural electrification:

"*On the environmental side, one negative impact was the deforestation that occurred during land preparation. Trees were cleared to make space for the solar infrastructure, which may have environmental consequences.*"

One key environmental cost of the mini-grid system is the continued reliance on diesel generation, especially at night when solar energy is unavailable. According to the mini-grid management, approximately 6,000 litres of diesel are consumed monthly to ensure power supply. Based on estimates from the U.S. Energy Information Administration (EIA, 2024), one litre of diesel emits approximately 2.6 kg of CO_2. This results in an estimated 15.6 tons of CO_2 emissions per month, or 187.2 tons annually, from diesel usage alone.

Despite this, the mini-grid project is designed to reduce greenhouse gas emissions by replacing diesel generators with solar energy. As the Director of Rural Electrification explained:

"*While I am not sure if the project had explicit environmental goals, I believe reducing environmental impact—especially CO_2 emissions—was likely one of the motivations. Across the country, rural communities, including Bissora, previously relied on large-scale diesel.*"

At full operational capacity, the Bissora mini-grid is estimated to save 525 tons of CO_2 equivalent (tCO_2e) per year (Sema, 2020).

However, this projected benefit is currently limited by low customer uptake and reliability issues. Survey data show that almost half of the connected users did not acquire new electrical appliances, indicating continued reliance on traditional energy sources such as diesel, charcoal, and firewood. Frequent and prolonged interruptions, particularly at night, mean that many households still use polluting fuels to meet their daily needs.

Despite existing limitations, 53% of customers reported acquiring new appliances such as light bulbs, refrigerators, water heaters, and printers. This indicates a gradual shift away from traditional energy sources like biomass and diesel, contributing positively to emission reductions. In the absence of the SMG, these appliances would likely rely entirely on diesel generators, increasing both operational costs and environmental impact. The uptake of these appliances suggests that renewable mini-grids can facilitate cleaner energy use in rural communities when users are empowered to expand their energy consumption.

This stands in contrast to the experience in Zambia, where users were not permitted to use heating appliances such as electric irons, stoves, and water boilers due to system limitations (Kapole et al., 2023). As a result, none of the five mini-grid projects studied there had contributed to reducing deforestation, air pollution from traditional fuels, or the time and labour burden of collecting firewood for cooking (Kapole et al., 2023).

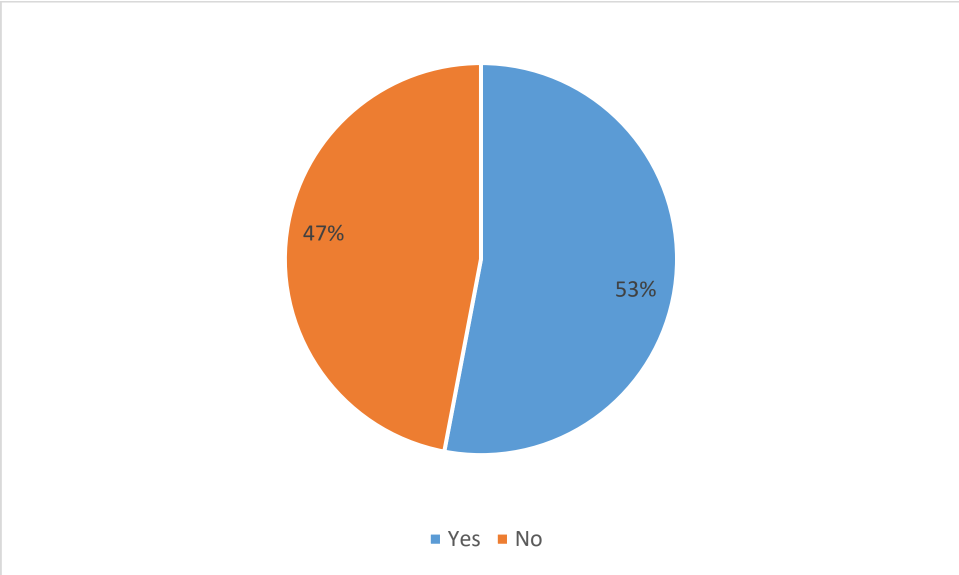

Figure 11 - Additional Appliance Usage with Mini-Grid Electricity

Based on the analysis above, it is evident that the current business model of the Bissora SMG presents both promising impacts and notable limitations. On the one hand, the system has introduced cleaner energy alternatives, contributing to reduced reliance on biomass and diesel fuels among a significant portion of users. On the other hand, reliability issues and limited customer adaptation continue to hinder the full realization of its environmental and social benefits.

To better visualise these insights, Figure 12 summarises the key strengths and limitations of the Bissora SMG business model at its current stage of development.

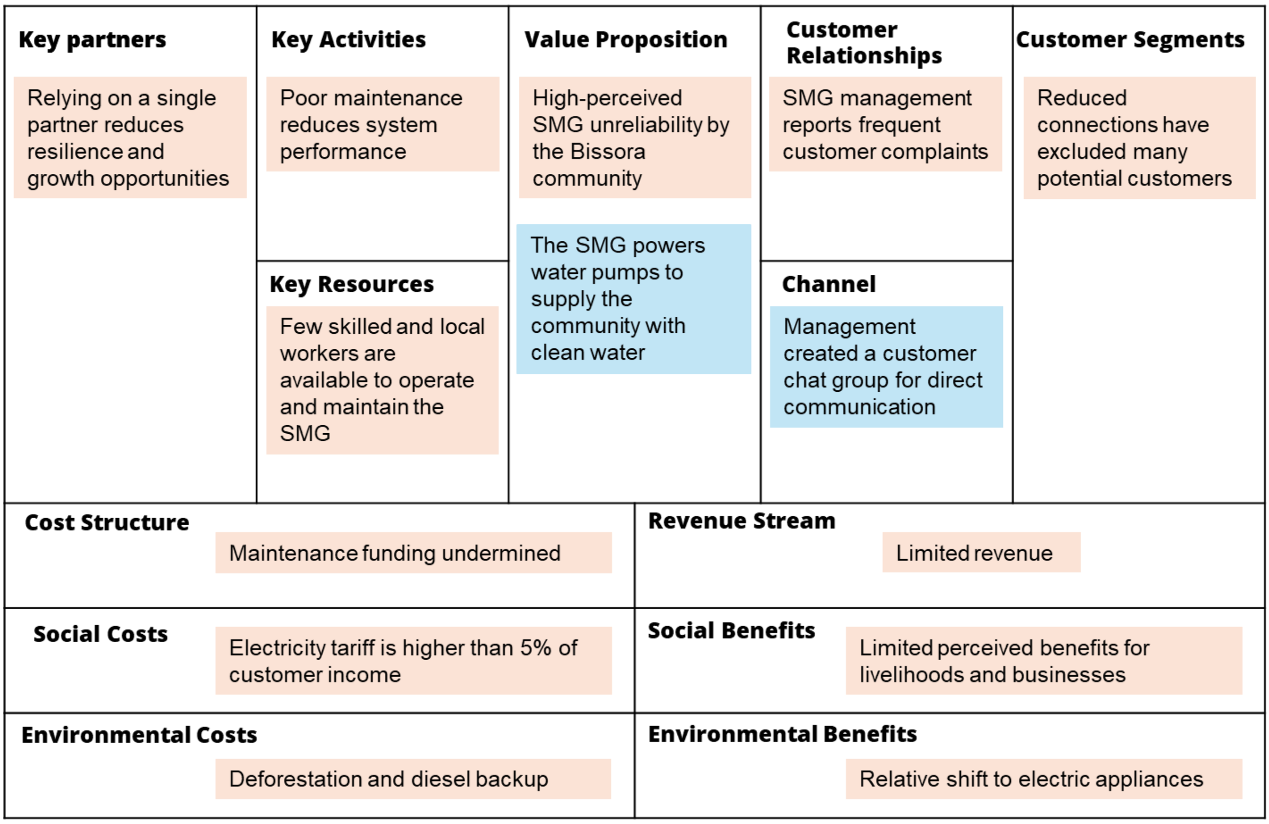

Figure 12 - Documentation of Bissora SMG current business model

4.2. SWOT analysis

Internally, the current business model exhibits several notable strengths. It supports, according to the mini-grid management, when interviewed, water provision through electric pumping systems, thereby improving community well-being and enhancing access to basic services. The business model is based on the use of renewable energy, thereby reducing dependence on fossil fuels and enhancing environmental sustainability. Decentralized renewable energy systems such as SMGs offer long-term benefits in mitigating climate change and improving rural energy access (Nyarko et al., 2023). The project also generates local employment and stimulates economic activity.

Despite these strengths, the mini-grid is constrained by significant internal weaknesses. The electricity supply is unreliable, particularly at night, which undermines user confidence and potential benefits. Technical limitations also led to a tariff increment to discourage connection. This is against energy justice. Decentralised energy systems in rural areas needs to incorporate strategies for inclusive approaches to also reach lower-income groups in the communities to ensure that 'no-one is left behind' (Stritzke & Jain, 2021). In parallel, the absence of a circular plan for equipment end-of-life management exacerbates environmental concerns. At baseline, recycling rates remain low, which shifts the environmental burden upstream due to unrecovered materials. In such cases, the negative environmental impacts are effectively transferred to the traditional incumbent business model (Mukoro et al., 2022a).

Furthermore, the system suffers from a lack of preventive and corrective maintenance, compounded by a shortage of specialized technical personnel. These factors threaten the system's long-term operability. The absence of strategic partnerships restricts innovation, limits access to external resources, and hinders efforts to build technical capacity.

The external environment presents a number of promising opportunities. There is a strong willingness among unconnected households to join the system, indicating a potential for customer base expansion. The availability of a large physical area allows for future system upgrades and scaling to accommodate population growth and rising electricity demand. Expanding the mini-grid beyond its initial customer base represents a critical opportunity to strengthen the long-term sustainability of the business model. The mini-grid can sell electricity directly to consumers at retail tariffs and sells surplus power to the main grid—a model that supports revenue generation (Segura-Rodríguez et al., 2025). Another strategic opportunity lies in capacity building. A training school dedicated to electricity production and installation provides a foundation for enhancing local skills, which is essential for the long-term sustainability and operational efficiency of the mini-grid (Sawadogo et al., 2025).

Despite these opportunities, several threats could compromise the mini-grid’s viability. A critical threat is the risk of system abandonment due to two key factors: (1) grid encroachment, where consumers switch to the main grid due to its lower tariffs and perceived reliability; and (2) technical failure, often stemming from poor maintenance, low-quality components, inadequate funding for reinvestment, and limited consumer awareness (Segura-Rodríguez et al., 2025). Moreover, the project’s financial sustainability is hindered by a limited capacity for self-financing, leading to a dependence on external funding. Without long-term financial strategies, the risk of system abandonment remains high.

A summary of the SWOT analysis is presented in Table 4.

Table 4 - SWOT analysis

Internal / External	**Strengths** 1. Local employment 2. Water supply 3. GHG and pollution reduction 4. Load-Sufficient System	**Weaknesses** 1. Lack of maintenance 2. Lack of strategic partners 3. No circular plan for equipment end-of-life
Opportunities 1. High willingness for potential customers to connect 2. Local vocational training school on electricity production and installation 3. Population growth	**Strategy - SO** 1. Partnership with the local training school to support and upskill the local workforce continuously 2. Selling electrical appliances through partners to ensure the expected social and environmental benefits 3. Expansion of the system to increase the power capacity	**Strategy - WO** 1. Seeking strategic partners for sustainable mini-grid implementation 2. Including potential customers in the long-term plan (expand the system)
Threats 1. Reliable competitor 2. Scepticism toward transitioning to productive and cleaner energy consumption 3. Uncertainty of continued external funding	**Strategy - ST** 1. Planning grid service provision 2. Community engagement and awareness	**Strategy - WT** 1. Budget for large-scale maintenance and system routine maintenance to provide reliable electricity (enhancing competitiveness) 2. Increasing self-financing capacity through improved revenue collection mechanisms 3. Channeling decommissioned materials to recycling partners

4.3. Designing a SBM

This subsection presents the design of a sustainable business model for a SMG to enhance rural electrification in Guinea-Bissau. The resulting business model obtained through the TLBM canvas, composed of three (3) layers, and finally reinforced by strategic planning as presented below:

Economic layer

In a SBM, the value proposition is the provision of reliable electricity with an affordable tariff. This is because the electricity service satisfaction can only be guaranteed with the reliability of supply. In fact, in (Ogeya et al., 2021) Kalenge SMG mapping, the users illustrated a range of wellbeing and social benefits resulting from the use of the mini-grid services. For instance, light load users (lighting, TV and radios) were generally satisfied with services and highlighted benefits such as access to reliable power (compared to solar home systems, solar lanterns or battery-powered torches), which enabled them to charge phones, read at night and watch TV (Ogeya et al., 2021). Reliability must be supported by a strong technical foundation, including both preventive and reactive maintenance. While these measures may increase operational costs, they can positively impact revenue by enhancing service quality and increasing customers' willingness to pay. As Tenenbaum et al. (2014) argue, "systems with regular maintenance demonstrate significantly higher reliability, which directly influences user satisfaction, productive use, and willingness to pay".

We choose to collaborate with strategic partners: financial institutions to support key activities and resources needed to deliver the value; technical skill providers and procurement companies to support the steady efficiency of the mini-grid so that the value proposition cannot be compromised.

The village serves as both the current customer base and the source of potential future connections. Customer segments remain households (the majority), small businesses, and a few institutions. The customer relationship is maintained through personal engagement, supported by call centre to ensure quick response to issues, recognizing that the primary stakeholder is the rural community. Gradually, most operators have adopted call centers in Kenya, that operate 24 h to ensure uninterrupted services and enhance producer – user relationship (Ogeya et al., 2021).

Costs include investments in SMG and water pumping assets (such as panels, batteries, backup generators, distribution lines, and other complementary infrastructure), along with operational expenses (maintenance and overhead). Additional costs arise from acquiring electric appliances and setting up the related sales business, including human resources and storage facilities. Revenue primarily comes from customer electricity tariffs. Water delivery offers an additional income stream while also helping address local water challenges. Furthermore, sales of electric appliances provide another revenue source, strengthening the profitability of the business model.

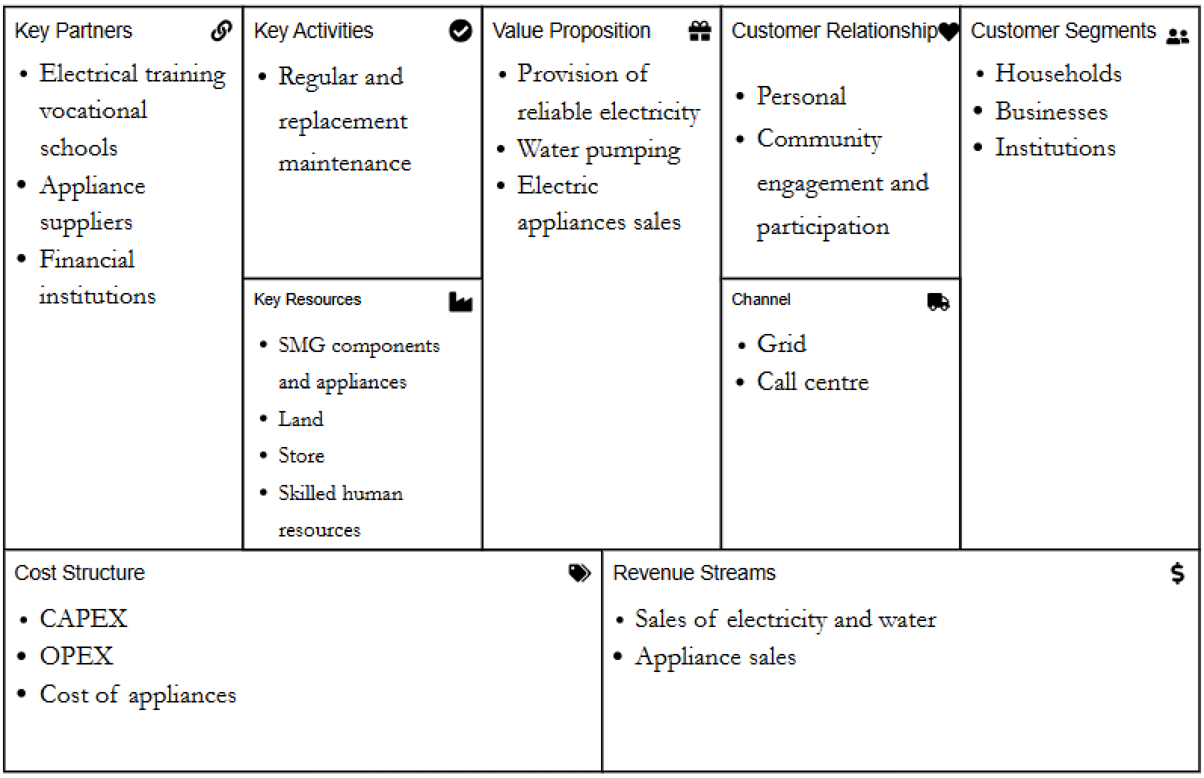

Figure 13 - Economic layer

Social layer

As an extension of the value proposition within the economic dimension, the operator's mission includes generating tangible benefits for key stakeholders, particularly electricity and water end-users within the community. The social value created aims to enhance community well-being through reliable access to electricity and water, while also empowering users with electric appliances that support productive use. In addition, the reliability of electricity is essential for the functioning of schools, health centers, and administrative services, critical components of community infrastructure. The business model also supports small businesses by enabling them to operate at full capacity, contributing to local economic vibrancy.

This empowerment is intended to generate broader social impacts, including improved access to education, healthcare, information and communication, and greater inclusion of women in economic activities. Prioritizing these areas aligns with evidence from development studies, which show that energy access can act as a catalyst for multidimensional poverty reduction (Pueyo et al., 2013). Furthermore, the most important benefit of electricity access is improved quality of life through better lighting, health services, education, and income-generating opportunities (World Bank, 2021).

Furthermore, it aims to create local jobs and ensure fair compensation, recognizing community members not just as beneficiaries, but as active stakeholders in the system's success.

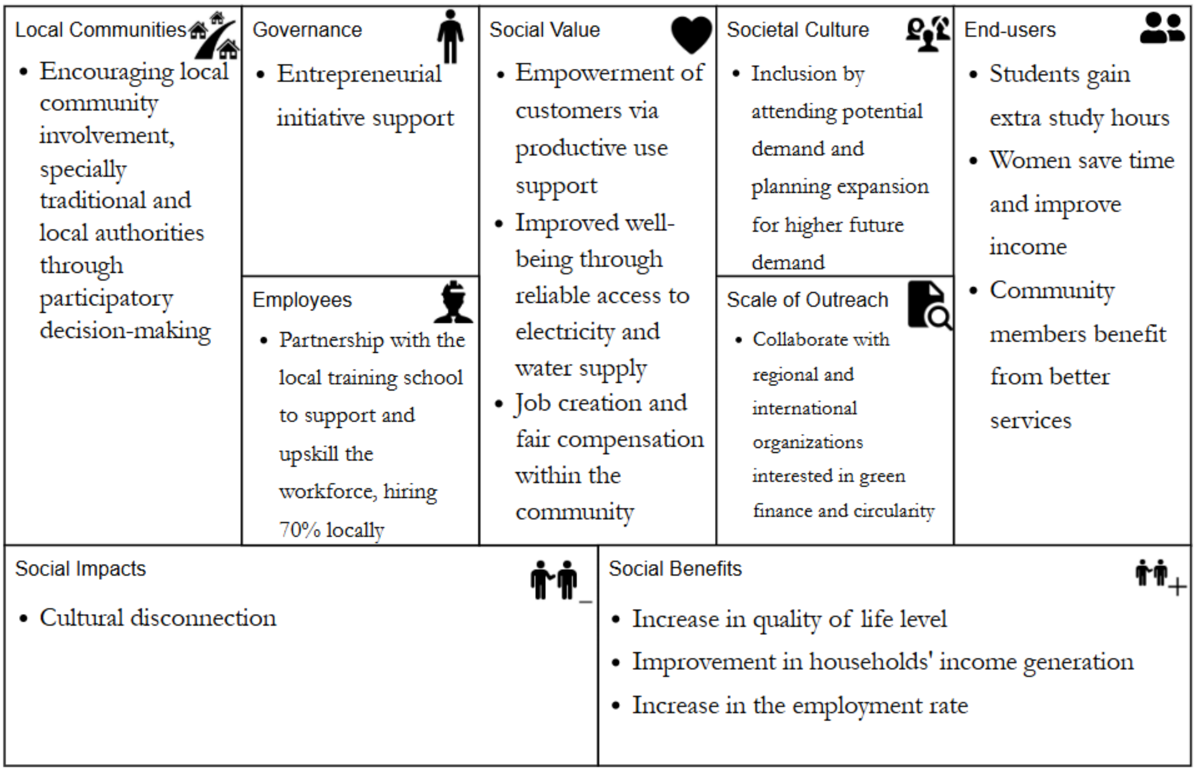

Figure 14 - Social layer

Environmental layer

The business model presents strong functional value within the environmental layer by enabling the transition to a cleaner, more sustainable energy system. By leveraging renewable energy sources—specifically photovoltaic (PV) solar power—it has the potential to cover an average of 656.6 MWh per year of energy demand. This shift from fossil fuels to clean energy is estimated to avoid approximately 525 tonnes of CO_2 equivalent emissions annually. This contribution is not only technically significant but also aligns with broader goals of environmental sustainability and climate mitigation. As Smith et al. (2019) highlight, transitioning to renewable energy offers long-term environmental benefits, including reduced greenhouse gas emissions and decreased air pollution.

Moreover, the project promotes contributing to a circular approach to material use by planning for end-of-life recycling of system components, closing the loop on resource use and minimizing environmental harm. Integrating circular business models into the project's design has the potential to further reduce greenhouse gas emissions by 25% to 55%, with a climate change potential ranging between 33.8 and 58.4 g CO_2 eq./kWh (Mukoro et al., 2022).

Electric appliances for connected users must be ensured during the use phase to guarantee a transition away from traditional fuel sources commonly used in rural communities. However, some negative impacts remain unavoidable, including water depletion, land use for establishing SMGs, and emissions from diesel generation in hybrid systems.

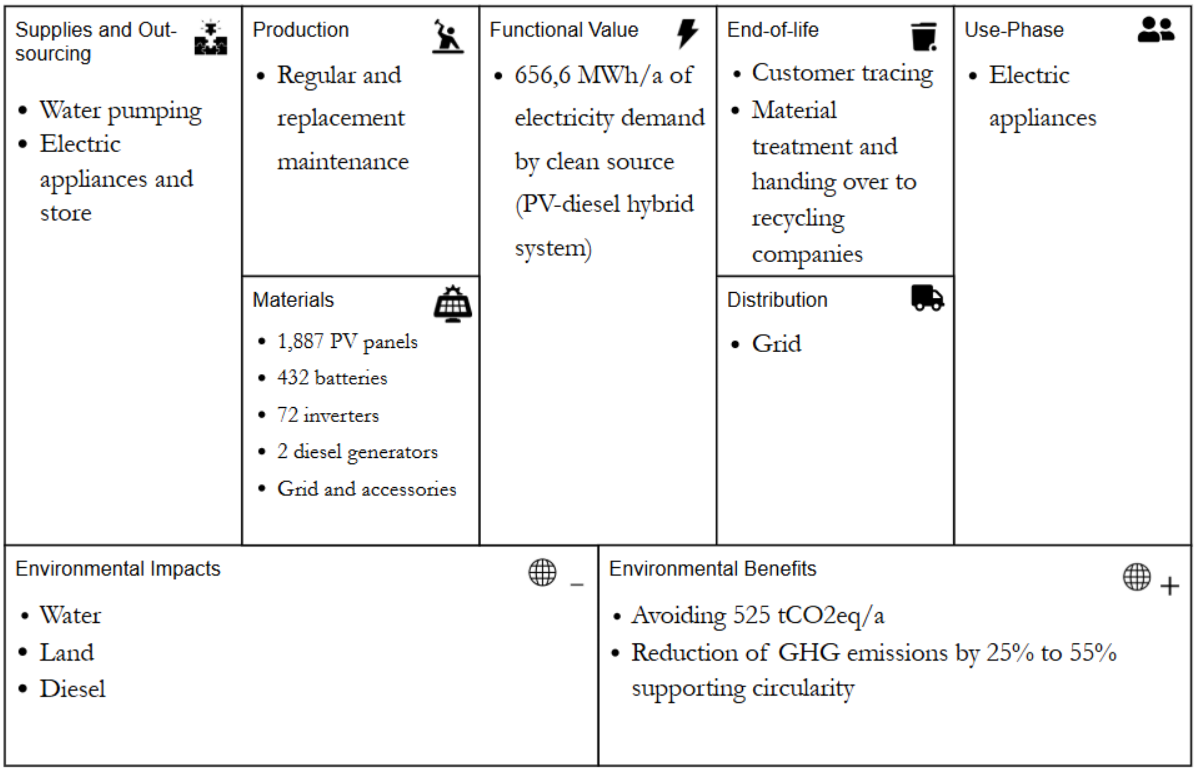

Figure 15 - Environmental layer

The three layers of the TLBM - economic, social, and environmental - are interconnected, each reinforcing the other to create a sustainable mini-grid business model. From the economic layer, the core value proposition of providing reliable and affordable electricity extends beyond financial returns, directly influencing the social layer by enabling households, small businesses, schools, and health centers to benefit from dependable services. Preventive maintenance and strategic partnerships increase costs but improve service quality, leading to greater customer satisfaction and willingness to pay, which in turn strengthens financial sustainability.

The social layer amplifies this impact by translating electricity access into tangible improvements in community well-being. Reliable energy supports education, healthcare, productive uses, and women’s participation in local economic activities. These outcomes not only reduce poverty and enhance quality of life but also reinforce trust between operators and communities, ensuring better cost recovery and long-term viability of the economic layer.

The environmental layer complements both by embedding clean energy into the system. Solar PV generation reduces greenhouse gas emissions, mitigates climate change, and protects community health, while circular approaches to recycling further minimize environmental harm and potential costs. By reducing reliance on fossil fuels and traditional fuels, it also supports productive water use and sustainable livelihoods.

4.3.1. Strategic Planning

The 25-year roadmap for the Bissora mini-grid is structured into interdependent phases, with continuous community engagement as its backbone. Sustained participation through village energy committees, early tariff acceptance, and local employment builds ownership and reduces conflict, aligning with evidence that community involvement is essential for long-term sustainability (Ngoti, 2024).

During years 1–10, the priority is to stimulate productive demand through anchor loads (e.g., milling, cold storage, agro-processing), supported by training and equipment finance. Productive uses stabilize revenues and lower the levelized cost of energy (Booth et al., 2018). Appliance uptake in both households and enterprises can increase over time, but this might not happen soon enough to make mini-grid investments profitable in the mid-term (Peters et al., 2019).

From years 5–25, the focus shifts to promoting efficient appliances and accessible financing models such as pay-as-you-go, which broaden energy access while raising average revenue per user (IRENA, 2020).

Digital monitoring and data-driven O&M form a cross-cutting pillar, enabling predictive maintenance, improved billing compliance, and evidence-based tariff adjustments (Mereu/LEAP-RE, 2022). Between years 11–13, capacity upgrades are phased in based on measured demand growth, leveraging falling component costs and reducing risks of oversizing (State of the Global Mini-Grids Market, 2024).

In years 21–25, strategic renewal and replication are prioritized: replacing batteries and inverters, refurbishing distribution assets, and codifying operational lessons into a standardized package for expansion to neighbouring communities. Opportunities for hybridization (e.g., wind or biomass) are considered only when local resource assessments prove viable.

4.4. Policy implications and recommendations

In this subsection, we highlight the lessons the developers, operators, management, and policymakers can draw from the presented findings, as well as propose what to do and its relevance or importance of these proposals, supported by the evidence and the larger effect they might have on the sustainability of SMG development in Guinea-Bissau and beyond.

Having a reliable funder as a partner is crucial for SMG deployment, as UEMOA helps alleviate the high upfront costs. However, the absence of partnerships with appliance suppliers, financial institutions, and productive-use actors limits the developmental benefits of electricity access. Building such linkages can enhance customer appliance uptake, enable income generation, and strengthen business model viability. Governments and donors can facilitate this through matchmaking platforms to bring together different actors in order to cooperate and create more sustainable value for all potential stakeholders in the context of SMG for rural electrification.

Electricity provision in Bissora supports not only household lighting but also water pumping, small enterprises, and community services. This highlights the importance of multi-sectoral planning, aligning mini-grid deployment with rural development initiatives in agriculture, health, education, and water. Mini-grids should be framed as infrastructure for community transformation rather than energy delivery alone.

Despite Guinea-Bissau's commitment to a 30% GHG reduction by 2030 (NDC, 2021), the climate mitigation potential of SMGs is largely overlooked. Integrating sustainable mini-grid business models into national climate and energy strategies, alongside systematic monitoring of CO_2 savings, could unlock access to climate finance instruments such as carbon credits and green bonds.

Current reliance on grants reflects limited private investment due to high risks and uncertain returns. De-risking instruments like guarantees, results-based financing, and blended finance are needed to attract private capital. Developers should also consider anchor-client models, cross-subsidies, or bundled services to improve bankability.

Potential scenarios from future grid expansion or private competition require adaptive planning. Strategies such as modular upgrades, grid interconnection readiness, and clear policies on compensation or integration post-grid arrival are essential.

Finally, gaps in monitoring operational, social, and environmental performance constrain informed decision-making and investor confidence. Digital tools and data-sharing platforms can support transparency and learning across projects.

CONCLUSION

The existing business model lacks clarity in its objectives, particularly regarding social and environmental dimensions. From a sustainability perspective, it has not achieved financial viability, as it currently operates with negative cash flow. On the social side, the business model is not effectively positioned to deliver meaningful benefits to the community, as residents of Bissora continue to face frequent power outages, high tariffs, and the exclusion of potential customers. On the environmental side, there is likewise no clear strategy to create added value through emission reductions, particularly when compared to the traditional energy context that existed before the SMG.

Nevertheless, the Bissora SMG case demonstrates that a SBM can offer financially viable and socially meaningful solutions for rural electrification in Guinea-Bissau. The system shows potential for cost recovery and multiple community benefits, ranging from household lighting and water pumping to small enterprise development and service provision. Active community engagement, proper system maintenance, and diversified partnerships are essential to fully realizing this potential. Beyond this, reliable electricity access supports children's ability to study at home, reduces the time women spend on household chores, and enhances overall well-being. From an environmental perspective, mini-grids reduce greenhouse gas emissions by replacing polluting energy sources, while a lifecycle approach that includes equipment recycling and responsible disposal is needed to maximize sustainability.

Key lessons highlight that mini-grid strategies must move beyond access alone, embedding sustainability through regular maintenance, reinvestment, and adaptive planning for future grid integration. Inclusive electrification also requires flexible financing mechanisms and targeted subsidies for low-income households.

This study is based on a single case and relies on both primary and secondary data, which may limit the generalizability of findings. Data gaps on long-term performance, household-level socio-economic impacts, and precise environmental benefits constrained the depth of the analysis. Future research should therefore expand to multiple case studies across Guinea-Bissau and the wider region, allowing comparative analysis on reliability, affordability, productive use, and social outcomes such as gender empowerment, education, and well-being. Further exploration of policy frameworks is also required to enhance the scalability and resilience of SMG, as well as research on lifecycle management practices to promote recycling and circularity.

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APPENDICES

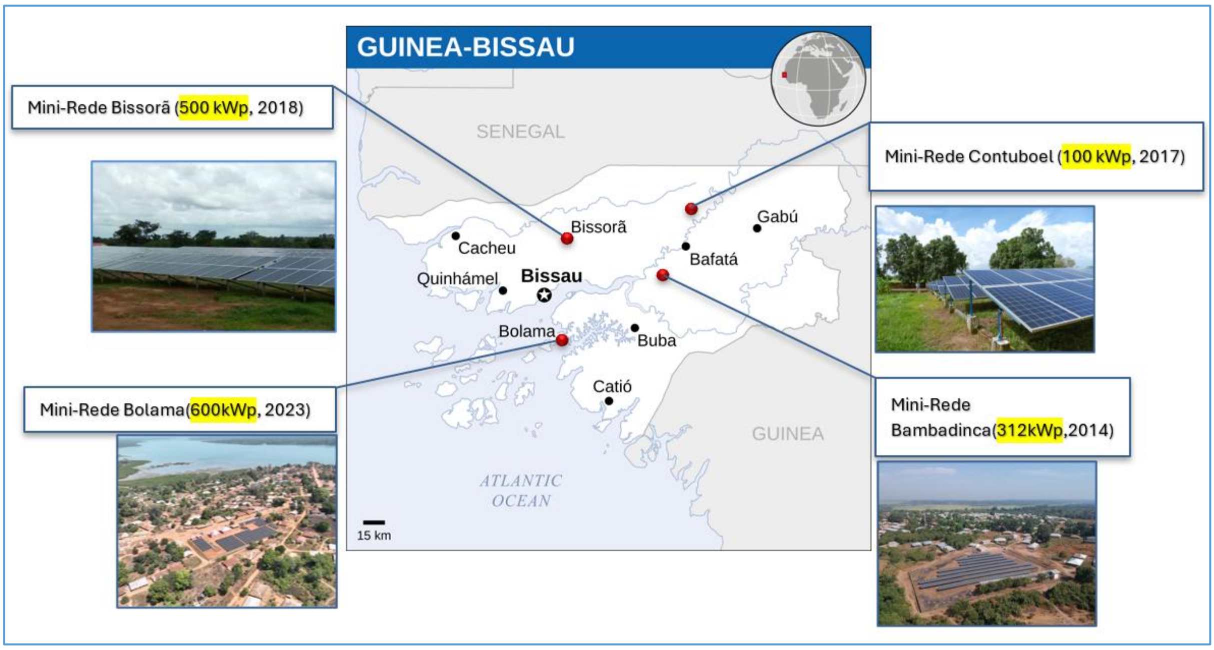
Appendix 1. Country information.

Country	**El. Rate**	**Urban El. Rate**	**Rural El. Rate**	**PWE (M)**	**Grid Price ($/kWh)**	**Scheme**
Benin	33%	58%	9%	8	0.26	IPP+G&T+D
Burkina Faso	22%	69%	2%	16	0.34	IPP+VIU
Cape Verde	96%	>99%	89%	<1	0.51	IPP+VIU
Cote d'Ivoire	76%	>99%	51%	6	0.21	IPP+VIU+ID
Gambia	49%	69%	16%	1	0.44	IPP+VIU
Ghana	85%	93%	75%	5	0.14	IPP+G+T+D
Guinea	46%	84%	24%	7	0.35	IPP+VIU
Guinea-Bissau	28%	56%	7%	1	NA	IPP+VIU
Liberia	12%	18%	6%	4	0.66	IPP+VIU+ID
Mali	50%	78%	28%	10	0.33	IPP+VIU+ID
Niger	14%	71%	2%	20	0.19	IPP+VIU+ID
Nigeria	62%	91%	30%	77	0.21	IPP+G+T+D
Senegal	71%	94%	50%	5	0.35	IPP+VIU+ID
Sierra Leone	26%	52%	6%	6	0.55	IPP+G&T+D
Togo	43%	77%	19%	5	0.33	IPP+G&T+D

Source: (Antonanzas-Torres et al., 2021)

National electrification rate (El. Rate), urban electrification (Urban El.), rural electrification (Rural El.), and population without electricity (PWE) in million people for 2019. IPP stands for independent power producer, G generation, T transmission, D distribution, VIU vertical integrated utility and ID isolated distribution.

Appendix 2. Map showing the location of installed mini-grids in Guinea-Bissau



Source: (AMAP, 2025)

Appendix 3. KoboCollect Survey Questionnaire Overview – Bissora Solar Mini-Grid

Bissorã Solar Mini-Grid

Welcome! This survey aims to understand the effects of the solar mini-grid and its impact on your community in Bissora. Your responses will contribute to better recommendations for mini-grid management, as well as improved energy planning and policymaking. Thank you for your time and participation!

Your participation in this survey is voluntary, and all your responses will remain anonymous. Do you agree to take part in this survey?

- ◯ Yes
- ◯ No

Survey assistant information

Full name

Date of survey

Location of survey

- ◯ Braga
- ◯ Joaquim N'com
- ◯ Other

Please specify

Respondent's information

Full name

Respondent category

- ◯ Household
- ◯ Business
- ◯ Institution

Are you connected to the mini-grid?

- ◯ Yes
- ◯ No

Why are you not connected to the mini-grid?

Household

What is your main source of electricity?

- [ ] Solar mini-grid
- [ ] Diesel generator
- [ ] Solar Home System
- [ ] Batteries
- [ ] Other

Please specify

What is the approximate total monthly income of your household?

- ○ Less than 25,000 XOF
- ○ 25,000 – 50,000 XOF
- ○ 50,000 – 100,000 XOF
- ○ 100,000 – 200,000 XOF
- ○ More than 200,000 XOF

How has the mini-grid affected students' ability to study at home?

- ○ It improved study time
- ○ No change
- ○ It made it harder to study
- ○ No students at home
- ○ I don't know

Please explain why

How has the mini-grid affected your household's access to information and communication?

- ○ Improved
- ○ No change
- ○ Worsened
- ○ Don't know

Please explain why

What effect has the mini-grid had on the time women in your household spend on chores?
(e.g., cooking, fetching water, grinding, ironing)

- ◯ It reduced the time spent on chores
- ◯ No change
- ◯ It increased the time spent on chores
- ◯ No women in the household
- ◯ We don't use electricity for chores
- ◯ I don't know

Please explain why

Has access to the mini-grid created any opportunities for your household to earn extra income?

- ◯ Yes
- ◯ No
- ◯ Not sure

In what way has the mini-grid helped generate extra income?

Are you using additional appliances now with electricity from the mini-grid?

- ◯ Yes
- ◯ No, I still use charcoal, firewood, or diesel appliances

Please specify

- ☐ Electric fan
- ☐ TV
- ☐ Electric cooker/stove
- ☐ Refrigerator
- ☐ Electric water heater
- ☐ Light bulbs
- ☐ Other

Please specify

What appliances or fuels did your household use before?

- Hand fan
- Candles
- Solar lamp
- Charcoal stove
- Firewood
- Kerosene
- Other

Please specify

Business

What type of business do you run?

- Grocery store
- Barbershop
- Tailoring
- Phone charging
- Other

Please specify

What is your main source of electricity?

- Solar mini-grid
- Diesel generator
- Solar Home System
- Batteries
- Other

Please specify

What is the average monthly income (or revenue) of your business?

(This refers to the total sales or earnings before deducting costs.)

- Less than 50,000 XOF
- 50,000 – 100,000 XOF
- 100,000 – 250,000 XOF
- 250,000 – 500,000 XOF
- More than 500,000 XOF
- Prefer not to say

How has electricity from the mini-grid affected your business income?

- Increased
- No change
- Decreased
- Not sure

Please explain why

Are you using additional appliances now with electricity from the mini-grid?

- Yes
- No, I still use charcoal, firewood, or diesel appliances

Please specify

- Electric fan
- TV
- Electric stove
- Refrigerator
- Water pump
- Electric sewing machine
- Phone charger
- Other

Please specify

What appliances or fuels did your business use before?

- ☐ Charcoal/gas stove
- ☐ Solar lamp
- ☐ Firewood
- ☐ Diesel
- ☐ Other

Please specify

Institutions

What type of institution do you represent?

- ◯ Health Center
- ◯ School
- ◯ Administrative Office
- ◯ Police Station
- ◯ Other

Please specify

What is the main source of electricity for your institution?

- ◯ Mini-grid
- ◯ Diesel generator
- ◯ Solar home system
- ◯ Batteries
- ◯ Other

Please specify

How has access to electricity from the mini-grid affected your ability to deliver services?

- ◯ Improved
- ◯ No change
- ◯ Made it more difficult
- ◯ I don't know

Please explain why

Are you using additional appliances now with electricity from the mini-grid?

- ◯ Yes
- ◯ No, we still use charcoal, firewood, or diesel appliances

Please specify

- ☐ Electric stove
- ☐ Refrigerator
- ☐ Computer / printer
- ☐ Water pump
- ☐ Other

Please specify

What appliances or fuels did your business use before?

- ☐ Charcoal/gas stove
- ☐ Solar lamps
- ☐ Firewood
- ☐ Diesel
- ☐ Other

Please specify

When do you need electricity the most during a typical 24-hour period?

- ☐ Morning (5:00 AM – 12:00 PM)
- ☐ Afternoon (12:00 PM – 6:00 PM)
- ☐ Evening (6:00 PM – 12:00 AM)

How many hours per day is electricity usually available from the mini-grid?

- ◯ Less than 4 hours
- ◯ 4–8 hours
- ◯ 8–16 hours
- ◯ 16–22 hours
- ◯ More than 22 hours

When is electricity often available during a typical 24-hour period?

- ☐ Morning (5:00 AM – 12:00 PM)
- ☐ Afternoon (12:00 PM – 6:00 PM)
- ☐ Evening (6:00 PM – 12:00 AM)

During the hours when electricity is usually available, how often is the supply interrupted in a typical week?
(An interruption refers to any time the electricity is cut off for 2 hours or more during the hours when electricity is usually available)

- Rarely (0–3 times per week)
- Occasionally (4–7 times per week)
- Frequently (8–14 times per week)
- Very frequently (more than 14 times per week)
- No electricity at all

How much do you spend on electricity per month?
(Estimate your average monthly electricity expenses)

- Less than 7 €
- 7 – 15 €
- 15 – 22 €
- 22 – 30 €
- 30 € or more
- Don't know

How much do you spend on other energy sources per month?
(e.g., charcoal, firewood, gas, kerosene, or diesel)

- Less than 3 €
- 3–8 €
- 8–15 €
- 15–23 €
- 23 € or more
- Not sure

Have you noticed any change in health since using the mini-grid?

- Yes
- No

What kind of changes?

- [ ] Less smoke
- [ ] Fewer burns or injuries from traditional fuels
- [ ] Better lighting (less eye strain)
- [ ] Reduction in noise pollution from backup generators
- [ ] Other

Please specify

____

What are the main challenges you face with the mini-grid service?

____

X

What suggestions do you have to improve the mini-grid service?