Henock Dandena Dibaba

ANALYSING THE INTERPLAY BETWEEN BUSINESS MODELS AND SUSTAINABLE MINI-GRID ECOSYSTEMS

ACTA UNIVERSITATIS LAPPEENRANTAENSIS 1150

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Abstract

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Global advancements have been made in improving electricity accessibility, yet persistent challenges remain, particularly in rural areas of sub-Saharan Africa (SSA). Distributed Energy Resource (DER) technologies, notably mini-grids, have gained traction as potential solutions to address these challenges. Recent technological innovations have enhanced the feasibility of mini-grid solutions, making them economically viable options for expanding energy access in SSA. This evolution involves diverse stakeholders engaging in various aspects of the value creation process, thereby reshaping the business landscape.

The primary objective of this doctoral dissertation is to conduct a comprehensive study on business models in rural mini-grid projects, addressing critical research gaps and providing practical insights for stakeholders. To achieve this, the research seeks to answer key questions: identifying components and considerations in rural microgrid business model design, exploring the economic viability of off-grid systems and methodologies for assessing it, examining the implications of adopting inclusive business models for mini-grid development, and providing an evaluation framework for rural mini-grid ecosystems.

The methodology employs a mixed-methods approach, combining qualitative and quantitative research methods. A review of existing literature is conducted to understand theoretical frameworks, key concepts, and research gaps in rural mini-grid business models and community involvement. The key findings highlight various aspects of rural mini-grid projects: identifying key components and considerations in business model design, emphasizing economic viability and methodologies for assessment, and showcasing the economic empowerment potential of inclusive business models for marginalized communities.

The implications of these findings provide practical insights and guidance for developers, government agencies, NGOs, and community organizations involved in rural mini-grid projects, facilitating the design of sustainable business models and fostering community involvement.

Keywords: mini-grids, business model, rural electrification, willingness to pay, inclusive business model, business model evaluation

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I am deeply grateful to my supervisors, Professor Samuli Honkapuro and Associate Professor Antti Pinomaa, for their guidance and support throughout this work, as well as their assistance during my doctoral studies and research projects. I also extend my gratitude to my former supervisor, Dr. Evgenia Vanadzina, for her support during the initial stages of my doctoral studies and our collaboration as co-authors. Additionally, I would like to thank all my colleagues at the Laboratory of Electricity Markets and Power Systems.

I express my appreciation to all the research project partners from Africa and Europe for their collaboration.

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Lastly, I am incredibly thankful for the unwavering support of my parents, Dandena and Tigist, and my siblings, Freazer, Yonas, and Abdi, throughout my doctoral studies.

Henock Dibaba
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Publications

List of publications

This dissertation is based on the following papers. The rights have been granted by the publishers to include the papers in the dissertation. Two of the articles (Publications I and III) are presented and published in peer-reviewed conference proceedings. Publications II and IV are published in peer-reviewed journals.

I. Dibaba, H., Vanadzina, E., Mendes, G., Pinomaa, A., Honkapuro, S. (2020). Business Model Design for Rural Off-the-Grid Electrification and Digitalization Concept. In: *17th International Conference on the European Energy Market (EEM)*. Stockholm, Sweden.

II. Dibaba, H., Demidov, I., Vanadzina, E., Honkapuro, S., Pinomaa, A. (2022). Feasibility of rural electrification and connectivity—A methodology and case study, *Applied Energy*, Vol. 315, No. 19013.

III. Dibaba, H., Pacenti, A., Tomas Fillol, L., Pinomaa, A., Honkapuro, S. (2023). The Prospect of Inclusive Business Model for Mini-Grid Development. In: *2023 IEEE PES/IAS PowerAfrica*. Marrakesh, Morocco.

IV. Dibaba, H., Tomas Fillol, L., Pinomaa, A., Honkapuro, S. (2023). Measuring success: Evaluating the business model of rural mini-grid ecosystems. *Energy Research & Social Science*, Vol. 106, No. 103296.

Furthermore, the author of this doctoral dissertation has contributed to additional publications, both as a primary author and as a co-author, which support the research on the dissertation topic. However, these publications have not been included in the present work. In these supplementary publications, the author has been involved in modelling and drafting sections of the content found in the articles. The specific publications are listed below:

- Dibaba, H., Demidov, I., Pinomaa, A., Annala, S., Honkapuro, S. (2023). Assessing the Economic Benefits of Demand Response for Rural Area Off-Grid Microgrids in Emerging Markets. In*: 2023 IEEE PES/IAS PowerAfrica*. Marrakesh, Morocco.
- Demidov, I., Dibaba, H., Pinomaa, A., Honkapuro, S. Nieminen, M. (2020). System Platform Enabling Peer-to-Peer Electricity Market Model for Off-Grid Microgrids in Rural Africa. In: *17th International Conference on the European Energy Market (EEM)*. Stockholm, Sweden.
- Demidov, I., Dibaba, H., Pinomaa, A., Honkapuro, S. Nieminen, M. (2023). Energy Management System for Community-Centered Off-Grid System with a Blockchain-Based P2P Energy Market. In: *19th International Conference on the European Energy Market (EEM)*. Lappeenranta, Finland.

- Tomas Fillol, L., Honkapuro, S., Annala, S., Pinomaa, A., Dibaba, H. (2022). An assessment of the diffusion of Private Mini-Grids operating in rural Kenya. In: *18th International Conference on the European Energy Market (EEM)*. Ljubljana, Slovenia.
- Tomas Fillol, L., Honkapuro, S., Annala, S., Pinomaa, A., Dibaba, H. (2022). Analysis of Private Mini-Grid Development for Rural Rwanda. In: *18th International Conference on the European Energy Market (EEM)*. Ljubljana, Slovenia.

Author's contribution

I am the principal author and investigator in all the publications included in the dissertation. Additionally, I am responsible for ideating, preparing, developing theoretical frameworks, writing, and editing these publications. Moreover, I acted as the corresponding author for all publications throughout the review process. My supervisors, Samuli Honkapuro and Antti Pinomaa, who also acted as co-authors in all publications, aided in narrowing down ideas and refining thoughts for successful publication. Furthermore, my senior colleague, Evgenia Vanadzina, and colleague, Iurii Demidov, assisted in conceptualizing, methodology, and formal analysis for Publication II, and were co-authors in that paper. Furthermore, my colleague, Leticia Tomas Fillol, who is a co-author in Publications III and IV, assisted in refining ideas and developing theoretical frameworks.

Nomenclature

SSA	sub-Saharan Africa
DRE	distributed energy resource
SHS	solar home systems
RFDI	radio-frequency identification
ICT	information and communication technology
GPS	global positioning system
RS	remote sensing
ESMAP	Energy Sector Management Assistance Program
IPP	independent power producer
ESCO	energy service company
SI	system integrator
EPC	engineering, procurement, and construction
PUE	productive use of electricity
BESS	battery energy storage system
NGO	non-governmental organization
ISV	IEEE smart village
WTP	willingness to pay
WTA	willingness to accept
BMC	business model canvas
OEM	original equipment manufacturer
B2B	business-to-business
B2B2C	business-to-business-to-customer
BMI	business model innovation
EaaS	energy-as a-service
PPA	power purchase agreement
ABC	anchor-business-community
LCOE	levelized cost of energy
BoP	base of the pyramid
CVM	contingent valuation method
HRESs	hybrid renewable energy systems
PAYGo	pay-as-you-go
NPV	net present value
CAPEX	capital expenditures

1 Introduction

Electricity assumes a dual role in modern society, serving as both a catalyst for expanding economic activities and a byproduct of economic development. Electricity serves as a facilitator rather than an end product, shaping how people consume a variety of services(Winther, 2015). This significance is underscored by its recognition in the framework of the 2030 Agenda for Sustainable Development, established by the UN General Assembly in 2015(United Nations, 2015a), and the Paris Agreement on Climate Change (United Nations, 2015b). Within this integrated agenda, energy holds a pivotal position, particularly emphasized through Sustainable Development Goal 7, which strives to ensure universal access to affordable, reliable, sustainable, and modern energy (United Nations, 2023).

Despite significant global progress, as evidenced by the increase in electricity access from 83% in 2010 to 91% in 2020, challenges persist, particularly in the Global South (The World Bank, 2022). Sub-Saharan Africa (SSA), in particular, faces the substantial hurdle of achieving widespread electricity access, affecting nearly half of its population, especially in rural areas. The prevalence of low and sparsely populated rural areas with economic challenges contributes to the difficulty in extending electricity access (Ehimen et al., 2023).

To address this issue, there is a growing momentum among policymakers, industry leaders, and developers for renewable-based distributed energy resource (DER) technologies (Radley and Lehmann-Grube, 2022). These technologies, such as solar home systems (SHS) and micro/mini-grids, aim to revolutionize the energy landscape of SSA.

Among these solutions, mini-grids have proven particularly effective in high-demand, densely populated areas where the primary grid encounters challenges. Along with the term ‘mini-grid’, the term ‘microgrid’ is also employed in this dissertation. While it is recognized that these terms are used in different contexts and may have distinctive scopes and definitions, in this work, they are used interchangeably, as discussed and explained in more detail in Section 2.1.1. A mini-grid is a localized and decentralized electricity generation and distribution system that serves a specific community or group of consumers. It typically operates independently (in island mode) or in conjunction with the main power grid, catering to the energy needs of areas that are geographically isolated or lack reliable connection to a centralized electricity network (Moner-Girona et al., 2018).

Mini-grids, often misunderstood as novel technologies, trace their roots back to the very inception of electricity grids. Historically, these mini-grids played a pivotal role in shaping the contemporary electrical grid systems of developed nations during periods of industrialization and development. Originating as isolated mini-grids, they gradually interconnected over time to evolve into the centralized grid system we are familiar with today (ESMAP, 2019).

The World Bank's classification sheds light on the evolutionary stages of mini-grids. The first generation, introduced in the late 19^{th} and early 20^{th} centuries, is identified as the inaugural generation. Moving forward, the second generation emerged in the 1980s and persisted through the early 2000s. This iteration specifically targeted local communities and isolated households in developing countries, providing essential electricity services. Serving as a precursor, the second generation offered valuable insights into the technical and financial viability of mini-grid systems. These insights paved the way for the current, third generation of mini-grids. Leveraging advanced generation and operational technologies, this generation emphasizes the application of productive use of electricity (PUE) to enhance local economic activities and prepare for grid interconnection. Benefiting from declining costs of technical components and advancements in technologies like Radio-Frequency Identification (RFID), Information and Communication Technology (ICT), Global Positioning System (GPS), Remote Sensing (RS), and wireless data communications including 3rd, 4th, and 5th generation mobile networking, mini-grids now boast improved energy utilization, digital payment options, and remote control features. This empowerment of communities through mini-grids facilitates enhanced participation in economic activities, marking a significant step forward in the sustainable development of electrical infrastructure (ESMAP, 2022).

Recent data from the Energy Sector Management Assistance Program (ESMAP) underscores the success of mini-grid initiatives, connecting 48 million people to 21,500 mini-grids, with plans for expansion to reach over 35 million people. These mini-grids, primarily utilizing solar PV hybrids, are owned and operated by private companies employing transformative technologies. In SSA, nearly 291,000 population clusters are identified as suitable for solar mini-grid deployment, varying in size from small settlements to more significant communities (ESMAP, 2022).

While the earlier generation of mini-grids predominantly relied on the traditional value chain concept, the new generation is pushing boundaries by embracing a more expansive approach through the mini-grid value network and a broader business ecosystem. The newer generation of mini-grids envisions an evolution from a constrained value chain to a more dynamic value network, where private-sector stakeholders (facilitators) play a pivotal role in diverse value creation processes (ESMAP, 2019). These stakeholders can include independent power producers (IPPs), energy service companies (ESCOs), system integrators (SIs), engineering, procurement, and construction companies (EPCs), and original equipment manufacturers (OEMs). This involvement spans from supporting activities, such as software providers and analytics to crucial elements like technical services, flexibility options, battery energy storage systems (BESSs), digital payment technologies, civil work, and finance.

Simultaneously, the role of mini-grid project developers has undergone significant transformations. Project developers can be local or international governments, private companies, public–private partnerships, community cooperatives, individuals, or non-governmental organizations (NGOs). Unlike the conventional model where developers bore all responsibilities, the present scenario sees private companies assuming a significant portion of these tasks. This shift prompts developers to transition into organizational forces with roles centered on overarching development efforts, community engagement, and overseeing the financial aspects of energy services.

Moreover, various NGOs are dedicated to empowering energy communities through entrepreneurial education and practical solutions. For instance, organizations like IEEE Smart Village[1] (ISV) focus on capacity building through comprehensive training, community-based education, and entrepreneurial opportunities within energy-deprived communities.

Additionally, companies that provide productive use solutions play a crucial role in the off-grid ecosystem. For example, Asaga Technologies[2] specializes in food and agro-processing appliances, offering portable dry food grinders for both home and small business use. In a similar vein, KickStart[3] focuses on irrigation technologies tailored to enhance productivity for smallholder farmers. Despite being different companies, both contribute to addressing rural needs through innovative technologies. This collaborative and interconnected approach reflects the evolving landscape of value creation in the contemporary mini-grid industry (see Figure 1.1).

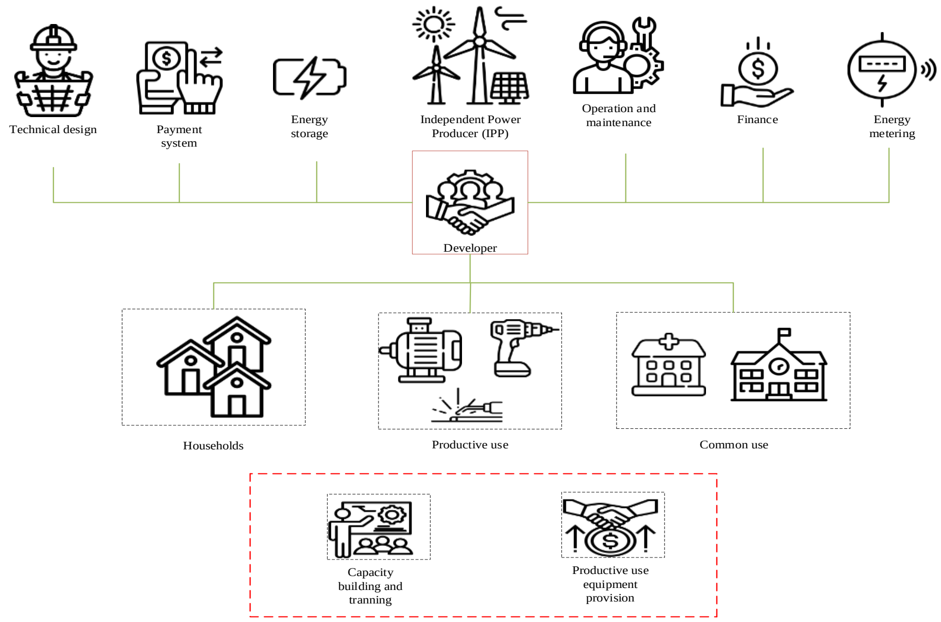

Figure 1.1: Typical value network for mini-grid development (adapted from Publications III and IV).

[1] https://smartvillage.ieee.org/
[2] https://asagatech.com/
[3] https://kickstart.org/

In the evolving business landscape, the business model of mini-grids is being influenced, emphasizing the significance of diverse strategies within the value network. The mini-grid business model encompasses the fundamental aspects of how a mini-grid functions, generates income, and maintains itself over time. It typically outlines the structure, key components, and relationships within the system, shedding light on how it interacts with customers, partners, and other stakeholders in the energy ecosystem while aligning with the broader goal of creating economic, social, and cultural relevance (ESMAP, 2022).

In addition, to enhance the viability of a mini-grid, it is essential to systematically integrate the community throughout both the development and operational phases, emphasizing the imperative of inclusivity. Unlike conventional approaches, an inclusive business model distinguishes itself by prioritizing economic opportunities for the community (Likoko and Kini, 2017). This model ensures the active involvement of the community members in the value creation process, allowing them to partake in the benefits generated (Feix et al., 2020). In the context of mini-grid development, the adoption of an inclusive business strategy becomes imperative for not only creating economic opportunities but also fostering local ownership, sustainability, and the equitable distribution of electrification benefits to marginalized communities.

Furthermore, comprehending the economic dynamics of mini-grids is pivotal for their business model, playing a crucial role in the development of these systems. Therefore, a thorough understanding of the financial landscape is imperative to assess the feasibility and sustainability of mini-grid projects. One of the key components in this economic framework is the concept of willingness to pay (WTP), which holds significance for value-based pricing strategies and gaining insights into the preferences and financial capacities of mini-grid customers (Taale and Kyeremeh, 2016). Recognizing the economic dynamics of mini-grid operations is fundamental to assessing the viability of these systems. The costs associated with initial investments, ongoing operational expenses, and the overall revenue generation play pivotal roles in shaping the business model. Consequently, the need for WTP becomes apparent, serving as a valuable metric to determine the affordability of mini-grid services for the target community (Rahnama, 2019).

In the realm of mini-grid development, customer WTP is not only an economic indicator but also a crucial parameter for setting prices that align with the financial capacities of the community. Balancing the costs and revenue aspects ensures that the economic sustainability of mini-grid projects is achievable in the long term. Tailoring pricing models to match the WTP ensures that the economic aspects of mini-grid projects are in sync with the social and financial fabric of the communities they serve. Thus, the integration of WTP considerations into the pricing strategy becomes an essential step for the successful and sustainable deployment of mini-grid initiatives.

Another crucial aspect of the mini-grid business model involves its evaluation. This practice ensures the refinement of services and the sustained competitiveness of organizations. Notably, this principle extends to entities engaged in rural electrification and mini-grid businesses. Business model evaluation is a critical component of the planning process for such organizations. It allows them to gauge the feasibility of their models in the current and future business landscape, whether implementing a new business model or improving an existing one (Alexa, 2014; Steinhöfel et al., 2018). For mini-grid developers and facilitators, conducting business model evaluations is essential. It facilitates the maintenance of service quality, cost reduction, increased profitability, and sustained competitiveness in the market. Beyond these immediate benefits, business model evaluation enables companies to identify potential risks and promote sustainable operations.

However, current scientific literature lacks comprehensive coverage of mini-grid business models, as highlighted in Chapter 3 of the state-of-the-art research. Studies are sparse and tend to focus narrowly on specific facets, such as frameworks, impacts, and configurations. Despite advancements, significant research gaps persist, including the need for deeper exploration of business model design and comprehensive evaluations of performance. Understanding users' WTP and aligning it with developers' capabilities is crucial for economic viability. Additionally, fostering inclusive practices is essential for integrating all stakeholders into the mini-grid ecosystem, crucial for effective rural electrification strategies.

1.1 Research objective and questions

The dissertation comprises a series of empirical studies centred around micro/mini-grid and rural electrification organizations. It investigates the significance of the business model within the mini-grid ecosystem, specifically addressing less-explored and less-organized aspects that play a crucial role. This involves a comparative analysis of ongoing discussions on mini-grid business models, including topics such as business model design, evaluation, the influence of community participation in mini-grid development, and an exploration of the WTP and its role in price formation.

The overarching research questions seek to explain the business model and its constituent elements, offering insights into its development and distinctiveness within the micro/mini-grid ecosystem as opposed to traditional energy businesses. The research questions are:

- What are the key determinants influencing the design of business models for rural microgrids, and how do these factors impact the overall success and sustainability of microgrid projects? (**Publication I**)
- What is the WTP among different consumer segments for microgrid services, and how does this willingness impact the feasibility of implementing and sustaining microgrid projects in various socio-economic environments? (**Publication II**)
- To what extent do inclusive business models contribute to social equity, community engagement, and sustainable development in the context of mini-grid implementation? (**Publication III**)

- How can the effectiveness and efficiency of business models for mini-grids be systematically evaluated, considering factors such as economic viability, scalability, and adaptability to diverse contexts? (**Publication IV**)

The study makes contributions in three key areas. Firstly, it provides clarity by defining and identifying various facets of the evolving business model and its significance in the development of mini-grids. Secondly, it emphasizes the importance of value-based pricing, which incorporates understanding customers' WTP into the pricing process. This approach ensures that pricing strategies align with the perceived value of the service, thus optimizing market acceptance and financial sustainability. Thirdly, the study introduces practical methodologies for evaluating mini-grid business models. It outlines evaluation indicators tailored to the mini-grid business ecosystem, allowing a comprehensive assessment of the roles played by stakeholders such as developers and facilitators. These evaluation methods provide valuable insights into the effectiveness and viability of different business models, facilitating informed decision-making and fostering the growth of sustainable energy solutions.

1.2 Outline of the work

The doctoral dissertation is divided into two main sections. The initial section offers an overview of the dissertation, outlining the research objectives and results. The subsequent section presents the research addressing the specified research questions. Within the first part, Chapter 2 delves into providing a theoretical foundation for the research questions. Chapter 3 provides the state of the art on the topics. Chapter 4 outlines the objectives of the research approach and the motivation behind the study, and Chapter 5 summarizes the key findings from relevant research publications. Lastly, Chapter 6 engages in a discussion on the topic, draws conclusions, and reflects on the work undertaken in the dissertation and outlines direction for future research.

The second part of the dissertation comprises four original reference articles. Two of these papers were presented at international conferences, and the remaining two articles have been published in international scientific journals. A summary of the articles and the author's contributions to each is provided below.

Publication I *Business Model Design for Rural Off-the-Grid Electrification and Digitalization Concept*

Publication I proposes a framework for designing and assessing a business model for rural off-grid systems. The proposed framework utilizes the business model canvas (BMC) as a tool to assess various business elements within the context of rural SSA. Additionally, the publication examines external factors, including market forces, key trends, industry forces, and macroeconomics. The study employs a case study approach, focusing on the pilot microgrid of the Fusion Grid research project. This project aimed to provide power, connectivity, and digital services for rural areas, presenting a novel development opportunity. The publication also highlights crucial considerations for developers during both the development and operational phases. These considerations include using the WTP as a benchmark for pricing and incorporating community inclusivity and socioeconomic factors. This study establishes a groundwork for future publications addressing WTP and inclusive business models for off-grid systems. The author of the dissertation was the principal author of the publication.

Publication II *Feasibility of rural electrification and connectivity—A methodology and case study*

Publication II presents a novel methodology for assessing the economic viability of a solar PV–battery energy storage off-grid system based on the expressed demand or WTP of customers. The methodology outlined in the study incorporates the demand–supply concept of price formation to comprehend and establish customer demand expressed through WTP. Additionally, it considers the willingness to accept (WTA), primarily associated with recovering the capital cost of the system. The study proposes a unit of service concept to bridge the gap between WTP and WTA, facilitating the understanding and identification of a suitable price agreeable to both parties. WTP data were gathered through surveys conducted in a village in northern Namibia, specifically where the Fusion Grid research project pilot site supplying electricity and delivering connectivity to local previously under-served community is located. WTA values were derived from the actual cost of the Fusion Grid microgrid system. The author of the doctoral dissertation carried out the analysis, wrote the major part of the paper, and was the principal author of the publication.

Publication III *The Prospect of Inclusive Business Model for Mini-Grid Development*

Publication III introduces the concept of an inclusive business model within the context of mini-grid development and operation. Diverging from conventional business models, an inclusive business model places emphasis on offering economic opportunities to marginalized or low-income individuals. It involves them in the value creation process, enabling them to partake in the benefits of the organization, rather than solely focusing on maximizing profits for the company and its shareholders. Within the mini-grid ecosystem, the paper argues that inclusive actions are crucial for both value creation and capturing processes. Community members can actively participate in various aspects of the mini-grid system, including installing rooftop solar panels to generate and add capacity to the mini-grid, handling basic maintenance tasks to reduce downtime and ensure continuous power supply, and actively managing their electricity consumption patterns to optimize usage. This involvement allows them to reap economic benefits while alleviating financial and operational burdens for the developer. Additionally, community members can retain or capture value through ownership and the implementation of productive use of electricity and value-added services. The author was the corresponding author in the publication.

Publication IV *Measuring success: Evaluating the business model of rural mini-grid ecosystems*

Publication IV provides a framework for evaluating the business model in the context of mini-grid ecosystems. The evaluation framework presented in the study draws upon various business model theories and evaluation approaches and includes indicators for assessing performance. To demonstrate the usefulness of the framework, six companies currently operating in rural mini-grid projects in Africa were provided with a questionnaire and evaluated. Consistent evaluation of these business models is essential for adapting to changing conditions, identifying areas for innovation, and sustaining competitiveness, thereby furthering the field of business model assessment. By bridging this gap between business model evaluation methodologies and rural electrification studies, the study contributes to understanding the transformative effects of mini-grid projects, extending beyond traditional energy access metrics. The author of the dissertation was the principal author in the publication and was responsible for the evaluation analysis.

2 Theoretical background

In this chapter, relevant topics related to the mini-grid business model are discussed based on literature, within the broader context of the evolving energy sector. Before delving into the specifics of the mini-grid business model, the chapter first examines the evolution of the energy sector over the past decade, encompassing technological advancements, issues related to climate change, the emergence of green technology, and global trends. Since mini-grids are both a product and a component of the energy system, understanding the broader context of the energy sector is crucial. Following the discussion on the energy sector and its relation to mini-grids, the chapter proceeds to explore the theoretical background of business models, inclusive business models, and business model evaluation. Additionally, it introduces the concept of WTP-based pricing as an indicator for financial viability. By incorporating these elements, the chapter aims to construct and clarify the subsequent discussion section.

2.1 The evolution of energy infrastructure and off-grid solutions

The surge in renewable energy technologies, the deregulation of the energy market, and the evolving digital landscape are reshaping the dynamics of the energy industry, giving rise to new patterns in monetary transactions, information exchange, and energy distribution (Necoechea-Porras et al., 2021). These transformations are challenging conventional business models, as seen in the evolving roles of consumers and collaborative energy initiatives, such as energy communities. Furthermore, the growing utilization of distributed generation is empowering individuals and communities with more authority over electricity generation and consumption. In this changing operational environment and paradigm shift, however, companies are also under increasing pressure to align their operations with sustainable development goals, responding to mounting regulatory and social pressures to reduce contributions to climate change and pursue net-zero ambitions (IRENA, 2019). Nevertheless, many have failed to respond effectively to climate change. For instance, in a study about institutional investors, which play a crucial role in the oil and gas sector, (McDonnell et al., 2022) finds that they face significant challenges such as a lack of accountability and loopholes in net-zero policies. Additionally, these investors often lack transparency in their climate action plans, further complicating efforts to reduce fossil fuel extraction. Similarly, case studies (Ruiz Manuel and Blok, 2023) reveal that while initiatives like Science-Based Targets and RE100 show potential for emissions reductions, progress evaluation is limited. Reductions are mainly seen in a few companies, with many relying on renewable electricity purchases for progress. Challenges include data complexities, double-counting, and differing reporting standards, which undermine the effectiveness of corporate climate efforts.

In response to the above-described paradigm shift, a new set of business indicators, encompassing environmental, economic, and social considerations, are emerging. Firms operating in this transformed energy landscape may need to redefine their business models, embracing the principles of sustainable business models that encompass value creation and delivery across economic, social, and environmental dimensions (Hamwi and Lizarralde, 2017). The contemporary energy business is characterized by decarbonized energy systems, decentralized renewable energies, and a digitalized environment. This transformation has introduced new energy consumers, including prosumers, who both consume and produce electricity, along with the emergence of energy communities (See Figure 2.1).

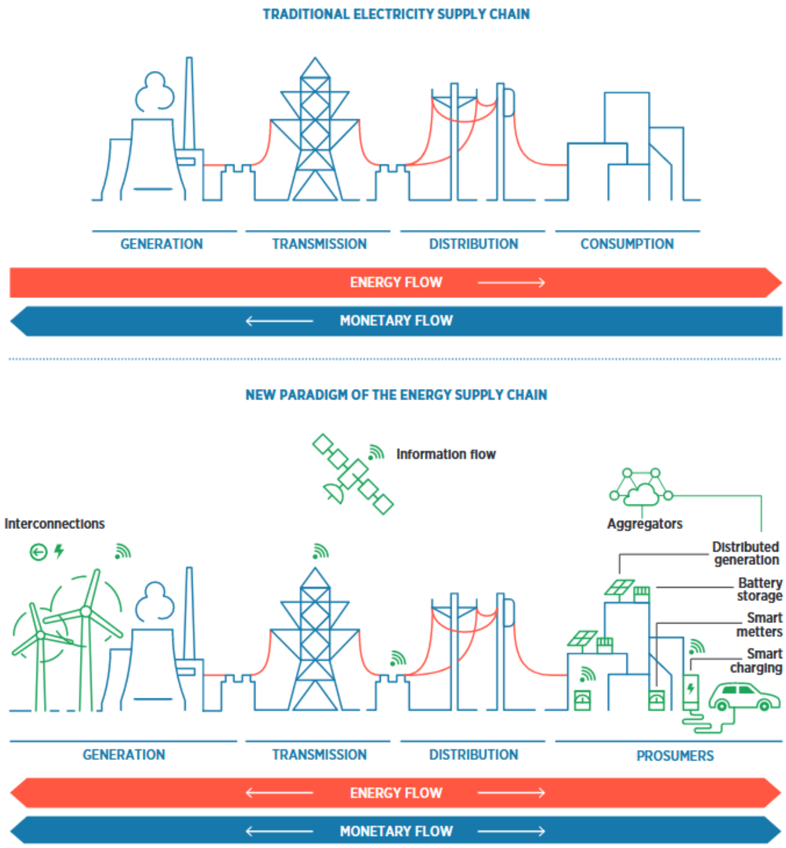

Figure 2.1: Traditional and new energy supply chain (IRENA, 2019).

Contrary to the traditional unidirectional energy and monetary flow, where the relationship between the energy provider and consumer is linear, the new environment encourages active consumer participation in energy generation. Consumers are no longer merely end users but can also function as prosumers, generating and consuming their own power within or outside the existing grid (Karami and Madlener, 2021). This evolution has given rise to innovative ventures, such as collaborations between firms creating business innovation in electric vehicle charging stations and grid operators or e-mobility service providers.

The new energy landscape has fostered a participatory role for consumers, leading to the emergence of novel energy activities like energy storage providers and e-mobility service providers. Innovative schemes, including community ownership models, are gaining prominence, facilitating renewable energy supply in both off-grid and connected areas. Consequently, the changing energy landscape necessitates the development of new paradigms to craft innovative business models within the energy value network (IRENA, 2019).

Concurrently, the off-grid energy sector is undergoing significant changes, propelled by advancements in technology and cost reductions in renewable energy generation technologies. Historically, off-grid systems have evolved through distinct generations, each tailored to meet specific needs and demographic requirements (ESMAP, 2022). The current iteration, known as the third generation, builds upon insights gained from previous phases and leverages advanced generation and operational technologies to bolster local economic activities and prepare for seamless integration with the main grid.

Within the off-grid energy sector, developers have traditionally played a central role in coordinating finance, deploying technology, and engaging with stakeholders (ESMAP, 2022). However, the ecosystem surrounding off-grid systems is expanding, welcoming new participants, such as original equipment manufacturers (OEMs) and service providers. These entities contribute added value through the provision of hardware, software solutions, technical support, and financing options (see Figure 2.2). Consequently, this growing network of stakeholders is fostering the establishment of novel business-to-business (B2B) and business-to-business-to-customer (B2B2C) relationships within the off-grid sector, thereby strengthening the resilience and sustainability of off-grid energy solutions.

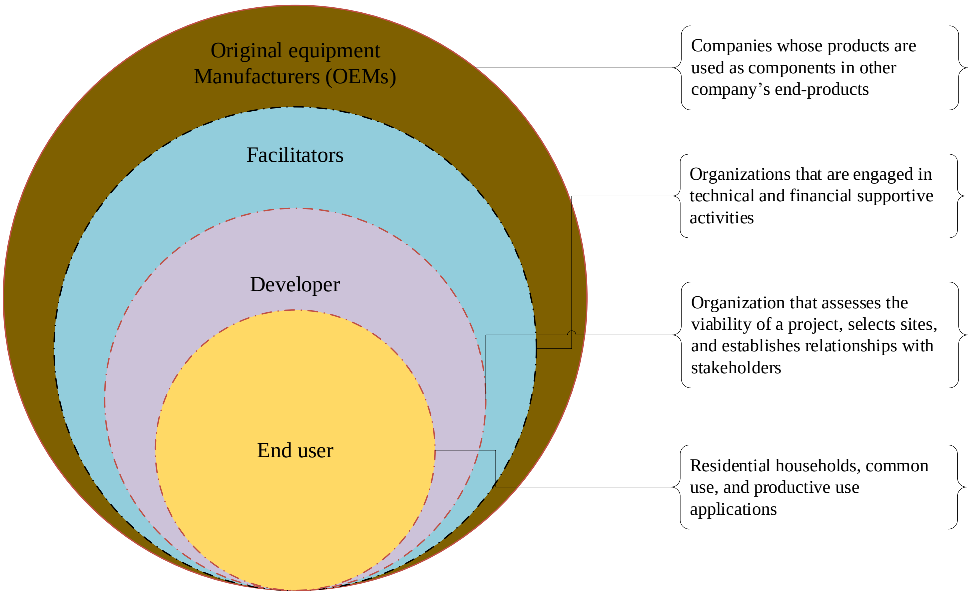

Figure 2.2: Multi-tier mini-grid ecosystem (adapted from Publication IV).

However, this is not always the case. Companies like Powerhive[4], a mini-grid developer primarily operating in Kenya, offer comprehensive solutions. They serve as both developers and facilitators, as well as OEMs for mini-grid development, encompassing activities ranging from market visibility studies to site identification and system design. Additionally, they provide their own cloud service platforms and smart meters. Furthermore, Powerhive promotes e-mobility for motorcycles with battery swapping technology and supports poultry businesses within communities.

2.1.1 Microgrid vs. mini-grid

Microgrids, as employed in industrial countries, are often designed with the capability to operate in isolation from the national main power grid system. This islanding feature allows them to function independently, providing resilience and localized control over energy distribution. Microgrids in developed regions are characterized by their flexibility and adaptability, catering to specific energy needs and promoting sustainability (Ton and Smith, 2012).

[4] https://powerhive.com/

In contrast, mini-grids in developing countries are structured to act as primary energy sources for densely populated areas that may not have full access to the central power grid. One distinguishing feature of mini-grids is their ability to connect to the main grid when it reaches these under-served areas. This connectivity enhances the overall reach and efficiency of energy distribution, allowing integration with the broader grid infrastructure as it expands into these regions (ESMAP, 2019).

The distinction between microgrids and mini-grids reflects not only differences in scale but also the operational characteristics that make each system suitable for its respective context. While microgrids emphasize independence and flexibility in developed areas, mini-grids prioritize energy access and connectivity provision, and their integration as they serve as vital energy resources in developing regions. It is important to note that in this dissertation, the terms ‘microgrid’ and ‘mini-grid’ are used interchangeably, recognizing the evolving nature of these concepts and their context-dependent applications.

2.2 Theoretical concept of business model

The term ‘business model’ was first mentioned in the scientific literature by Lang (1947) and later by Bellman et al. (1957). However, the concept gained popularity in the 1990s with the emergence of e-commerce and new economy businesses (Nielsen and Lund, 2018). At the time, the increasing adoption of the internet and the increased computing power helped a new type of e-businesses to roll out, which is also referred to as the ‘New Economy’. The New Economy was a shift from the traditional brick-and-mortar model to more online-based and high-tech services. The concept of business model lost its popularity during the burst of the dot-com bubble; however, the increased globalization, technological advancements, and shorter market cycles have brought back the concept as an instrument employed by academia and industries (DaSilva and Trkman, 2014).

The term ‘business model’, however, has frequently been misused and used as a buzzword by many academics and practitioners (Nielsen and Lund, 2018). Often, the term is used as an anchor point by business managers to describe the functionality of their firms. In the late 1990s, the term also appears in much of the literature to compare between the new e-business value creation and the mortar-and-bricks counterparts (Nielsen and Lund, 2014). In addition to that, the interchangeable use of the term with other similar terms such as strategy, economic model, and revenue model further contributed to a vague idea about the business model concept (DaSilva and Trkman, 2014), (Krumeich and Loos, 2011). Many of the alleged business models in the past describe one aspect (the most visible part) of a business model rather than the business model in its entirety (Linder and Cantrell, 2000). This is similar to people mistakenly using the country name The Netherlands interchangeably with Holland, which is actually a province within The Netherlands. Such different perspectives of business models led to a wide range of definitions and understandings, which later resulted in stretched and equivocal meanings of the term. For instance, some scholars use the term ‘business model’ to comprehensively describe how a firm conducts business while others use the term to stress only the economic value chain of a particular business (Krumeich and Loos, 2011; Zott et al., 2011).

The concept of a business model is subject to diverse interpretations among scholars, resulting in a lack of consensus on its definition (Peric et al., 2017). Various conceptualizations of the business model serve the specific context of each phenomenon under study. These definitions encompass a range of functions, such as articulating value propositions, identifying market segments, defining value chains and networks, estimating cost and profit structures, and formulating competitive strategies. Table 2.1 presents diverse definitions of the business model over time provided by various scholars.

Table 2.1: Business model definitions in timeline

Study	**Definition**	**Elements**
(Timmers, 1998)	'Business model is an architecture for the product, service, and information flows, including various business actors' roles and potential benefits.' (p. 4)	Architectural elements
(Linder and Cantrell, 2000)	'An operating business model is the organization's core logic for creating value, explaining how it makes money.' (p. 2)	Value proposition and logic
(Alt and Zimmermann, 2001)	'Business models determine participation of partners, channel conflicts, and revenues etc.' (p. 2)	Participation and relations
(Osterwalder and Pigneur, 2002)	'We understand business models as the missing link between strategy and business processes.' (p. 77)	Business logic
(Magretta, 2002)	'Business modeling is the managerial equivalent of the scientific method, involving hypothesis testing in action and revise if necessary.' (p. 5)	Value proposition and logic
(Camponovo and Pigneur, 2003)	'A business model provides a description of the roles and relationships, flows of goods, information, and money, emphasizing benefits.' (p. 4)	
(Andersson et al., 2006)	'A business model is created to make clear who the actors are in a business case and explain their relations, which are formatted in terms of value exchange between the actors.' (p. 483)	Participation and relations
(Janssen et al., 2008)	'A business model reflects the core business of an organization and its useful to describe (and even prescribe), the organization from perspective of its main mission, and the product and service that providing to customers.' (p. 2)	Core elements
(Johnson et al., 2008)	'The business model comprises four interlocking elements that create and deliver value: customer proposition, profit formula, key resources, and key processes.' (pp. 52–56)	
(Osterwalder and Pigneur, 2010)	'A business model describes the rationale of how an organization creates, delivers, and captures value.' (p. 14)	

(Weiner and Weisbecker, 2011)	‘A business model is an abstract description of a company’s business logic and provides an aerial view on several elements of a business, like value proposition, target customers, revenues stream and processes.’ (p. 21)	Abstract description
(Zott et al., 2011)	‘A business model is a new unit of analysis, as a system-level concept, centered on activities and focusing on value.’ (p. 1037)	System-level concept
(Schief and Buxmann, 2012)	‘Business models describe the strategic direction of a firm and have a significant impact on the success of innovations.’ (p. 1)	Strategic direction
(Nielsen and Lund, 2014)	‘A business model describes the coherence in the strategic choices which facilitates the handling the processes and relations which create value on both the operational, tactical, and strategic levels in the organization. The business model is therefore the platform which connects resources, processes and the supply of a service which results in the fact that the company is profitable in the long term.’ (pp. 4–5)	Strategic direction and logic

The multifaceted and dynamic nature of the business model is underscored by its varied functions and roles within organizations, as highlighted in (Foss and Saebi, 2017). They identified three overarching roles of the business model: (i) explaining, (ii) managing, and (iii) developing the business. These roles encompass a range of functions. Firstly, in explaining the business, the business model serves to abstract, describe, outline, and reflect upon the organizational structure and value proposition. Secondly, in managing the business, it establishes activity systems, frameworks, and blueprints to effectively manage operations. Lastly, in developing the business, the business model employs approaches, designs, and conceptual tools to innovate and adapt to changing market dynamics.

Furthermore, Gassmann et al. (2016) examined the components of a business model, revealing its systemic nature and emphasizing activities, value networks, and collaboration mechanisms among stakeholders. According to the authors, the understanding of the business model encompasses seven dominant schools of thought:

- *The Activity System School* defines the business model as a set of interdependent activities spanning firm boundaries, with a focus on transaction design, structure, and governance to create value.
- *Process School* views the business model as a dynamic process of balancing revenue, costs, organization, and value, emphasizing continuous evolution and adaptation.
- *The Cognitive School* characterizes the business model as a cognitive model guiding firm behaviour, providing exemplars and recipes for imitation and innovation.

- The *Technology-Driven School* sees the business model as a mediator between technological inputs and economic outputs, focusing on commercializing new technology.
- *The Strategic Choice School* emphasizes that the business model results from strategic choices, influencing competitive tactics and stakeholder values.
- *The Recombination School* views the business model as a recombination of patterns to address fundamental business questions, emphasizing innovation based on existing knowledge.
- *The Duality School* highlights the need for ambidextrous thinking in managing dual business models, balancing exploration, and exploitation in a competitive market.

The absence of a unified consensus regarding the precise definition of a business model stems from the misapplication of its terminology, alongside varied interpretations, and definitions. Moreover, tailored conceptualizations aimed at specific contexts exacerbate this disparity. The concept of a business model has evolved over time, driven by market dynamics, technological advancements, and shifts in consumer behaviour. Continual emergence of new business models serves to broaden the spectrum of definitions further.

Additionally, businesses operate within intricate ecosystems involving multiple stakeholders, such as customers, suppliers, and partners. Consequently, a universal definition that applies to all scenarios remains elusive. Nevertheless, despite the diverse viewpoints presented by various schools of thought, the various theoretical perspectives offered by scholars serve to enhance comprehension of the concept.

2.2.1 **Business model innovation**

Business model innovation (BMI) involves the process of crafting, altering, or specifying the fundamental framework and elements of a business model with the aim of developing fresh value propositions, seizing novel market opportunities, and attaining a competitive edge. Expanding upon the literature that explores the intersection of business models and innovation, the concept of business model innovation is crucial, whether applied to an existing model or the creation of a new one. This implies that BMI encompasses designing the business model for a newly established organization, involving entrepreneurial activities and the creation and implementation of a new business model. Alternatively, it can involve a scenario where managers alter the existing business model or restructure the organization, requiring a certain level of radicalization. As presented in Figure 2.3, both phenomena can result in BMI, positioning it as a subset of both business model design and business model reconfiguration (Massa and Tucci, 2013).

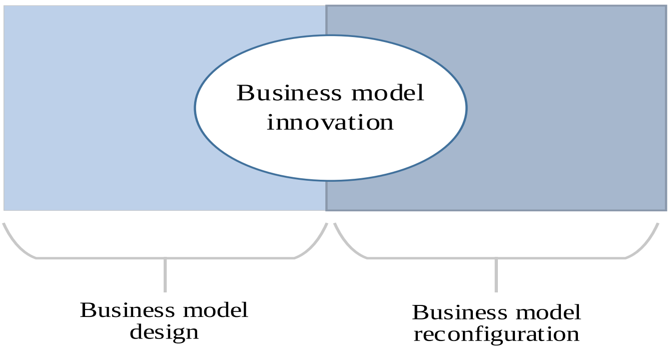

Figure 2.3: Business model innovation: a subset of design and configuration (Massa and Tucci, 2013).

2.2.2 **Business model abstraction across multiple reality levels**

The examination of business models uncovers a multifaceted construct involving various actors, interdependences, and dynamics. Understanding business models has become increasingly complex, leading to the development of various tools, frameworks, and ontologies to facilitate comprehension and practical application. These tools serve essential functions such as establishing a common language for communication, simplifying experimentation with BMI, and offering graphical and verbal representations. These representations play a crucial role in articulating the value of ventures, engaging external stakeholders, and facilitating resource activation and action (Massa and Tucci, 2013).

Massa and Tucci (2013) introduced tools like perspectives, frameworks, and ontologies to fulfil three primary functions (see Figure 2.4). Firstly, these tools create a *reference language* for dialogue, shared understanding, and collective sense-making. Secondly, they enable *graphical representations* that simplify cognition and provide a platform for virtual experimentation. Lastly, they *empower managers* to articulate venture value and seek support from external stakeholders for legitimacy.

Examining deeper into the business model concept, Massa and Tucci (2013) adopted the categorization of business model innovation tools, spanning distinct levels of depth and complexity. This comprehensive framework provides insights into business models at various levels of abstraction.

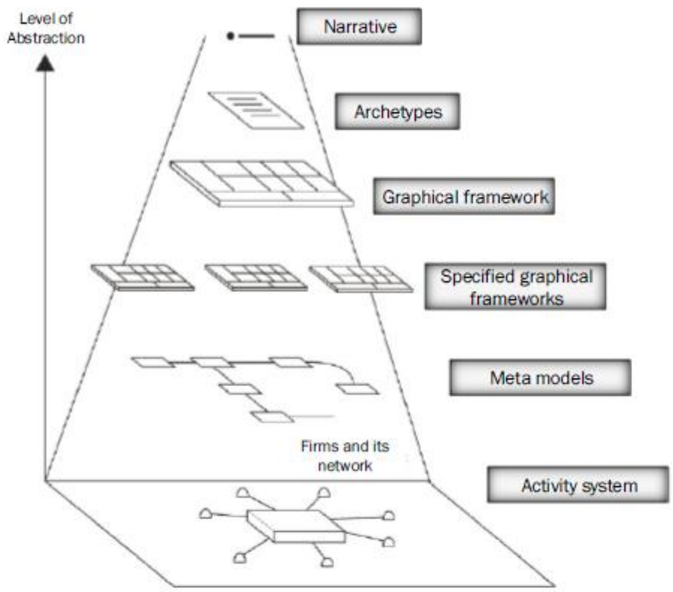

Figure 2.4: Decomposition of the business model (Massa and Tucci, 2013).

At the *Narrative* perspective level, the business model is perceived as a narrative or story. This approach simplifies cognition, making complex concepts more accessible. It serves as a powerful tool for communication and persuasion with external stakeholders. Emphasizing storytelling in business model innovation allows businesses to craft compelling narratives, effectively conveying the essence of their model and garnering support from various external parties. The *Archetype* level involves recognizing patterns and ideal examples in business model structures. These archetypes serve as types that can be imitated, providing valuable insights for innovation and emulation. At the *Graphical Framework* level, detailed insights into business model components are provided. Popular examples include the BMC by Osterwalder and Pigneur (2010), condensing crucial blocks into a single visual representation for analysis and manipulation. The *Meta-Models* level explores the dynamic nature of business models, integrating static and dynamic functions. It represents choices and consequences, influencing the behaviour of business models. This level offers a nuanced understanding of the complexities involved. The *Activity System* perspective level defines a business model as a system of interdependent activities. It incorporates design elements; content, structure, and governance, and design themes; novelty, lock-in, efficiency, and complementarities (Hamwi, 2019; Massa and Tucci, 2013).

2.2.3 Business model archetypes / patterns

Among the abstraction levels of a business model, business model patterns hold a valuable insight for developing and reconfiguration of business models. Business model archetypes/patterns are components of a business model that can be replicated for creating a new business model (Weking et al., 2020). They are already tested and proven models that can act as a base for innovating a new business model or improve an existing one. For instance, the conventional *bricks and mortar* pattern involves the physical presence of a store (bricks) and conducting sales or service operations in a store or office (mortar). With the increased application of digital services, *the bricks and clicks* pattern emerges as a new form of conducting business, that is, integrating the use of a digital marketplace in addition to a physical shop.

Business model patterns are specific to different parts of a business model. Table 2.2 provides some of the existing business model patterns in relation to their specific business model elements based on the detailed work on the topic presented in (Fox, 2020; Osterwalder and Pigneur, 2010; Osterwalder et al., 2020; Weking et al., 2020).

Table 2.2: Sample archetypes/patterns and their corresponding business model areas

Archetype/patterns	**Description**	**Specific area of a business model**
Open content	Accessible content development by a global community of contributors as a voluntary work	Value proposition development
Reverse engineering	Deconstruction of a product into its components to build a comparable product	
Digital service provider	Produce and deliver different type of services online	
Digitization	Offer a traditionally physical product with a digital format	
Customization	Provide customized products or services	Value proposition
Data as a service	Provide data files for customers over the internet	
Energy as a service	Provide energy service to a customer without having to make upfront investments	
Open business models	Value creation by operational synergies into the company's R&D process	
Auction	Make customers to offer the price they are willing to pay	Payment/ Pricing model
Barter	Provide a non-monetary compensation in exchange to actual money	
Flexible pricing	Vary prices based on demand of the product or service	

Freemium	Provide basic services for free while charging a premium for advanced features or contents	Payment/ Pricing model
Free	Offer customer services for the use of other sources, such as advertising to create revenue	
Pay what you want	Setting the price based on customers' WTP	
Flat rate	Charge a single fixed price for a service and allow the customer to have unlimited access in exchange	
Subscription	Provide products or services at a regular interval to customers for recurring upfront fee	Revenue Stream
Usage fee	Charge customers depending on their usage amount	
Pay per use	Charge for each use of a product or service	
Resource castle	Establish a competitive edge through key resources that are challenging or impossible for competitors to replicate.	Key Resource
Lock-in	Increase customer retention within your ecosystem by significantly raising switching costs through imposing formidable obstacles.	Customer relationship
Repurposer	Involves repurposing existing key resources to meet proven demand or target new customer groups, creating new value propositions by effectively utilizing these resources.	Customer segment
Revenue sharing	Share the revenues with other stakeholders to create a symbiotic relationship	Channel/Value delivery
Self-service	Transfer a part of the value creation to the customer	
Shared infrastructure	Share a common infrastructure among several operators	

Through the adoption of established patterns and frameworks, organizations can foster innovation and enhance their business models, thereby generating increased value for both their customers and stakeholders. For example, in 2007, Safaricom, Kenya's largest telecom operator, launched M-Pesa, a mobile money transfer system using their telecom infrastructure. This initiative exemplifies the Repurposer business model pattern, which involves repurposing key resources to meet proven demand or target new customer groups, creating new value propositions (Osterwalder et al., 2020). M-Pesa addressed the high demand for mobile payments among Kenyans, where traditional financial services were costly and insufficient. It quickly gained popularity, with 10,000 new registrations daily, and by 2010, handled over 90% of the country's mobile money transactions. M-Pesa significantly impacted Kenya's economy, lifting an estimated 2% of households out of extreme poverty. By 2018, it accounted for 28% of Safaricom's total revenue, primarily through transaction fees and other financial services.

Figure 2.5 illustrates the Safaricom repurposer pattern in the BMC. The abbreviations used in the BMC include: VP for Value Proposition, CR for Customer Relationship, CS for Customer Segment, CH for Channel, RS for Revenue Stream, CS for Cost Structure, KP for Key Partner, KA for Key Activity, and KR for Key Resource.

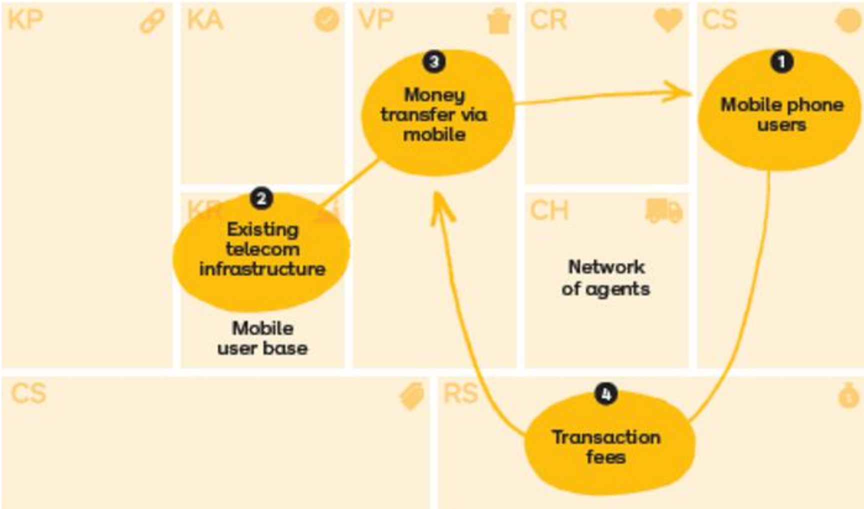

Figure 2.5: Safaricom's repurposer pattern formation (Osterwalder et al., 2020).

In the energy sector, a variety of business model patterns are showcased, and novel services are introduced to meet evolving demands. One such model is the Aggregator, which consolidates diverse resources or services within the energy sector to provide flexibility to markets. The aggregator's role is to pool electricity supply and/or demand and sell this capacity in the electricity markets (IRENA, 2019). Another innovative concept is Energy-as-a-Service (EaaS), which offers consumers comprehensive energy-related services, providing a hassle-free approach to access and manage their energy needs (Karami and Madlener, 2021). Another commonly used model is the Power Purchase Agreement (PPA), which entails a contract between a power producer (or a supplier) and a buyer for the exchange and delivery of energy (Accenture and ARENA, 2022). Furthermore, Community-Ownership models promote collective ownership of energy resources or infrastructure by a community, empowering local communities to have control over energy generation and distribution.

In the off-grid energy sector, innovative business model patterns have emerged to address various challenges and cater to specific needs. For instance, Appliance Financing offers appliances with credit to rural customers to stimulate electricity demand. The Anchor-Business-Community (ABC) model strategically mitigates the risk of uncertain power demand by prioritizing anchor customers first, followed by businesses and the community (Ramchandran et al., 2016). Another innovative concept is pay-as-you-store (chill) or chilling-as-a-service, which enables agricultural producers in the cold value chain to pay for using cold storage facilities when needed (USAID et al., 2019). The KeyMaker model facilitates the participation of mini-grid power-based rural manufacturers in the value chain of product trading businesses (Cabanero et al., 2020; Peterschmidt and González

Grandón, 2019). Additionally, the Split Asset model divides the financing of generation and distribution assets between developers, governments, or communities to address the capital cost burden (United Nations Industrial Development organization, 2020).

Moreover, adopting a nexus approach (integrator model), such as the Energy–Food Nexus, Energy–Agriculture Nexus, Energy–Telecom Nexus, or Energy–Water Nexus offers integrated solutions to communities. This approach facilitates a comprehensive understanding of the interconnections between energy, food, agriculture, water, health, and telecommunications, enabling sustainable resource management. By considering the synergies and impacts across sectors, it facilitates the design, evaluation, and prioritization of interventions with broader implications.

Furthermore, such business model patterns influence energy demand by enhancing productivity, which, in turn, increases the demand for energy. For instance, a study by CrossBoundary's Mini-Grid Innovation Lab, analysing data from 25 mini-grid sites and over 12,000 connections over four years, showed that appliance financing schemes, especially for productive use, drive consumption. The findings revealed that average consumption per user is 48% higher at sites with appliance financing, and the top 20% of appliance financing users consume 16 times more than their peers by meeting high community demand (CrossBoundary, 2022). This improvement in energy utilization also boosts the load factor, defined as the average load divided by the peak load over a specified period, consequently impacting the levelized cost of electricity (LOCE). The LOCE is closely intertwined with the economic feasibility of mini-grid projects, directly influencing energy tariffs, and accelerating cost recovery for developers (ESMAP, 2019, 2022).

2.2.4 **Inclusive business model**

The concept of an inclusive business model has expanded the traditional understanding of business models, shifting attention towards addressing social problems and sustainability concerns. Inclusive businesses actively involve income-constrained groups in their value chains and provide solutions to neglected issues, prioritizing the needs of these groups. They recognize the interdependence between environmental and socio-economic value, particularly for rural income-constrained communities, and aim to address environmental degradation and climate change vulnerabilities. By adopting sustainable models, inclusive businesses strive to create net value for income-constrained groups, reinvesting economic surplus to broaden and deepen value creation while sustaining operations without relying on charity (Feix et al., 2020; Gill-Wiehl et al., 2022; Schoneveld, 2020).

Inclusive businesses integrate income-constrained groups into their core operations as suppliers, distributors, retailers, or customers, forming profit-oriented partnerships with them. They focus on building the capacity of low-income farmers and entrepreneurs, enhancing access to finance, and adapting products to local needs. Innovative distribution approaches ensure that products and services reach marginalized communities, while collaborations with civil society organizations and farmer groups address market failures and provide improved inputs and markets (Schoneveld, 2020).

Scholars define inclusive business as a means of including the base or bottom of the pyramid (BoP) population into business activities for poverty alleviation, emphasizing its potential to surpass traditional development programs (Likoko and Kini, 2017). They stress the importance of considering human dignity and rights in business practices, advocating for economically viable models that generate social impact. Practitioners operationalize inclusive business by integrating small holders into markets with mutual benefits, promoting systemic impacts that benefit low-income communities, and emphasizing the dignity and well-being of the poor. Their definitions focus on including the BoP as employees, producers, business owners, and consumers, with a strong emphasis on partnerships and sustainable development goals (Likoko and Kini, 2017). As presented in Figure 2.6, inclusive business actions lie within or encompass the areas between the economic goal of profit maximization and the social objective of philanthropy within an organization.

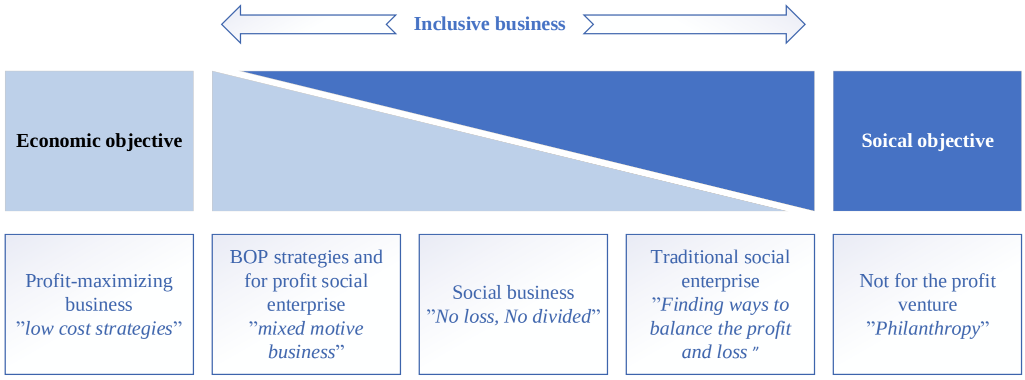

Figure 2.6: Positioning inclusive business (Adopted from HEC Paris, 2020).

2.2.5 Business model evaluation

In recent years, there has been a surge in attention towards innovation and the adaptation of existing business models. However, amidst this wave of change, a fundamental question arises: can a business model withstand the relentless evolution of the environment it operates in? This prompts the necessity for a systematic evaluation of business models in a scientific manner to determine their sustainability (Kayaoˇ et al., 2013; Steinhöfel et al., 2018).

Consequently, the discourse surrounding the evaluation of business models has become increasingly active within both research and practical domains. A considerable portion of this discussion is centred on devising appropriate tools, methodologies, and approaches for assessing the viability of business models. The evaluation process itself is a systematic approach used to gain a measurable understanding of a given business model, which can be applied either before the implementation of a new model (*ex-ante*) or to enhance an existing one (*ex-post*). By conducting evaluations, stakeholders within the business ecosystem can identify strengths, weaknesses, and overall performance, thereby aiding in strategic decision-making. Moreover, evaluating a business model empowers organizations to set future goals, refine strategies, and ultimately enhance their profitability and success (Mateu and Escribá-Esteve, 2019; Tesch and Brillinger, 2017).

The evaluation process commences with the establishment of specific objectives tailored to the economic and/or social goals of the organization (Batocchio et al., 2017). These objectives serve as a guide for developing relevant indicators, each assigned a respective weight, to measure progress and accomplishments towards achieving the desired outcomes. These indicators, essentially markers of performance, are designed to address evaluation questions and provide valuable insights into the operational dynamics of the organization's business activities.

Although the realm of business model evaluation methods has not been extensively explored, the scientific literature presents a multitude of proposed approaches. Within this literature, numerous business model evaluation methods are available, each tailored to specific domains and originating from authors with diverse backgrounds. These varied approaches are crafted to assess various dimensions, such as enterprise performance, entrepreneurship, innovation, and technology development, collectively offering a comprehensive framework for evaluating business models within the scientific discourse.

While certain methods focus solely on evaluating the fundamental components of a business model, others delve deeper by conducting thorough scenario analyses and rigorous risk assessments (Steinhöfel et al., 2018). This diversity in approaches ensures a multifaceted examination of business models, catering to the complexities inherent in different industries and organizational contexts.

2.3 WTP as a key element in pricing strategy

WTP represents the maximum amount of money an individual is willing to spend to obtain a particular product or service (Breidert et al., 2015). It is a crucial concept in economics and market research, providing insights into consumer preferences, demand, and pricing strategies. Understanding WTP helps businesses and policymakers make informed decisions regarding product development, pricing, and resource allocation.

WTP is a pivotal aspect of the value-based pricing strategy, which hinges on customers' perceived value of goods or services. This approach emphasizes evaluating the unique value a product or service offers compared with alternatives, rooted in identifying various value drivers like emotional, economic, and community factors. These drivers inform market segmentation, facilitating targeted approaches to different customer segments. While WTP is commonly factored into pricing decisions, it is essential to grasp that WTP is influenced by perceived value, not by an independent metric. Thus, framing value appropriately is critical in shaping WTP (Channa and Pitafi, 2023; Forth, 2019; Tai, 2020).

The nexus between value and price is forged through value metrics (how customers derive value) and pricing metrics (how customers are charged). By aligning these metrics, businesses can craft pricing models that reflect the distinctive value offered to diverse customer segments. Segmenting based on value drivers ensures that pricing strategies cater to the needs and preferences of each segment, thereby maximizing WTP. Understanding the significance of WTP in value-based pricing entails recognizing it as a reflection of perceived value, rather than as a standalone metric. By prioritizing value drivers, employing market segmentation, and aligning pricing with value, businesses can effectively influence and shape customers' WTP (Channa and Pitafi, 2023; Tai, 2020).

According to (Twerefou, 2014), WTP can be evaluated by examining how a consumer's utility changes with their consumption choices. In simpler terms, the more satisfaction or benefit a consumer perceives from a product or service, the more they are willing to pay for it. This implies that factors beyond mere affordability, such as perceived value and satisfaction, play significant roles in determining WTP.

Surveys and studies have shown that the impact of information on WTP varies depending on the personal relevance of the information to the individual. Additionally, the quantity and complexity of the information presented can influence its effectiveness; too much complexity may lead to cognitive overload and subsequent disregard of the information (Frederiks et al., 2015). For instance, In the United Kingdom, researchers investigated how information influences consumers' WTP for electricity and water attributes. while information effects were observed in the valuation of certain service attributes like blackouts, they were absent in the WTP for other attributes like water service disruptions, suggesting a low relevance to respondents (Akcura, 2013).

Moving beyond individual preferences, WTP also holds immense importance in the context of off-grid electrification projects. It serves as a critical factor in determining the feasibility and sustainability of such projects. Insights into consumers' WTP for electricity services can guide developers in introducing new products or services and crafting pricing strategies that align with market demand while ensuring profitability (Choynowski and Development Bank, 2002). Moreover, factors such as social, economic, demographic, cultural, and technical considerations influence consumers' WTP for electricity in developing regions, underscoring the multifaceted nature of this concept.

As presented in Figure 2.7, WTP estimation methods can be broadly classified into two categories: revealed preferences and expressed (stated) preferences. Revealed preferences are derived from price responses obtained from market data or through field and laboratory experiments, including auctions. On the other hand, expressed preference involves respondents directly stating their WTP for the product or indirectly providing it through rating and ranking estimated preferences. Examples of indirect survey methods include conjoint and discrete choice analysis (Breidert et al., 2015). The Contingent

Valuation Method (CVM) functions as a survey-based technique aimed at assessing the economic value of goods and services. Widely recognized as one of the foremost stated-preference methods, the CVM is especially prominent in environmental economics for evaluating the economic worth of environmental resources (Venkatachalam, 2004).

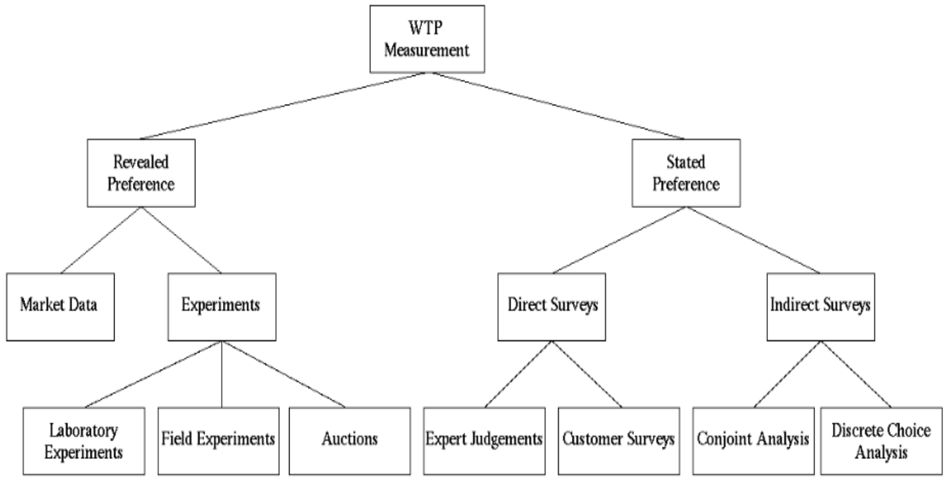

Figure 2.7: Classification of WTP study methods (Breidert et al., 2015).

For instance, in revealed WTP studies focusing on rural energy sources, respondents may be asked about the current prices of alternative energy sources, such as kerosene, candles, batteries, or the current electricity price if they are already connected to the grid. In contrast, expressed WTP studies involve formulating questions to describe a hypothetical electric service to consumers and then asking for the maximum amount they would be willing to pay for such a service. This approach requires creating a realistic scenario in which the interviewer offers the consumer a reliable electric service at a rational rate feasible for the project (NRECA International, 2016).

3 State of the art

To the best of the author's knowledge, there is limited research on mini-grid business models, with current studies predominantly examining isolated aspects like business model frameworks, commercial and social impacts, and socio-technological configurations. Similarly, studies on WTP for electricity in rural settings are limited. Most of the studies primarily employ CVM-based analyses. The following section outlines recent studies found using specific keywords and Boolean operators in research databases.

3.1 Studies related to the mini-grid business model

Mukoro et al. (2022) conducted a systematic literature review of renewable energy business models in Africa, providing insights into their types, adoption reasons, and viability factors. They emphasized the commercial viability of solar home systems and pico systems (a very small power system with a limited capacity), highlighting the significance of demand stimulation and incentivizing the adoption of energy-using products for mini-grid sustainability. Similarly, Bandi et al. (2022) addressed challenges encountered by social enterprises in rural India, particularly in reconciling business viability with customer affordability in mini-grid operations. Their study underscored the necessity of managing socio-technical complexities for sustainability and proposed a business model framework integrating social and technical aspects to address challenges in rural BoP markets.

Cabanero et al. (2020) explored the potential of KeyMaker Models in SSA, particularly in reducing grant requirements for financing mini-grid systems. They demonstrated that well-selected KeyMaker Models, such as agro-processing projects, could significantly enhance the financial viability of mini-grid projects, contributing to sustainable electrification in the region. Additionally, Come Zebra et al. (2021) analysed hybrid renewable energy systems (HRESs) for off-grid electrification in developing countries, highlighting their affordability and sustainability compared with traditional diesel-based technologies. Their findings underscored the importance of government support and community organization for the successful integration and operation of HRESs, offering insights into optimizing sustainable electricity supply in remote areas.

In relation to studies on energy–agriculture nexus models, the paper by Wamalwa et al. (2023) discussed challenges of low electricity access and irrigation rates in SSA. They proposed an integrated model combining mini-grids with smallholder irrigation farming to address these issues. Their simulation results showed a potential cost reduction in mini-grid energy. The study also explored the impact of pay-as-you-go (PAYGo) incentives on irrigation profitability, highlighting the profitability of horticultural crops over staple crops. The study offered insights for planning mini-grids and irrigation projects to enhance rural energy access and agricultural productivity.

Ogeya et al. (2021) investigated the integration of user experiences into mini-grid business model design in rural Tanzania, addressing the challenge of designing models that balance affordable service provision with acceptable cost recovery. The study employed a service design method called ‘user journey mapping’ to understand users’ needs, expectations, and experiences associated with adopting and using electricity services from the mini-grid. Their findings emphasized the importance of expectation management and continuous engagement to improve the user experience and prevent service disuse or ‘energy stacking’. Similarly, (Knuckles, 2016) developed a business model framework for analysing mini-grid business models serving the ‘base of the pyramid’ (BOP) markets. The study identified 29 configurations of elements within these models that meet the growing demand for electricity in BOP markets, highlighting trends within the off-grid electrification sector and discussing implications and areas for further research.

Rodriguez Zabala et al. (2021) proposed a business model for energy transition towards operational and economic sustainability for rural electrification in Colombia. Their study focused on incorporating distributed energy resources into isolated microgrids to guarantee sustainability and energy transition. The proposed modified business model canvas offers a useful tool for supporting microgrid market scheme development, emphasizing the importance of integrating rural electrification into the national energy regulation system to incentivize sustainable projects in rural areas.

These studies collectively contribute to understanding mini-grid business models, addressing challenges, proposing frameworks, and providing insights for future research and policy interventions in the field of rural electrification.

There is also limited literature related to the social and inclusive aspects of mini-grid development. In connection with social issues, Pedersen and Nygaard (2018) discuss how private companies providing electricity to rural areas in Kenya blend both profit-making and social welfare goals in their operations. The paper examines four different companies to understand how they balance making money with improving people’s lives. Some companies focus more on making profits, while others actively pursue social welfare objectives alongside their commercial goals. This study emphasizes the importance of finding a balance between making money and benefiting society in projects aimed at providing energy access to rural communities, and suggests that more research is needed to fully understand how these companies operate and the impact of their approaches.

Related to inclusive action, Lukuyu and Taneja (2023) underscore the pressing need for policies to stimulate electricity demand in SSA, crucial for socio-economic development. Despite increased accessibility, low consumption rates persist, hindering inclusive growth. Their analysis across sectors like residential, commercial, agriculture, transportation, and cooking highlights the importance of inclusive strategies to bridge existing gaps. They advocate research to enhance effectiveness and sustainability, emphasizing policy considerations to ensure accessibility, reliability, and affordability. This inclusive approach necessitates collaborative efforts among stakeholders to address infrastructure challenges and promote large-scale electric mobility adoption, fostering economic progress and reducing inequalities in the region. In addition, Gill-Wiehl et al. (2022) explored into the pivotal role of community involvement in mini-grid projects, stressing its importance for achieving universal electricity access and sustainable operation. Their study underscores that effective participation, particularly during operations and maintenance, is indispensable. Additionally, the paper advocates a broader perspective on community engagement beyond mere customer acquisition, aiming to expedite universal access and promote green economic recovery. Best practices highlighted in the paper include early involvement, broad inclusion, investment in community capacity, and clear governance. Methodologically, the paper provides a comprehensive literature review to understand the emergence and impact of community participation across project phases. It recommends fostering community ownership through decision-making involvement, including processes like tariff setting and revenue management, and maintaining open communication channels to ensure sustained support and participation.

3.2 Literature on the WTP for energy services

Korzhenevych and Owusu (2021) provided estimates of households' WTP for renewable-based electricity in rural Ghana through the CVM. Their findings revealed considerable WTP for high-quality renewable-powered electricity services, indicating the potential for renewable mini-grids to meet off-grid communities' electricity needs. Meanwhile, (Wen et al., 2023) conducted a choice experiment survey in rural Tanzania to explore off-grid households' preferences for electricity services. Their study emphasized the importance of tailoring tariff structures and business models to accommodate the diverse demands of different customer segments, highlighting the need to understand households' preferences for effective policy and business strategy formulation in rural electrification initiatives.

Bhandari et al. (2020) conducted a survey in rural Niger to study the effect of rural communities' WTP for renewable-based electricity supply. Their comparative analysis assessed the WTP for electricity service compared with the cost of off-grid systems, demonstrating that community empowerment through ownership increased WTP. Similarly, Taale and Kyeremeh (2016) investigated factors influencing households' WTP for reliable power in Ghana, finding that households are willing to pay significantly more for improved reliability. Likewise, (Oseni, 2017) studied WTP for reliable electricity supply in Nigeria, finding that having a backup generator increased households' WTP because of the high cost of unreliable grid supply.

Furthermore, there are CVM-based WTP studies in developing countries focusing on electricity reliability and service quality. For example, Arega and Tadesse (2017) examined households' preference for a renewable-based off-grid system in addition to the already connected grid supply, providing valuable insights into households' preferences and WTP for electricity services. Similarly, Entele (2020) analysed the welfare gain of renewable energy and WTP attributes for the green energy transition in Ethiopia. These studies contribute to our understanding of households' preferences and

WTP for electricity services, offering valuable insights for policy-making and the development of sustainable electrification strategies in rural areas.

3.3 Summary of the state of the art

While significant strides have been taken in comprehending mini-grid business models, there are research gaps in various aspects. These include the need for further exploration of business model design considerations to enhance the financial viability of mini-grid projects. Additionally, there is a gap in comprehensively evaluating the performance and impact of these business models.

In addition, understanding users' WTP and aligning it with developers' willingness to accept or sale is also crucial for ensuring affordability and sustainability. Furthermore, fostering inclusive actions to integrate users into the value network of the mini-grid ecosystem requires attention. These gaps must be addressed to develop effective strategies for rural electrification, which are in line with theoretical and practical concepts from business schools and theories.

4 Research design

This dissertation embarks on an empirical inquiry into the intricacies of the business model governing rural mini-grids, with a specific focus on user-centric feasibility. The investigation systematically delves into various dimensions of the business model, encompassing its design, evaluation processes, and inclusivity considerations. Additionally, it employs a WTP-based analysis to examine the economic viability of rural off-grid initiatives. The primary aim and scholarly contribution of this dissertation are rooted in illuminating the pivotal role of business modelling while providing a nuanced understanding of design considerations within the value network of the rural mini-grid ecosystem.

Furthermore, this dissertation evaluates methods for assessing business models and delves into their practical implementation within the mini-grid ecosystem. Beyond that, the study critically assesses how a mini-grid ecosystem achieves inclusivity throughout the value creation and capturing phases of its business model. This involves a comprehensive analysis of inclusivity considerations that are distinct from the evaluation aspects. The publications integrated into the dissertation (Publications I, III, IV) systematically analyse the multifaceted components of the mini-grid business model, covering design, evaluation, and inclusivity facets. Notably, Publication II provides a comprehensive feasibility analysis for rural electrification, employing WTP as a value-based pricing strategy.

The primary focus of the first three publications is to conduct a thorough examination of the factors influencing the design of microgrid business models. This analysis is based on the framework proposed in Publication I, which suggests that a business model design should encompass considerations such as WTP as a benchmark. Furthermore, the publication emphasizes the importance of inclusivity in the design process of rural electrification projects, integrating various values of co-creation.

Following the framework outlined in the first publication, feasibility studies based on WTP were conducted in Publication II. The paper explores consumer WTP for microgrid services and investigates its impact on the feasibility of projects. Subsequently, in Publication III, the research aims to quantify the contributions of inclusive business models to social equity and sustainable development in the microgrid context. Finally, Publication IV strives to establish a comprehensive framework for systematically evaluating the effectiveness and efficiency of microgrid business models, with a focus on factors such as economic viability and adaptability.

Collectively, these objectives seek to offer a nuanced understanding of microgrid business models, shedding light on their design features, inclusivity, and the factors influencing their success.

4.1 Research approach and method

The publications within this dissertation employ varied methodological approaches to address the research inquiries. In Publication I, the Business Model Environment (Osterwalder and Pigneur, 2010), a derivative of the BMC developed by Alexander Osterwalder and Yves Pigneur, is utilized to systematically map and evaluate the environment within the microgrid business model environment. This structured approach encompasses four distinct areas: Market Forces, Key Trends, Industry Forces, and Macro-Economic Trends, which exert influence on the formulation of the business model. Additionally, the publication introduces external factors crucial for designing microgrid business models, namely WTP-based pricing as a benchmark, an inclusive design process, and considerations related to socioeconomic aspects.

In Publication II, a methodology is devised to leverage customer WTP for energy in constructing a demand curve, which is then cross-linked with a supply curve derived from the WTA perspective of a microgrid developer. Through the creation of these demand and supply curves, the study seeks to evaluate the feasibility and pricing of microgrids, considering both WTP and WTA. The WTP and WTA analyses are developed using questionnaire data and microgrid pilot economic costs, implemented through an iterative MATLAB code.

Publication III presents a theoretical framework addressing how a mini-grid project can incorporate the local community across various stages of value creation and capture. Employing the inclusive business model theory, the study explores the application of this framework within a mini-grid ecosystem, outlining areas where consumers engage.

Publication IV introduces a methodology for constructing a business model evaluation framework tailored to mini-grid ecosystems. This entails the application of diverse business model evaluation theories, resulting in a comprehensive framework that encompasses the varied stakeholders involved in mini-grid development.

4.2 Research data

The research data used in the dissertation were sourced from a microgrid pilot site and residents situated in rural regions of Namibia, where the pilot site was established. Additionally, data were gathered from companies operating in developing regions, serving various roles, such as developers, facilitators, and OEMs. These data formed the basis for Publication II, focusing on the WTP and WTA, and originated from the pilot site areas in rural Namibia as part of the Fusion Grid research project. It also encompassed information regarding the costs associated with the hardware and system of the actual microgrid.

In the context of Publication IV, which pertains to the development of a business model evaluation framework, the data were collected from six companies operating in rural areas of developing regions. These companies were engaged in the role of developers and providers of energy services.

4.3 Research limitations

The dissertation encountered several limitations during the research process. One notable limitation was the lack of access to large datasets from rural electrification projects. This scarcity of data hindered the ability to conduct comprehensive analyses and draw robust conclusions. Additionally, the quality of available data varied, which posed challenges in ensuring the reliability and validity of research findings. Another limitation stemmed from difficulties in reaching out to energy companies operating in rural Africa. Limited engagement with industry stakeholders restricted access to valuable insights and perspectives, potentially overlooking important factors influencing business model design and implementation in the context of rural electrification.

Furthermore, the scarcity of literature specifically focusing on the business models of rural electrification, particularly within the realm of business scholarship, posed a challenge. The existing literature predominantly originates from interdisciplinary fields, such as development studies or engineering, rather than traditional business disciplines. This lack of literature constrained the depth of theoretical frameworks and conceptual understanding available for analysis and discussion.

5 Research findings and contribution

This chapter summarizes the publications of this dissertation and draws the main conclusions. An overview of objectives, methods, and findings is presented in Table 5.1 below.

Table 5.1: Summary of the publications

	Title	Objective	Method	Findings
Publication I	Business Model Design for Rural Off-the-Grid Electrification and Digitalization Concept	Propose a framework for designing rural off-grid business models, utilizing the business model canvas, and considering external factors.	Qualitative and case study	The findings emphasize considerations for developers during development and operation, including using WTP as a pricing benchmark and integrating community inclusivity and socioeconomic factors.
Publication II	Feasibility of rural electrification and connectivity —A methodology and case study	Provide a new method to evaluate the economic feasibility of a photovoltaic (PV)/battery off-grid system by considering customer WTP.	Algorithm development for demand curve estimation	The findings indicate that there is a specific price range for the service within which a microgrid project can be deemed economically viable while also meeting the local consumers' WTP for the service.
Publication III	The Prospect of Inclusive Business Model for Mini-Grid Development	Propose an inclusive business model for mini-grid development, involving marginalized communities in energy processes to create economic benefits and shared value.	Qualitative and case study	Effective inclusive strategies for mini-grid developers should focus on generating economic opportunities, promoting local ownership and sustainability, and ensuring accessibility of electrification benefits to marginalized communities in developing countries

Publication IV	Measuring success: Evaluating the business model of rural mini-grid ecosystems	Conduct a brief review of rural mini-grid business models and evaluation methods in the off-grid energy systems sector to introduce and test a novel evaluation method.	Qualitative and case study	The study introduced and tested a novel evaluation method designed to identify organizations, rank indicators, and provide insight into the rural mini-grid business environment.

5.1 Business model design for a rural off-grid electrification and digitalization concept

The primary focus of the first paper (Publication I) lies in understanding how to construct effective business models tailored specifically for rural microgrid projects. It delves into the intricacies of this process by employing a widely recognized BMC tool, which serves as a blueprint for mapping out various operational facets essential for project success (Osterwalder and Pigneur, 2010). By breaking down critical components like identifying target customers, establishing supply chains, assessing infrastructure needs, and ensuring financial viability, the BMC provides a structured framework to guide strategic decision-making and project planning.

An illustrative case study highlighted in the paper is the Fusion Grid project, which epitomizes the practical application of the BMC methodology. This innovative initiative aims to address the dual challenges of energy provision and digital connectivity in rural areas by integrating telecommunications and electricity services (Vanadzina et al., 2019). By showcasing how the BMC can be applied to Fusion Grid, the paper demonstrates its utility in navigating the complexities inherent in such multidimensional projects. The Fusion Grid business model components are presented in Figure 5.1.

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">Educational institutions
Government bodies
Local community organizations
Telecommunications providers
Electric utility</td><td>Provision of 24/7 reliable electricity
Provision of continuous internet connection
Provision of digital services
Maintenance of off-grid systems
Remote assistance</td><td rowspan="3">The service offers an integrated solution comprising reliable electricity supply, internet connection, and digital service platforms tailored for remote areas with restricted access to utility grids and telecommunication infrastructure. These digital services encompass educational, e-commerce, e-government, and peer-to-peer energy sharing concepts, catering to the diverse needs of users in such regions.</td><td>Customer relationships can be established either through direct face-to-face interactions or via an information and communication technologies platform facilitated by the system's internet connection.</td><td rowspan="3">Residential neighborhoods characterized by clustered houses, typically comprising communities;
Small-scale businesses and public service facilities including healthcare centers, schools, and town halls;
Organizations operating in remote regions, such as construction and mining companies, lodges, and park management entities.</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>A microgrid integrating renewable-based energy generation and Battery Energy Storage Systems (BESS) for electricity delivery, complemented by essential digital service platforms for education, e-commerce, e-government, and businesses, stands as a crucial resource.</td><td>The proposed concept seeks to establish direct and virtual channels to access potential customers in remote areas.</td></tr>
<tr><th colspan="2">Cost Structure</th><th colspan="3">Revenue Streams</th></tr>
<tr><td colspan="2">The cost structure encompasses the capital cost (CAPEX) for the microgrid system, which represents the major portion, along with additional expenses including maintenance, security, and operational costs (OPEX).</td><td colspan="3">Encompasses the sale of electricity, internet connection, and various digital services including e-commerce, educational, and e-government offerings.</td></tr>
</table>

Figure 5.1: BMC outline for the Fusion Grid microgrid concept.

Moreover, the paper delves into an assessment tool proposed in (Osterwalder and Pigneur, 2010), designed to evaluate the broader business landscape encompassing market forces, trends, industry dynamics, and macroeconomic factors. This holistic approach to understanding the business environment is deemed essential for making well-informed decisions regarding project feasibility and sustainability.

In addition to discussing the practical application of the BMC and the assessment tool, the paper identifies three key considerations crucial for designing effective business models for rural electrification projects. Firstly, it underscores the importance of pricing strategies based on customers' WTP, ensuring that revenues generated cover the costs associated with energy production. Secondly, it advocates a community-inclusive design process, emphasizing the necessity of engaging local stakeholders and fostering mutual value creation. Lastly, the paper highlights the significance of evaluating not only the direct technical and financial impacts of electrification but also the indirect social and cultural ramifications (Winther, 2015).

Furthermore, by placing a particular focus on exploring the intricacies of WTP evaluation in value-based pricing strategies and incorporating inclusive measures to ensure the success and sustainability of rural off-grid initiatives, the paper lays the groundwork for further research on these subjects.

5.2 Feasibility of rural electrification and connectivity—A methodology and case study

The second paper (Publication II) builds upon the framework established in the first paper, aiming to delve deeper into the consideration of WTP-based pricing strategies for rural off-grid electrification projects. Essentially, WTP serves as a cornerstone of value-based pricing strategies, where the price of a product or a service is determined by the perceived value to users rather than production costs (Breidert et al., 2015). Studies on WTP play a critical role in understanding customers' preferences and financial thresholds for electricity services, particularly in the context of rural electrification projects. In this realm, the CVM, also known as stated-preference studies, is widely employed (Venkatachalam, 2004). The CVM is a survey-based approach commonly used in environmental economics and essential infrastructure projects to ascertain individuals' WTP to maintain or be compensated for the loss of a utility.

The paper comprehensively explore various methodologies applied in rural electrification studies, with a primary focus on understanding customers' WTP. It proposes a methodology to assist microgrid developers in justifying investments and minimizing non-payment risks. One innovative metric introduced in the paper is the *unit of service*, which correlates customers' preferred prices with service provider profitability, encompassing both electricity and telecommunications in one package. This metric is crucial in evaluating affordability based on service quantity and customers' monthly income. The developers' WTA relies on the annual revenue needed throughout the project's lifetime, which can be calculated using the net present value (NPV) function. NPV considers the discounted cash flows associated with the investment over its lifespan. Therefore, for the developer to have a viable project during the lifespan, the cumulative value of cash flows minus the initial capital expenditures (CAPEX) must be at least greater than zero.

The paper draws insights from a case study conducted in Revon C district, Oniipa Town in Northern Namibia, where the Fusion Grid microgrid pilot site is established. Data collected from respondents' WTP for electricity per household per month, alongside the cost of the microgrid system, were used to create WTP and WTA curves.

The results highlight that customers' income levels significantly influence their WTP for electricity services, with an average WTP of 655 NAD (~ €37) per month, representing approximately 21.6% of the average income. Access to reliable electricity services and the perceived value of additional bundled services play crucial roles in shaping WTP. Furthermore, the study identifies an equilibrium price point of around N$898 or €50 per unit of service per month, where WTP and WTA are equal. This price enables the developer to install a microgrid sized between 5 and 20 units of service, covering capital costs. Moreover, the paper discusses how changes in customers' future WTP and cost factors affecting WTA can impact equilibrium prices. By analysing the relationship between WTP and WTA, microgrid developers can adapt their business strategies in response to customer behaviour and market dynamics. Nonetheless, it is important to note that in real-world scenarios involving profit-driven developers, merely covering CAPEX is insufficient. A profit margin must be included, which can result in higher prices due to this added margin.

5.3 The prospect of inclusive business model in mini-grid development

The third paper (Publication III) primarily focuses on highlighting the importance of inclusive business models in rural mini-grid projects, building upon the concept introduced in the first publication as a key consideration for rural electrification project development. By comprehensive examination of the value chain of the mini-grid ecosystem, the aim is to underscore the importance of integrating income-constrained groups into this framework.

Inclusive business models aim to tackle overlooked issues and encourage the active involvement of marginalized communities (Likoko and Kini, 2017). Distinguishing itself from conventional business models, an inclusive business model prioritizes providing economic opportunities to marginalized or low-income individuals by engaging them in the value creation process. This model enables them to share the benefits of the organization, rather than solely focusing on maximizing profits for the company and its shareholders (Schoneveld, 2020). The theoretical basis of this exploration lies in recognizing mini-grids as vital solutions to the persistent challenge of electricity shortages, particularly in regions like SSA. Mini-grids not only serve as sources of electrical power but also as catalysts for economic development within communities, stimulating economic activity and facilitating productive energy use across sectors, such as agriculture, rural enterprise, health, and education.

The exploration highlights the dual capability of mini-grids to operate independently or interconnected with the national utility power grid. It stresses that inclusive business strategies in mini-grid development play a crucial role in generating economic opportunities, fostering local ownership, ensuring sustainability, and extending electrification benefits to marginalized communities. Additionally, the paper explores the synergy between energy potential and other services, such as water or food services, through collaborative partnerships. By integrating these services, mini-grids can offer enhanced value for stakeholders, promoting a holistic and sustainable approach to development.

Further, the paper delves into the intricate details of inclusive approaches within mini-grid development, emphasizing community involvement in the value creation and capture system of the mini-grid. This involvement spans various aspects, including participation in power generation, energy storage, flexibility through demand response programs, and various financial and ownership roles within the mini-grid network. Simultaneously, it explains how communities can benefit from the value created by the mini-grid system, promoting local entrepreneurship, applying productive uses of energy, offering value-added services, and implementing revenue-sharing mechanisms. In essence, the exploration aims to provide a comprehensive understanding of the multifaceted advantages of inclusive approaches in the development and operation of mini-grids.

5.4 Measuring success: Evaluating the business model of rural mini-grid ecosystems

The final paper (Publication IV) presents a method for evaluating the business model of a mini-grid ecosystem. Business model evaluation is a systematic process used to understand its effectiveness, either before implementing a new model or improving an existing one. It helps stakeholders identify strengths, weaknesses, and performance, aiding in setting future goals and restructuring for success (Alexa, 2014; Mateu and Escribá-Esteve, 2019). This process involves setting objectives, developing suitable indicators, and gaining insights into business activities. Business model evaluation methods cover a wide range of areas, including enterprise performance, entrepreneurship, innovation, and technology development. These methods vary in complexity, from basic assessments to more detailed analyses and risk assessments (Steinhöfel et al., 2018). Despite the importance of mini-grids in rural electrification, there is a shortage of evaluation methods specifically designed for these cases. This highlights the need for new approaches and indicators that are relevant to rural mini-grid projects. By using existing methods and including indicators that focus on users, it is possible to create a thorough approach to evaluating the mini-grid business ecosystem.

The paper introduces a framework designed to assess business models within the realm of rural mini-grid ecosystem. By bridging the existing gap between business model evaluation methodologies found in and rural electrification studies, the paper aims to provide a comprehensive understanding of the transformative effects of mini-grid projects that extend beyond traditional energy access metrics. This evaluation method identifies organizations by tier within the value network, offering indicators that comprehensively assess the roles of developers and facilitators in the rural mini-grid business environment.

In adapting to the dynamic conditions of the market, business models play a pivotal role in ensuring sustainability and competitiveness in rural electrification. This framework draws upon various business model theories and evaluation approaches. The need for these qualities extends not only to the mini-grid sector but also to businesses across diverse industries. Operating within the context of rural mini-grid ecosystems, these models must continuously evaluate and reassess their strategies, staying abreast of market trends, technological advancements, and regulatory changes.

The methodology employed in this study incorporates a survey designed by the authors, containing self-evaluation questions based on indicators and sub-indicators outlined in the paper. The study examines into a case-by-case analysis of six companies currently operating in rural mini-grid projects in Africa. The analysis, conducted through a survey and a comprehensive evaluation framework, examines the responses to self-evaluation questions and quantifies the data to retrieve numeric representations of indicators. The criticalness factor associated with each business model block is crucial in determining the relative importance of these blocks in achieving overall success. The small sample size and subjective evaluations by stakeholders are acknowledged as limitations.

The findings underscore the potential for improvement in business models within the mini-grid sector, particularly in areas like customer segmentation based on energy consumption behaviour. The proposed evaluation method, despite its limitations, provides valuable insights into the evaluation of rural mini-grid business models. It emphasizes the need for consistent evaluation to adapt to changing conditions, identify areas for innovation, and sustain competitiveness in the evolving landscape of rural electrification.

6 Discussion and concluding remarks

Electricity has distinct qualities that set it apart from tangible products. Unlike most consumer goods, its presence is intangible, only discernible through its effects. As a crucial catalyst for economic progress, the relationship between electricity generation and economic growth is robust. However, achieving universal accessibility and affordability while maintaining commercial viability and balancing profitability with accessibility and reliability with cost presents significant challenges, particularly in developing nations. This delicate equilibrium requires addressing a wide array of technical, economic, and social obstacles.

Next, the overarching themes of the dissertation, its scientific contributions, and potential areas for future research are discussed.

6.1 Viewing mini-grid development through business model theories

The concept of a business model has often been misused and misunderstood, leading to confusion among academics and practitioners alike. Frequently used as a buzzword, the term has been interchangeably used with similar concepts, such as strategy, economic model, and revenue model, further complicating its definition. This lack of clarity has resulted in various interpretations and understandings of the term, contributing to stretched and equivocal meanings. To address this ambiguity, scholars have proposed diverse interpretations of the business model, tailored to specific contexts. These definitions encompass a wide range of functions, including articulating value propositions, identifying market segments, defining value chains and networks, estimating cost and profit structures, and formulating competitive strategies.

Within organizations, the business model serves multiple roles, including explaining, managing, and developing the business. In the context of a mini-grid ecosystem, where facilitators collaborate with a developer, the Activity System perspective defines the business model as a system of interdependent activities. This perspective aligns with the definition provided by Zott et al. (2011), emphasizing the system-level understanding centred on activities and value creation. Moreover, the business model is viewed as a network of interconnected actions and processes, as described in (Andersson et al., 2006; Camponovo and Pigneur, 2003; Timmers, 1998). Each facilitator within the ecosystem contributes to specific activities, such as energy generation, distribution, maintenance, customer service, and financial management, shaping the overall effectiveness and efficiency of the business model.

To enhance their strategies and operations, both the facilitator and the developer can apply various business model perspectives within the mini-grid ecosystem. At the Archetype level, they can recognize patterns and ideal examples in business model structures, fostering innovation and emulation. Meanwhile, at the Graphical Framework level, detailed insights into business model components are provided through frameworks such as the BMC, enabling comprehensive visualization and analysis. This facilitates better understanding of interdependences among components and supports strategic decision-making to optimize operations within the mini-grid ecosystem.

The current scientific research lacks comprehensive coverage of mini-grid business models that adhere to business school guidelines and theories. Studies often narrow their focus to specific facets, such as frameworks, impacts, and configurations. Despite advancements, significant research gaps persist, including the need for deeper exploration of business model design and comprehensive evaluations of performance. Additionally, fostering inclusive practices is essential for integrating all stakeholders into the mini-grid ecosystem, which is crucial for effective rural electrification strategies.

6.2 Utilizing WTP for financial viability of a mini-gird project

Understanding the complex relationship between WTP, pricing strategies, and the perceived value of rural energy services is crucial for developers. WTP, serving as a cornerstone in value-based pricing, is closely linked to how much consumers think a service is worth, rather than being a separate measure. This understanding requires identifying various factors that influence value, such as emotions, economics, and community needs. By aligning these factors with pricing strategies, businesses can create pricing plans that cater to different customer groups, maximizing WTP.

In the context of rural electrification projects, evaluating WTP is essential for determining if off-grid initiatives are feasible and sustainable. Insights gained from understanding what consumers are willing to pay help developers introduce new products, energy services, and pricing strategies that are profitable and meet the market demand. Additionally, various social, economic, demographic, cultural, and technical factors influence how much rural consumers are willing to pay for energy services, highlighting the complexity of this concept.

Therefore, it is crucial to carefully consider how much rural customers are willing to pay to understand if off-grid projects are viable. By gaining insights into rural communities' WTP, developers can reduce the risk of losing profits and ensure that their services are valued appropriately. This proactive approach significantly increases the chances of project success and sustainability, empowering developers to adjust pricing strategies and offerings to better meet the needs of rural communities while also recognizing the pivotal role pricing plays in the financial viability of an organization's business model.

6.3 Scientific contribution

The dissertation attempts to address multiple gaps, and thereby makes contributions to the field of rural electrification and mini-grid development in SSA.

Firstly, the study addresses the gap in microgrid business modelling by employing the BMC for microgrid business model design. This approach fills a void in the literature by offering a visual representation and evaluation of key design considerations essential for the success and sustainability of microgrid projects in rural SSA.

Secondly, the research delves into the feasibility assessment of microgrid projects by exploring consumers' WTP across community members. By addressing this gap, where most WTP studies rely on statistical methods, the dissertation provides insights and methodology into the economic viability of microgrid services. It informs pricing strategies tailored to diverse consumer preferences and affordability levels using WTP data.

Thirdly, the study emphasizes the importance of inclusive business models in mini-grid development and proposes actions that can be taken in the value network, particularly in rural SSA. By promoting community engagement and local ownership, these inclusive approaches fill a gap in the literature by enhancing social equity and fostering sustainable development within rural communities. This empowerment of marginalized populations ensures long-term project viability.

Lastly, the dissertation introduces a novel framework for systematically evaluating the effectiveness and efficiency of microgrid business models. This addresses a gap in the literature by providing stakeholders with a structured approach to conduct comprehensive evaluations. It helps in identifying areas for improvement and sustaining competitiveness in the landscape of rural electrification.

Collectively, these contributions offer practical insights and frameworks that address critical research gaps in rural electrification, providing valuable guidance for stakeholders involved in microgrid projects. They advance the state of knowledge in sustainable energy access in SSA, ultimately contributing to the improvement of livelihoods and economic development in underserved communities.

6.4 Future research

As part of future research work, it is essential to investigate the role of business models in influencing the energy demand and supply of mini-grid systems in a quantitative manner. Additionally, understanding the impact of various business model architectures on revenue, cost structure, and overall financial benefits is crucial. Similarly, quantifying the effects of different inclusive actions on the viability and effectiveness of mini-grids is necessary. In the realm of WTP studies, further exploration of diverse WTP study methods, such as conjoint analysis, can enhance comprehension of customer preferences for achieving user-centric design. Moreover, standardizing business model evaluation through the refinement of effective indicators that encompass each stakeholder's role is necessary.

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Publication I

Dibaba, H., Vanadzina, E., Mendes, G., Pinomaa, A., and Honkapuro, S.
Business Model Design for Rural Off-the-Grid Electrification and Digitalization Concept

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Business Model Design for Rural Off-the-Grid Electrification and Digitalization Concept

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***Abstract*— Microgrids have been technically viable for rural electrification in Sub-Saharan Africa (SSA). However, despite growing interest in microgrid projects among stakeholders in developing markets context, the lack of well-defined business models remains a challenge. In this paper, a novel off-grid concept is analyzed using a business model canvas approach. The concept has been designed to supply renewable-based electricity, connectivity, and digital services as an integrated package to remote areas where such infrastructures do not exist. The paper also propose a framework for developing sustainable rural microgrids in SSA.**

***Index Terms*--Business model, Microgrid, Rural area electrification.**

I. INTRODUCTION

Despite considerable achievements in electrification across the world in the past two decades, there are still roughly one billion people, of which over half live in Sub-Saharan Africa (SSA), do not have access to electricity. And, nearly 80% of those lives in rural areas [1]. Similarly, in the telecommunications (telecom henceforth) sector, although a sharp increase in mobile phone line density has been seen over recent decades, broadband subscriptions and internet usage in the SSA still lags compared to other parts of the world [2].

Renewable distributed energy resource (DER) based microgrids are becoming an attractive solution for improving the electricity distribution sector in SSA and can be considered key drivers for affordable and flexible energy systems. Microgrids can improve the reliability and efficiency of power systems for households, businesses, communities, and organizations. Similarly, access to electricity enables telecommunication services to roll out, which provides new possibilities for rural communities through connectivity and digitalization platforms [1].

However, despite the growing interest in developing microgrid projects among stakeholders, the lack of well-defined business models remains a challenge, especially in attracting private investments. This has led to microgrid solution developments in SSA to be mainly driven by governments and donor initiatives [3].

Currently, there is no one-size-fits-all microgrid business model; instead, there are different innovative models dedicated to solving specific features of microgrid development and operations, such as project initiation, cost recovery, financial backing, and operation and ownership roles [3]. For instance, the lease-to-own agreements (LTO) provide microloans to own microgrid systems, where customers pay an initial deposit, followed by an installment payment. Also, the pay-as-you-go (PAYG) model is used as a revenue collection means, by allowing customers to purchase credits in advance of the electricity use.

For a microgrid project in rural SSA to be viable in the long-term, it is necessary to have a holistic approach towards project development that encompasses multiple operational and business features. This can further establish a clear set of information that an investor can evaluate the business proposal, and further smooths the investment process.

Investors by character require a clear and simplified illustration of a business process from proposition to capturing of a value. However, the information environment between the investors and investees can be challenging – especially for a start-up company seeking venture capital without having a previous financial history. Business planning has long been the main information vehicle among investors and investees. However, some studies have shown that business plans are becoming more symbolic, and judgments of investors have based in the first few pages of the business plan [4].

One way of outlining the key elements of a business process can be with the use of the business model canvas (BMC). Developed by Alexander Osterwalder, the BMC is used by many to visualize the key elements of a business organization [5]. The BMC hypothetically outlines how a project meets the strategic objectives, which require planning, implementing, and executing operations. The BMC covers four key areas of business: customers, supply, infrastructure, and financial viability. This partition consists of nine intertwined business blocks. These are customer segment, value proposition, channel, customer relationship, revenue stream, key partners, key activities, key resources, and cost structure. In addition to outlining the business's elements, assessing the business environment is a key to success. These assessments can be done using a framework of Osterwalder's environmental forces, which include market forces, key trends, industrial forces, and macro-economic forces [5].

Furthermore, assessing the indirect-value creation of infrastructural development in rural areas is essential for the project's long-term success. Indirect-value creation can be referring to the social, emotional, economic and cultural impacts that are created as a result of the primary goals [6]. To ensure the project's added value has a positive impact on the community's well-being, a community-inclusive approach in rural development can be a preferable methodological approach [7].

Pricing is another important component in microgrid economics. Setting up a price requires considering how much customers value the product or service rather than focus only on costs. In the case of rural microgrid development, how much customers are willing to pay for the service or product plays a significant role in the financial viability of the project. Thus, willingness-to-pay (WTP) surveys enable project developers to realize the ability of users to pay for the service so that the project generates enough revenues to cover its operational and maintenance costs. Otherwise, the project requires to have an additional source of revenue from added values or subsidies [8].

This forms the framework we are proposing that comprises the above-mentioned business and socio-cultural elements, which are illustrated in Figure 1.

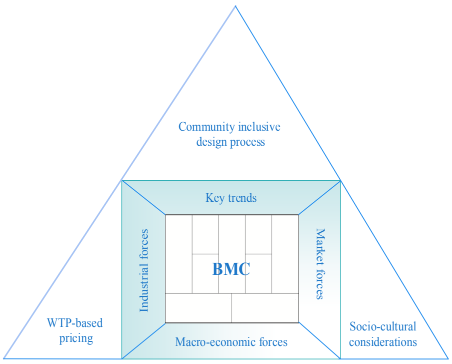

Figure 1: Rural microgrid development framework.

In this paper, a new lightweight off-grid concept providing electricity, connectivity, and digital services in an integrated package is used as a case study to assess the proposed framework. The concept is designed to supply renewable-based power, connectivity, and digital services as a turnkey solution to remote areas, where such infrastructures do not exist.

The rest of this paper is organized as follows. Section II describes the concept. Viable business model elements using a BMC for remote areas and surroundings in SSA are analyzed in Section III. Section IV outlines the necessary themes needed for the success of a sustainable rural microgrid implementation and roll out in SSA. Finally, Section V concludes the paper.

II. Proposed Off-Grid Concept

The concept comprises solar photo-voltaic (PV) panels, a battery energy storage system (BESS), and a 4G Long-Term Evolution (LTE) micro base transceiver station (BTS). The alternatives for the BTS backhaul connection in rural areas are 4G, microwave, or satellite. The backhaul connection is required for access to the internet, cloud services, and global value chains, enabling digital services that prompt socio-economic activities [3],[9].

The proposed concept is designed to be modular and can be scaled based on the energy and power needs of the customers or use case. The community microgrid is dimensioned to provide electricity and via 4G LTE mobile network connection internet access to consumers.

The concept's built-in control system uses weather forecasts, consumer behavior, and load profiles as parameters for system optimization [10]. Moreover, all processes are automated, monitored, and managed locally and remotely via an implemented supervision system and cloud connection. Besides, the microgrid information and communication technology (ICT) platform enables the possibility to establish a peer-to-peer (P2P) energy trading between microgrid customers. For instance, household customers with low daytime demand can share their surplus energy for productive use consumers [9]. Therefore, the power system dimensions to fulfill requirements for peak capacity, which impact the capital cost of the whole system can be minimized.

III. Business Model Design and Evaluation For Rural Microgrids

The definition and understanding of business models can vary depending on the conceptual abstraction, architecture, content, and approach included in the business model. Varied literature defines a business model according to the context of its application – leading to not having a single definition [11],[12]. However, a business model can be generally (conceptually) defined as actions required for a business to succeed in capturing value from a given activity. The created value can have economic, social, and cultural relevance. A viable and sustainable business model can be adopted or modified from previous models for acquiring a competitive edge in certain market environments. Many business models have been defined via this approach, which is known as a form of Business Model Innovation (BMI). BMI is becoming more inclusive towards sustainability factors, i.e. reducing negative impacts on environmental and societal factors, by modifying the processes of creation and capture of value [12].

Today, several business models have been designed and studied for public and commercial sector microgrids. However, many of these models focus on a specific part of the business process, such as economic benefits, success factors, or frameworks for policies and regulation. Hence, designing microgrid business models requires an inclusive consideration of target customers and use cases, as well as technical, financial, ownership, and operational roles. Especially in the case of rural areas of SSA, the assessment needs to take additional factors into consideration due to region's tangled socio-economic structure [3].

In the following section, the business model elements, as well as the business environment of the proposed off-grid microgrid concept are thoroughly assessed using the BMC framework.

A. Business Model Canvas (BMC) for Off-Grid

BMC can be one way of visualizing and formulating the necessary business elements for the proposed microgrid concept development in rural areas. The different elements of BMC for this case study concept are presented as follow:

1. *Customer segment* – specify the group of customers that a business organization wants to reach. The proposed off-grid concept serves different customer segments, which are categorized based on their needs for electricity and connectivity. The customers are grouped in distinct segments with common needs, behavior, or other attributes. These are: (1) residential houses that are clustered together as a community with medium or higher income; (2) small businesses; public services buildings (healthcare service, schools, townhouses, etc.) and (3) organizations operating in remote areas such as construction and mining companies, lodges and parks, etc.

2. *Value propositions* – describes what value a company proposes for the target customers. The value proposition should stand out with a new feature that is unique or disruptive. The proposed concept proposes a reliable electricity supply, internet connection, and digital services platforms for remote areas where access to a utility grid and telecom towers are limited. The digital services may include/comprise educational, e-commerce, e-government, and peer-to-peer energy sharing concepts to users.

3. *Channel* – define how the value proposition is delivered to the intended customer group. Value propositions are delivered to customers through communication, delivery and distribution, and sales channels. Channels can be either owned (company website, social media sites, etc.) or with a partner (wholesale and retail distribution, etc.). The proposed concept aims to establish direct and virtual channels to reach potential customers in remote areas. This can be done by partnering with other organizations such as healthcare and education.

4. *Customer relationship*s – are established and maintained with each customer segment. The type of customer relationship depends on customer segment characteristics. In the proposed case study customer relationship can be established either directly in face-to-face or with an information and communication technologies platform that is provided by the system internet connection.

5. *Revenue Streams* – refers to how a company captures the value with the proposed service or product. The concept's revenue comprises sell of electricity, internet connection and from other digital services such as e-commerce, educational, e-government.

6. *Key Resources* – are the required assets to make and deliver the value proposition. These resources can be physical, financial, intellectual, or human. The off-grid concept mainly relies on renewable-based energy generation and BESS for delivering electricity and provide connectivity in SSA regions. Besides, other digital service platforms for educational, e-commerce, e-government, and business are also considered as key resources.

7. *Key activities* – are the most important activities a business must do to make their model work. For the off-grid concept, providing 24/7 reliable electricity, internet connection, and digital services are its main activities. Besides, maintenance and remote assistance for the off-grid system are another key activity.

8. *Key partnership* – describes the network of suppliers and partners that make the business model work. The partnership can be created with non-competitors (strategic alliance), co-opetition, joint ventures, etc. These can be educational and government bodies; local communities; and telecom and power providers.

9. *Cost structure* – describes all the costs to operate a business. These costs are associated with creating and delivering the value proposition, creating a revenue stream, and maintaining customers relationship. Such costs can be calculated after defining key resources, key activities, and key partnerships. For the proposed microgrid, the cost structure includes the capital cost (CAPEX) for the microgrid system (which takes the major share) as the and other costs such as maintenance, security, as operational costs (OPEX).

B. Business Environment Assessment

Developing a business requires to assess different external threats, constraints, and opportunities. Assessing the business environment helps to make a business model better suited to its environment [9]. There are key questions that are required to assess the business environment for BMC: market forces, key trends, industrial forces, and macro-economic forces. The business model environment for the proposed concept is presented as follow:

1. *Market Forces* – are the key issues that are related to the demand for electricity and connectivity in rural areas of SSA. These issues can be related to the current customers' landscape, that is, the demand for reliable and affordable electricity, and faster internet connectivity, and its peripheral segments such as digital services for education, healthcare, commerce, etc.

2. *Key Trends* – are trends shaping the business model such as technology innovations, regulatory constraints, social trends, and more. In the case of rural SSA, these trends can be: (1) technological trends like mobile technologies, electronic appliances, digital services, etc., (2) social and cultural trends, which are related to the desire to transform and have a positive outlook towards adopting new technologies, and, (3) socio-economic trends, related to digital market and high-speed communication.

3. *Industry Forces* – imply issues associated with other key players in the power and telecom sector in the area. Dominant players are mainly local utility companies providing electricity distribution, local solar house systems (SHS) and microgrid

suppliers. They can have a competitive advantage due to their localized knowledge, with already existing customer and having access to local government assistance. However, reaching the remote customer and offering a reliable and affordable power and connectivity as a combined service can be their competitive disadvantage over the proposed off-grid microgrid system.

4. *Macroeconomic Forces* – are the rapidly changing forces in the world economy which can affect the power and telecom sectors. These forces are significant to business creation and future prosperity. These trends are global market conditions, access to resources, high or low commodities prices, and more. Some of the key issues that can affect rural microgrid development can be: difficulties in obtaining the required resources, difficulties in finding skilled manpower, costly and timely logistics, etc.

However, the proposed off-grid microgrid concept has a competitive edge in the present and future of rural power and telecom sectors. With key trends revolving around technological solutions for socio-economic improvements, the concepts' business model has a competitive advantage for narrowing the infrastructural gaps in the rural areas. And, the market trends allow such concept to tap the current customers' landscape demands.

IV. Rural microgrid development paradigm

The development of rural microgrid systems in SSA should consider different technical, business, and socio-cultural aspects. Similarly, active community involvement is needed throughout the process. The next section of the paper discusses the constituent elements of the proposed framework, described in Figure 1.

A. *Willingness-to-Pay as a Pricing Benchmark*

For rural microgrid development, customer willingness-to-pay can play a significant role. This is because covering the costs relies heavily on the revenue stream. Besides, efficient service pricing should also consider CAPEX as the main influential factors. This is because the CAPEX takes the major share of the cost structure and impacts heavily the return on investment of renewable-based microgrids. Hence, customers willingness-to-pay should be equal to or more than the cost of energy production by the microgrid. This means that the levelized cost of energy (LCOE) by microgrid system should be equal or less than desirable tariff.

B. *Evaluating the Indirect-Value Creations*

The indirect-value creations of electrification imply to the social and cultural impacts that are created in consequences to the primary goals. These values are measured differently unlike the direct-value creation that uses technical and financial units such as the number of household's connection. For instance, in a study made by [6] in relation to the user value of rural electrification, the authors grouped these value properties as: functional, social significance, epistemic, emotional, and cultural values. The functional value related to the utilitarian and function of the service or product that comprises, financial benefits; quality and performance; operational benefits; physical compatibility; and service. Social or identity values refer to the association with group belonging and prestige. Epistemic values refer to the increase of awareness and seeking new knowledge caused by electrification. These values are created by owning TV, radio, and by extending school hours opening for students, exposure to modern culture. Emotional values are related to association with different cultures and people; fun with family home entertainment; creating memorable moments; and the sense of security created by the improvised lighting and reduce the risk associated with lack of fuel [6].

Nonetheless, the long-term social impact created by rural electrification and telecom can be challenging to evaluate or quantify due to the complex and indirect ways they affect various services in people's life. In particular, the social effect of electricity requires a longer period to be observed. This is due to a longer time it takes to place infrastructure and to creating motivation and affordability for people to connect. At the same time, several social factors also need to work simultaneously to conduct social impact of the intervention [13].

Nevertheless, by considering the indirect-value properties of infrastructure developments, developers and policymakers can align their design and policies based on the understanding created from questions such as, what is the dominant value character for a community and why some values are more important than others, and what motivates the community in engaging in the development processes.

C. *Community-Inclusive Design Process*

The top-down approach has been adopted in conducting many rural electrification programs. However, such an approach has been shown to lack in integrating social, economic, and environmental aspects of rural areas in the design process. Another alternative solution can be a bottom-up approach – which implies designing from the ground-up by involving different mechanisms for value creation measurement, community participation, local resource assessment, etc. Such an approach enables designers to understand the rural area in-depth and establish a common design language with local communities. For instance, Blair, et al. [7] creates a bottom-up system in a small Amazonian village of Guyana that integrates social, environmental, and economic aspects with rural electrification by participating community in the decision-making of the project development. The approach uses steps that involves community visit and dialogues; formal and informal data gathering; qualitative and quantitative data analysis; exploring pathways and designs options for perceiving for the created values; gamifying scenarios with role-playing; decision making; timeline of a project; and develop a value map for the decision making. By taking such an approach, awareness about the necessary technical and environmental issues can be raised for the community.

V. Discussion and Conclusion

In this paper, a framework for sustainable rural off-grid microgrid development constituent elements centering business model were discussed. The lack of private investment has been shown to hinder the expansion of microgrid projects in rural SSA. This is mainly due to the lack of a clear business model that conveys the overall business process. Moreover, an inadequate understanding of the socio-cultural fabric of rural SSA obstructs the development process to reach its goal. The BMC is one tool to illustrate the business process that encircles the proposed value.

In the case study of a novel off-grid platform, the value proposition is to bring power, connectivity, and digital services for rural areas, thereby creating a whole new development opportunity. One of the important features of the proposed concept is digital services such as education, commerce, energy sharing (trading), and e-government for remote communities. These can further increase the number of stakeholders involved or interested in the project development such as education institutes to remotely connect with rural pupils via digital platforms or government bodies to create digital interaction with citizens. Furthermore, digitalization can resolve typical challenges in rural areas such as lack of business knowledge and market access, which are still present after electrification intervention and creating lower uptakes and low willingness to pay (WTP).

The paper also discusses the need to consider WTP in the pricing process. WTP can play a significant role in understanding customers' preferences and financial limitations in the context of rural communities. Besides, WTP should be a main indicator for the project costs balance, therefore, it should be higher than levelized cost of energy of the system concept.

Based on the research work presented and discussed in this paper, developing sustainable off-grid microgrid requires a holistic approach that involves a suitable business model, which addresses the business process, ancillary values creation considerations, and involvement of local communities in the process of development.

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Publication II

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Feasibility of rural electrification and connectivity—A methodology and case study

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Feasibility of rural electrification and connectivity—A methodology and case study

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HIGHLIGHTS

- A comprehensive review of different willingness to pay (WTP) study methods In rural electrification studies presented.
- The paper introduces a common measurement parameter, unit of service, that combines electricity and telecommunications in one service package to establish a link between customers' preferred price and profitability for the service provider.
- The paper proposed a methodology for microgrid developers to adequately justify their investment plan and minimize the risks of non-payments.

ARTICLE INFO

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Willingness to pay
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Rural microgrids
Unit of service
Electrification

ABSTRACT

Despite the recent development, electrification of rural sub-Saharan Africa remains a major challenge because of remote locations and the low income of the population in those areas. There is a clear need for novel approaches for addressing this challenge. This paper proposes a new method for analysing the feasibility of microgrid projects based on consumers' expressed willingness to pay for the service in rural sub-Saharan Africa and microgrid project developers' willingness to accept. The paper also introduces a common measurement parameter, unit of service, that combines electricity and telecommunications in one service package to establish a link between customers' preferred price and profitability for the service provider. Further, the proposed methodology is used to analyse a study case located in rural Namibia. The results suggest that there is a price range for the service where a microgrid project can be feasible while satisfying local consumers' willingness to pay for the service. By using the proposed methodology, microgrid developers can adequately justify their investment plan and minimize the risks of non-payments.

1. Introduction

The number of people without access to electricity dropped from 1.2 billion in 2010 to 770 million in 2019 [1]. Many countries have achieved significant results in the electrification rate through comprehensive approaches in policies and planning. However, without stepped-up actions, it has been estimated that approximately 650 million people, or 8% of the global population, will still live without electricity in 2030 [2]. Among those who will lack access to electricity, 90% will be living in sub-Saharan Africa (SSA), in areas where the national and regional girds may not always be economically viable for several reasons, including limited purchasing power, lower demand and consumption of energy, and geographical factors, such as people living in rural areas and being far away from the grid and also dispersed from each other [3,4].

Off-grid solutions, such as stand-alone systems and micro- and mini-grids, could be a solution not only for underserved people, but also for those who are near the low-voltage connection lines but are not connected for reasons like high connection costs (under-grid customers) and for those who are already connected but cannot afford appliances (idle-grid customers) [5]. Furthermore, a continuous decrease in costs of the key components for power installations and improved load factors of micro- and mini-grids over the past decades have resulted in a reduction in the levelized cost of energy (LCOE), and it is expected to further decrease by two-thirds by 2030 [6]. Most of the recent generation micro-grid and mini-grid are equipped with technologies (mobile telecommunication services) that enable an increase in energy utilization and

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further facilitate business activities with real-time monitoring, demand forecasts, remote control, and prepaid payment options. Such features also enable income-generating equipment (productive-use appliances) to connect with off-grid systems, thus prompting local economic growth [6].

Currently, a large share of micro- and mini-grid development is largely carried out by national utility companies. However, private investment is expected to drive the sector in the coming years. The private sector is progressively engaged in specializing in the value chain of micro- and mini-grid projects, such as distribution, metering, solar PV, storage systems etc.[7] This will significantly increase the annual profit potential of the value chain of micro- and mini-grids. According to an estimate by the Energy Sector Management Assistance Program (ESMAP), the annual value chain profit has the potential to increase from $510 million in 2019 to $4.7 billion in 2030 [8].

To enable economically viable and sustainable off-grid electrification projects, private investors and developers require economic modelling and planning tools. The economic viability of a project is measured in terms of securing initial capital funding for the project, and the operational and maintenance costs are covered by generating a satisfying amount of return on the initial investment. This requires a set of flexible operational plans that are also adaptable to future political, economic, and regulatory changes. Financial indicators, such as project and equity return expectation and the payback period, can be used to calculate the expected sales of electricity from off-grid projects and define the required revenue for making an investment decision [8]. Required revenue, in turn, defines a developer's willingness to accept (WTA) the price for the service or goods. In the context of this paper, WTA is defined as an acceptable price level at which the sale of service will be suitable for the economic viability of a project.

Customers' willingness to pay (WTP) for electricity services is another essential factor in the off-grid electrification project development. WTP is the range for the maximum monetary amount that a customer will pay for a unit of product or service. Understanding consumers' WTP can help developers to introduce new products or services and pursue a pricing strategy that is suitable for the marketing environment while reducing the risk of losing valuable profit. Many studies have shown that the customer response evoked by price variation can have a significant effect on revenue and profit [5,9].

There are different determinants for the WTP for electricity in developing regions, viz. social, economic, demographic, cultural, and technical factors. These factors can determine or strongly affect the WTP of electricity consumers. For instance, according to a review [5] of different studies on the WTP of consumers in developing regions, variables such as household income, education status, substitution for a traditional energy source, the number of children of school-going ages, and home business (household entrepreneurial aspirations) were found to have a positive effect on consumers' WTP. On the other hand, the study found that age, occupation, and household structures have a vaguer relationship to WTP in the literature. Moreover, cultural, and behavioural determinants, such as lack of trust, inattention, and information biases can be influencing factors. For instance, a lack of trust in the government in providing or improving electricity service will harm WTP; this lack of trust is mainly caused by past historical events that have shown politicians failing to deliver their promises. On the other hand, high trust in the government and a belief in political promises or a belief that higher prices will provide improved services can increase the WTP among consumers. Other cultural factors, such as acceptance of private electricity service providers and responsibilities of who should back up electricity provision can further complicate the WTP for electricity. From the technical preceptive, WTP can vary depending on the reliability of electricity supply. This can be measured based on consumers' definition of reliability, frequency of brownouts, or duration of outages and provision of information about possible outages beforehand.

The purpose of this study is to propose a methodology for defining a feasibility area of an electrification and telecommunication project in the context of rural SSA based on an equilibrium between the WTA of electricity and connectivity providers and the WTP of the rural community for the service. Such an evaluation can help assess the projects based on the correlation of the customers' WTP, with other relevant measurements, namely, ability to pay (ATP), that is, a customers' financial ability measured based on his/her financial income. Hence, we propose a direct WTP survey to reveal the preference with respect to the customers' energy and telecom needs. We also introduce a concept of a unit of service, which is designed to fit a quantified amount of bundled energy and telecom services as a benchmark. The aim is to help understand the true desires or preferences of customers. Oftentimes rural customers, in particular those who lacks access to electricity and telecom services, are faced difficulties in quantifying technical services. This can lead to under or overestimating their true demand and purchasing capability using power or energy units. The unit of service, therefore, serve as a measuring tool for developers based on customers willingness or ability. The relationship between the customers' and developers' price preference for a unit of service balances out and provides an equilibrium price. Application of unit of service can be found in sectors such as health service institutions, where, necessary patient care including transportation, medicine, lab tests, etc. are packaged together for billing or non-billing purposes [10].

In this paper, we focus on answering the following questions: What is the preferable WTP survey method for first-time electricity users? How can a microgrid developer assess the financial feasibility of a project based on the customers' willingness and ability? How a common instrument can be designed to bridge between the user and developer? How an acceptable price for can be reached based on customer and developer preferences?

The paper provides a study case analysis based on the proposed methodology and a survey from the rural village of Revon C in northern Namibia. The results suggest that using the direct WTP methodology can allow to define a feasibility area for the project developers and an affordability area for the customers to ensure long-term sustainability of the project. The main contributions to WTP studies in rural areas are 1) a measurement tool for quantifying demand based on preferred WTP is proposed, 2) unlike the already existing numerous economic-based and policy-oriented literatures, we provide a business feasibility approach founded on WTP of customers.

The paper is designed as follows: the second section provides definitions for the main concepts used in the study, such as WTP, ATP, and WTA, and discusses current WTP methods that are widely used to study rural areas. The third section reviews literature on rural electrification studies that apply the WTP approach. The fourth section describes a methodology for defining a feasibility area for an electrification and connectivity project based on WTP and WTA curves. The fifth section provides the results of a case study from the village of Revon C in Namibia and discusses the results, implications, and assumptions. Finally, the sixth section concludes the major findings of the research conducted in the paper.

2. Definitions

Willingness to Pay (WTP) is a market research method used to understand the maximum price range at which a consumer is willing to buy a product or a service. Understanding consumers' WTP can play a crucial role in new product development, pricing, and competition strategies. WTP measurements can involve three types of procedures: 1) a direct open format question, in which respondents are asked about their WTP for higher consumption of a particular good or a service, 2) a list model, in which a variety of values are presented for the participants, and they are asked about the amount they would pay for the listed values, and 3) a referendum model, where participants are asked whether they are willing to pay a certain amount of money for the good or not [11].

Based on the data collection method, WTP surveys can be divided into two major categories: revealed and expressed preferences. Revealed preference data are obtained from price responses. For instance, in the case of rural area customers, revealed preferences can be derived from the expenses of the local population for alternative sources of energy, such as kerosene for lamps or candles, and for charging phones. On the other hand, expressed preference data derived from surveys are frequently referred to as stated preferences or the contingent valuation method (CVM). In this case, consumers are asked to reveal the maximum amount they are willing to pay for a hypothetical service or product that is created by a market researcher. The methods produce a realistic scenario that offers a rational rate of electricity service that is also feasible for the electricity project [12].

Willingness to Accept (WTA) is a term that is used in economics to assess a monetary amount that a person is willing to accept to sell a service or a good. WTA is also used to evaluate a persons' stated price for compensation to bear a loss or forgo an environmental service, such as pollution, noise, or property rights [13]. However, in this research, we use WTA as the minimum monetary amount at which a service provider or seller is willing to sell without facing a financial loss or a positive net present value (NPV).

Another economic principle used in this paper is Ability to Pay (ATP), which states the amount of money that a person is able to pay relative to income and wealth. Although its application is mainly for taxation purposes [14], in this paper we use the term to further assess the income effect that bounds people to pay more than their WTP. Income level plays an important role for the determination of WTP; [5] found a significant correlation between WTP and the income level of the respondents in developing countries. Thus, ATP should be considered in addition to WTP.

3. Literature review on the contingent valuation method in electricity studies

Contingent valuation method (CVM) is a survey-based method for determining economic values of goods and services. The method is commonly used to estimate nonmarket values and non-use values in the areas of environmental economics and environmental impact assessment. The methods are applied by encouraging participants to consider trade-offs in the choices they make [15]. This method has been widely used to study individual preferences for basic infrastructure projects, such as water supply, electricity, and sanitation in developing countries.

Despite its extensive use, CVM has been criticized for its accuracy and reliability. For instance, the CVM survey method uses mainly a hypothetical market to study the trade-offs and preferences of participants. This can create a hypothetical bias that deviates from the market scenarios. Another challenge of the CVM studies can arise from strategic biases, where individuals understate their true WTP for public goods with the hope that others will pay enough for the service. This is also known as free riding behaviour. On the other hand, individuals can over plead their preference expecting that their WTP value would influence the provision of a good or a service. Furthermore, the information and scenarios provided for the survey respondents can influence the validity of the CV result both positively and negatively [11,15].

CVM is the most widely used method for measuring the WTP of electricity development in developing areas. Some of the most common CVMs that are used in WTP studies for electricity are:

- **Single-Bounded Dichotomous Choice (SBDC):** It is the most widely used method. It involves asking the respondents if they will pay a specified monetary amount to obtain a good or a service by giving them a YES or NO choice. This monetary amount (bid value) is varied across respondents, and the discrete choice format mimics a bargaining process [5].
- **Double-Bounded Dichotomous Choice (SBDC):** In this method, respondents are given two consecutive YES or NO choices. If the first choice for the bid value is YES, the following choice bid value will be higher than the first, on the other hand, if the first choice is NO, the bid value in the second choice will be smaller than the first amount [19 –22].
- **Multi-Bounded Polychotomous Choice (MBPC)**: In this method, the respondents are presented with a panel of values and response categories that are arranged into a matrix. The respondents are then asked to mark the degree of confidence that they feel about paying or not paying for each amount that is listed in the matrix [5].
- **Payment Cards**: This method lists possible values on a card and asks the customers to pick the value that best represents their WTP for the lower bound and the second choice as the upper bound [5].
- **Choice Experiments/comparative analysis:** This method asks the respondents to choose between two programs (A and B), which comprise different attributes and costs to choose or to refuse. This allows marginal valuation of each attribute [5,16].

There are a growing number of CVM-based WTP studies in developing countries that focus on the reliability and demand of electricity. For instance, Bhandari et al. [16] conducted a survey in rural Niger to study the effect of a rural community's WTP for renewable-based electricity supply. The study used comparative analysis to compare the WTP for electricity service with the collaborative consumption and cost of an off-grid system. The results showed that empowering communities to have a share of ownership in rural off-grid projects increased the WTP. In Ghana, Taale & Kyeremeh [17] studied factors affecting households' WTP for reliable power in the Cape Coast Metropolitan Area by using contingent valuation methods. The probit model was used to identify factors affecting the WTP for the reliability of electricity. Factors such as income, ownership of a separate meter, house size, and education were found to affect the WTP for reliability. The study showed that most of the households are willing to pay 44% more for improved reliability compared with their present electricity bill. Gunatilake et al. [18] investigated the benefit of reliable electricity in Madhya, India using a bidding game and the method of single-bounded closed dichotomous choice. In the study area, the existing grid supply was poor, and a better quality of power supply and service was the main priority among customers. In the study, the probability of consumers' WTP for improved quality of electricity was studied by using a dichotomous choice approach. Further, Oseni et al. 2017 [19] studied the WTP for reliable electricity supply for self-generating (diesel backup) households in Nigeria. Double-bounded dichotomous choice was used as the method to study the WTP. The study found that having a backup generator increased the households' WTP for reliability rather than decreased it. This was mainly due to the high cost of self-generation or outage cost that unreliable grid supply can cause. Similar electricity reliability- and service quality-based studies using dichotomous bidding methods can also be found in the literature for Senegal, Ethiopia, and Kenya [20–22]. A summary of sample cases is given in Table 1.

Nonetheless, most of the above-mentioned WTP studies are widely used to provide insight for policymakers from the economic standpoint rather than for market price research or compilation of a business strategy, which call for further studies that apply the results of WTP studies for novel price research and business feasibility.

4. Methodology

4.1. Introducing a concept of a unit of service

The rural population in SSA often has very limited purchasing power. From the consumers' perspective, it is very important to evaluate how much they would be willing to spend for a service or a product, while from the service provider's perspective, it is imperative to ensure that customers can pay for the service to secure a required revenue flow. The local population in rural communities has certain energy needs; however, in many cases, they lack understanding of concepts like a measure of energy unit, cost per energy unit, and data transfer unit. Therefore, we

Table 1
Sample literature on WTP for electrification services.

WTP study method	Country	Description	Power supply	Source
Choice experiment/ comparative analysis	Niger	The effect of rural community energy sharing and ownership in the improvement of WTP	Off-grid	Bhandari et al., 2020 [16]
Stated preference/contingent behaviours	Ghana	Factors affecting the WTP for reliable power supply	Grid	Taale & Kyeremeh, 2016 [17]
Bidding game and dichotomous choice	India	Estimating the benefits of an improved electricity supply to rural households		Gunatilake et al.,2012 [18]
Double-bounded dichotomous choice	Nigeria	The effect of self-generation on WTP for reliable power supply	Grid and own generation	Oseni et al. 2017[19]
	Ethiopia	The walfare gain of renewable energy and WTP attributes for green energy transition		Entele, 2020 [20]
		Household preference for a renwable-based off-gird system in addition to the already connected grid suppply		Arega & Tadesse, 2016 [21]
	Kenya	Estimating WTP for grid and PV generation and the relation of the household's entrepreneurial aspiration and reliability		Abdullah & Jeantyc, 2011 [22]
Open-ended questions, dichotomous choice	Senegal	WTP for high-quality electricity service	Gird & undergird	Deutschmann, Postepska, & Sarr, 2021 [23]

introduce a concept of a ***unit of service*** based on the Fusion Grid project [23–26], which considers the provision of a bundled service for electricity and connectivity to rural locations. One unit of service consists of a power and data package of 500 W nominal capacity and 512 Mb of internet data per month to cover basic needs. Those basic needs can include the use of television (80 W) for 4 h a day, three phone charges per day, laptop charging, lighting (5 × 5 W LEDs) for 6 h of daily usage, and a refrigerator (50–100 W). Customers with higher power or data needs may require more units of service depending on their demand and purchasing power, and therefore, the package can be scaled up to cover the increase in demand. The concept of a unit of service goes in line with home solar systems, which are often marketed with electric appliances that they can power (Fenix International, Azuri, BBOX). Representation of power solutions in such a way removes barriers of communication to potential customers who lack knowledge of measures of energy or data units.

4.2. *Defining WTP for combined service*

As it has been discussed above, assessment of WTP is usually based on the value that customers place on a good or a service considering their purchasing power, which often is the main challenge in rural areas. To determine the WTP for the combined service of electricity and connectivity ($WTP_{E\&C}$), we propose a survey where customers should indicate how much they would be willing to pay monthly for electricity and connectivity. The algorithm below shows how the WTP curves are created using the survey data and running price index. The running price indexes are price values (€/unit) that are artificially created for reference purpose.

Algorithm 1: Algorithm for WTP/unit of service analysis

```
Input: DATA_WTP_survey_matrix A; Reference running price index matrix B
  Output: PRINT: N_m
    Initialization: initialize matrix N_m
  Fist statement
  LOOP Process
     for j = 1: until length (DATA) do
        initialize matrix N
     for i = 1: until length (DATA) do
        if matrix A(i) ≥ matrix B(j) then
          matrix N(i) = matrix A(i)
        end-if
          matrix N_m(j) = sum (matrix N)/matrix B(j)
     end-for
  end-for
```

The algorithm first builds matrix **N** and matrix **N_m** to store new values. Then it executes a nested loop: in the inner iteration, we extract and store values that are greater than or equal to the reference running price index (matrix B), and in the outer iteration, we extract matrix **N_m** by dividing the sum of matrix N with matrix B. The data points extracted from matrix **N_m** create the WTP curve. Let's assume that the WTP data (Matrix_A) = [10,20,30,40,50] and the reference running price index (Matrix_B) =[5,10,15,20,25]. The step-by-step execution of Algorithm 1 can be as follow:

- **Step 1**: Read the WTP and the reference running index values from file
- **Step 2**: Create *matrix_N* and *matrix N_m* to store new values.
- **Step 3**: Checks of each raw element if *matrix_A(i)* ≥ *matrix_B(j)* and store in *matrix_N(i)*

for example, *matrix_A (0)* = 10 is greater than *matrix_B (0)* = 5, thus *matrix_N (0)* = 10.

- **Step 4**: Repeat the same steps for each raw.
- **Step 5**: Divide the sum the *matrix_N* values with each of the raw elements of *matrix_B* to find

matrix N_m elements. For example, the sum of the *matrix_N* = 150 and *matrix_B (0)* = 5, thus *matrix N_m (0)* = 30.

- **Step 5**: Repeat for same steps each raw.
- **Step 6**: Exit the loop.

The result table for the example is presented in the table 2 below.

Based on the resulting values, it is now easy to create the WTP curve or "demand-curve", that illustrate the relationship between changing price (matrix_N) and quantity demanded (matrixN_m) in a given period of time. (See Fig. 1).

As can be seen from the above figure, the price change has an effect on the and quantity of unity of service quantity demanded, where lowering the price value create more demand.

The main assumption in this methodology is that the customer with a higher WTP than the price for the unit would buy more units of service, proportionally to the WTP and the price for the unit difference. This assumption goes in line with the notion that customers with a higher purchasing power have a higher power demand, thus, would need more units of service to cover that demand. However, the relation between the

Table 2
Example table for Algorithm 1.

Matrix A(i)	Matrix B (j)	Matrix_N	Matrix N_m
10	5	10	30.0
20	10	20	15.0
30	15	30	10.0
40	20	40	7.5
50	25	50	6.0

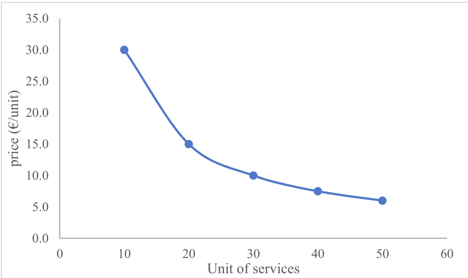

Fig. 1. WTP curve for example table.

increase in power demand and the number of units needed is not necessarily proportional.

4.3. Defining WTA of developer

FG (Fusion Grid) is a smart grid with an embedded connection to the Internet, and thus, all processes can be automated, monitored, and managed remotely. The main cost component of such a grid is the capital cost, which includes all the equipment costs for the production of electricity and the provision of Internet access. The variable cost of production of electricity is close to zero because it is based on renewable energy resources, and only the storage operation causes some variable costs, being also mainly a fixed cost. The variable cost of the Internet traffic is also zero, and it is mainly a subject of the capital costs of a base station and connection to the backhaul. The marginal cost of the services provided with access to the Internet, for instance, educational programs and digital platforms for jobs, is also very low. Therefore, the main cost component for the FG concept is capital expenses (CAPEX). The CAPEX of the off-grid system consists of the price of PV panels, batteries, inverter, LTE base station, cables, and other supporting equipment and their installations. The operating expenditure (OPEX) includes expenses for running and maintain the off-grid system. The key factor in the formation of WTA is the power system size, which determines the initial investment, see function (1).

$$WTA = f(CAPEX, OPEX) \tag{1}$$

The required revenue on an annual basis for the developer can be defined using the function for net present value (NPV). A project is financially feasible, if the NPV is at least zero:

$$NPV = \sum_{t=1}^{T} \frac{Revenue_t}{(1+r)^t} + CAPEX_n \geq 0 \tag{2}$$

$$Where Revenue_t = (monthly fee per subscription * number of subscribers)_t$$

Where T is the lifetime of the project, r is the discount rate, $Revenue_t$ is the required revenue to make the project neutral, and $CAPEX_n$ is the capital investments for n units of service. Further, the required revenue should be divided by the number of units of service that the off-grid system can serve:

$$WTA_t = \frac{Revenue_t}{n} \tag{3}$$

An off-grid system with a specific size can provide a limited number of units of service, because power and energy are limited by equipment restrictions and solar conditions that affect the generated power and energy. The system can be scaled with an increment of consumer needs and the number of units of service needed. Therefore, the cost of the concept increases with the size thereby affecting the WTA of the supplier, and thus, with an increase in the size of the FG concept installation the WTA will also increase. However, the relationship between CAPEX and WTA is not linear because of the nonlinear relationship between the size of a unit of service and the size of equipment needed to satisfy the needs for electricity and connectivity. An additional solar panel or battery storage can impact the CAPEX considerably while serving only one additional unit of service. Besides, yearly revenue variation can also affect the WTA. The revenue variation is due to fluctuations in monthly fees or the number of subscribers.

4.4. Equilibrium between WTA and WTP

A desirable market price for the service consisting of electricity and connectivity could be represented as an equilibrium price between WTA and WTP, see the equation below and Fig. 2, where the horizontal axis shows the number of units of service, and the vertical axis displays the price per unit.

$$WTA = WTP_{E\&C} \tag{4}$$

The area above the blue WTA line is the acceptance area for the project developer; any price above this line would result in a positive project NPV and thus, investments in the off-grid system and base station would be justified. The area below the red WTP line represents the customers' willingness to pay, and thus, at the unit price below the red line customers will be willingly paying for the service.

5. Results: Case study analysis

5.1. Study case area: Revon C

The study case area is located in Revon C, Okarevona, a rural village in northern Namibia. The area is a densely populated informal settlement with over 700 residents in the Oshikoto region, see Fig. 3. Most of the residents have a low income and are dependent on small businesses in the informal sector. Electricity supply is one of the main infrastructural challenges in the area, and only a few residents have access to electricity because of the high cost of connecting to the local grid.

A survey on electricity and connectivity needs was conducted between December 2018 and April 2019 in the village of Revon C as part of the Fusion Grid (FG) project to define the demand for these services as well as the WTP of the households within the community [24]. The survey includes both qualitative and quantitative questions which encompass different social and behavioural aspects. The questionnaire included a direct question about the willingness to pay for electricity and connectivity (Internet) monthly and the income level of the household. For selecting participants for the interview, a purposive sampling method (non-probability method) was used. Purposeful sampling – which is also known as judgemental, subjective, or selective sampling– is oftentimes used in qualitative research to identify and select information by focusing on participants which can enable to effectively answer the research questions.[28]. There were 107 respondents to the survey, each respondent representing his or her household. With an average household size of more than five people, the survey covered more than 76% of the community.

According to the survey, 37% of the community had access to electricity at the end of 2018. The regional electricity distributor NORED is the main supplier for the area. More than 90% of the community's households are not happy with the service, either because of not having access to electricity or because of the quality of the service. The survey shows, based on the exchange rate of 2018, that the average monthly income is 4 040 Namibian dollars (N$), or 221 €, which is lower than the average wage of 6 626 N$, or 363€, in the country.

From all responses, only 69 were qualified for the analysis, as some respondents did not answer the question on WTP for electricity or the Internet (or both), and some indicated a WTP higher than their monthly income, which we treated as an unreliable response. Based on the survey, the WTP range was from 20 N$ per month to 4 400 N$ per month

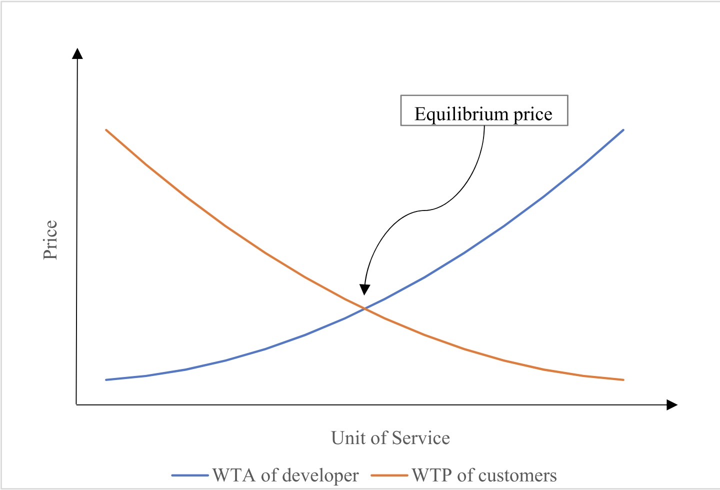

Fig. 2. WTP and WTA curves.

Fig. 3. Okarevona village, Oniipa, Namibia.

(1.15 €/month to 253 €/month). The average WTP was 655 N$ per month, or 38.25 €/month, which was 21.6% of the average income. The WTP curve was defined using the data from 69 respondents, who answered all the required questions and whose WTP did not exceed their income. Most of the respondents, 66%, indicated income levels not exceeding 5000 N$ per month per household, which is also reflected in a limited purchasing power and WTP, see Fig. 4 (a). Combined WTP for electricity and telecom services was from 200 N$ to 800 N$ for 75% of responses, see Fig. 3 (b).

The electrification and digitalization pilot of the Fusion Grid (FG) research project is installed and currently operating in the village since 2019 [24]. The FG project aims to provide electricity, Internet connectivity, and digital tools to sparsely populated areas that lack access to both electricity and telecom services. The project is designed with a notion that providing electricity and telecom services can improve the quality of life in rural communities while enabling small businesses to flourish with the aid of digital tools. The FG pilot microgrid includes solar PV, lithium-ion battery systems, and a 4G LTE base station, currently providing electricity and connectivity for five households. The microgrid control system is equipped with a power demand and weather forecast algorithm that enables to optimize and ensure adequate supply throughout the day [24–27].

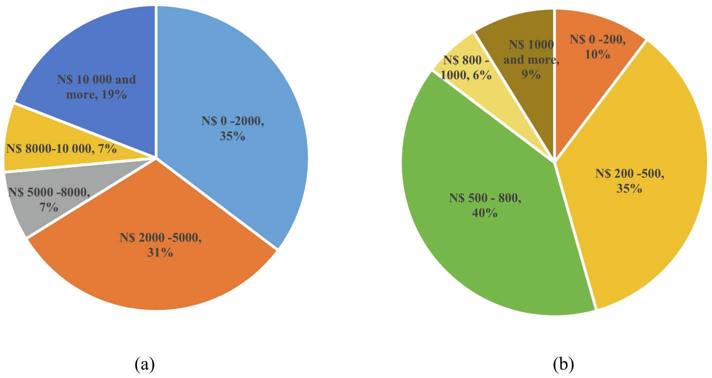

Fig. 4. Income level and WTP for combined service.

5.2. Willingness to pay and willingness to accept of Revon C

The WTA curve is based on the capital cost data from the FG project, and it is defined in the methodology discussed in section 4.3. Table 3 presents the NPV-based cost calculation result for different units of services that can be provided by the FG microgrid system. In our analysis, we assume the WTA is constant. However, we acknowledge that can be a variation caused by yearly revenue imbalance.

In the analysis, the lifetime assumed for the microgrid system is 20 years and the interest rate 5%. Further, one unit of service comprises a power and data package of 500 W nominal capacity and 512 Mb of internet data per month.

Based on the results from the WTP survey calculation and the above WTA calculation, the WTP and WTA graphs are created (see Fig. 5). In addition, the ATP of customers has been added. We use two tiers, 20% and the percent of customers reported monthly income, to evaluate the ATP against the unit of service quantity, which is a theoretical expected share of expenditure for electricity and telecom services. This can be used as an indication that the participants did not over- or understate their WTP.

According to the results, the customers' WTP for unit service increases steadily when the price drops. Similar trends can also be seen for the ATP values. On the other hand, when the monthly prices increase, the WTA for the FG increases. The equilibrium price where WTP and WTA are equal is around N$898 or €50 per unit of service per month. At this price, the developer will install a microgrid sized at 20 units of service and will be able to cover the capital costs. The feasibility area for the project in the study case is found for a microgrid sized between 5 and 20 units of service, which in our case corresponds to a 2.5–10 kW microgrid installation with a base station providing 2.5–10.24 Gb of monthly data. The larger the spread between WTP and WTA, the higher the IRR of the project, and thus, the profitability of the project.

The equilibrium prices can change based on the customers' future WTP and cost factors affecting the WTA of the microgrid system. For instance, if the customers' WTP increases from the current position, the WTP curve will move to the right and a new equilibrium price will be created. In contrast, if the customers' WTP decreases, for instance, because of a low income or finding an alternative option, the WTP curve will change in the lower part of the graph, creating a new price point. Similarly, the WTA curve of the supplier can shift to the right or left of the graph because of different cost factors. For instance, if the capital or operational cost of the microgrid system is subsidized, the unit of service price will fall, moving the WTA curve to the right. This will create a new decreased equilibrium price. Other cost factors, such as a lower equipment and installation price, can also attribute to the movement of the WTA curve. The prices of key components, such as PV panels and battery systems, are expected to further decrease in the coming years. This will affect the WTA of suppliers when scaling up microgrid systems. By analysing the relation of WTP and WTA, microgrid developers can strategize their business in relation to the behaviour of their customers and changes in their customer base.

Table 3
Cost calculation for a unit of services of the FG microgrid system.

Unit of Service	Capital cost [€]	Required revenue per year [€/Year]	Required revenue per unit of service per year [€/unit/year]	Required revenue per unit of service per month [€/unit/month]
5	24,400	1810	362.00	30.17
10	57,600	3700	370.00	30.83
15	130,600	9000	600.00	50.00
20	236,200	16,000	800.00	66.67
25	374,800	24,000	960.00	80.00
30	546,000	34,500	1150.00	95.83

6. Discussion

Access to electricity and telecom services remains a major challenge for many rural communities. Nevertheless, there is an untapped market potential, which requires novel ideas and approaches for the rollout of these services in rural settings. Understanding the market, potential consumers' preferences, and their willingness to pay for the services is the key for providing solutions that fit the local environment, as many studies reviewed in this paper suggest. Customers' willingness to pay (WTP) is an important factor in studies on off-grid rural electrification projects. So far, most of the WTP studies in rural areas largely focused on improvements in the quality and reliability of the electricity services, and the evaluation results mainly concentrating on the economic cost–benefit analysis for policymakers rather than on business strategies (Gunatilake et al.,2012, Arega & Tadesse, 2016, Abdullah & Jeantyc, 2011, and Deutschmann, Postepska, & Sarr, 2021). In electrification projects, which rely on revenue from electricity sales, the project developers' understanding of consumer behaviour has a significant impact on the revenue and profit of the project. Hence, accurate estimation of customers' WTP is important for compilation of business strategies.

Bundling dissimilar products or services as a single combined unit is used by many service providers as a marketing and price strategy. The bundled packages typically offer different price and services options. We

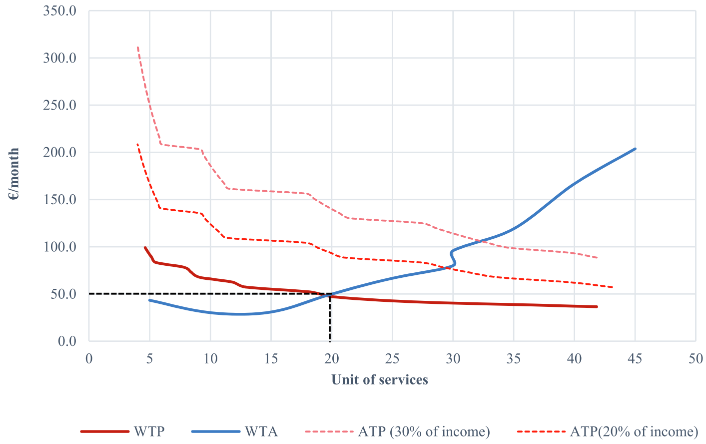

Fig. 5. WTA and WTP of the study case.

argue that packaging services as a unit of service can help developers to design the quantity needed and the packaging options. The proposed methodology for evaluating a microgrid and connectivity project based on customers' WTP and the cost of the microgrid system, or WTA for the project developer, addresses the uncertainties related to the feasibility of such projects. In addition, introduction of a common measurement parameter as a unit of service helps to better integrate the new power and telecom solutions, especially in communities lacking understanding of the measures of power and Internet data units. While WTA can be easily assessed based on the project CAPEX, consumers' WTP is based on surveys on potential customers. In our research WTP survey is constructed of direct questions on how much potential consumers would like to pay for the service on a monthly basis, which are then converted into the WTP for the unit of service. Establishing such an evaluation mechanism helps avoid hypothetical bias, which is common in WTP survey methods (L. Venkatachalam,2004). We argue that rural people may be unable or find it difficult to quantify their demand and consumption for electricity or telecom services. Hence, the WTP survey should mainly focus on the amount of money these people are willing to spend on those services rather than on questions that might be difficult to understand or force them to imagine unquantifiable values. Furthermore, ability to pay (ATP) is compared with WTP to avoid implications of strategic bias. Even if the responses to a survey are influenced by strategic bias, a higher ATP than WTP indicates that the consumers are not over pleading their WTP, which is the most relevant factor when ensuring future revenue flow. In the case of a higher WTP than ATP, over pleading of WTP may take place, and further research must be conducted. An ATP curve can be used as a control measure for strategic bias.

The feasibility range is further defined by constructing WTP and WTA curves, determining a feasible service pricing at the range where the WTP is higher than the WTA. The results of this study show that both the customers and developers would be satisfied with the pricing below the equilibrium price of €50 per unit of service per month. Because of the nonlinear nature of WTA and WTP, it is hard to estimate the optimal pricing for the service; nonetheless, the methodology provides a clear understanding of the current potential of the market and a viable pricing strategy that ensures a sustainable revenue flow for the developers and keeps prices at an affordable level for the consumers.

However, even if poor rural customers are willing to pay a substantial part of their income for electricity, subsidies should also be considered as part of the financial scheme by the government bodies. The subsidies can be on initial investment or on reducing the energy cost for customers.

7. Conclusion

Overall, this paper aimed to cover the research gap found in the reviewed literature, which often focuses on economic analysis for policy implications rather than on business analysis. Further, the paper proposed a novel methodology to analyse the economic feasibility of electrification and connectivity, which can serve as a pricing tool for sustainable project and capacity building.

The main assumption of the methodology is that an individual consumer's demand for units of service is directly related to their WTP, which might not be the case in a real situation. In our study, we kept the size of the unit of service small to limit the impact of the assumptions on the results. Also, the study does not cover the developers' risk associated with such economic and price evaluation methods. For better accuracy, the size of the unit of service can be further reduced. In addition, the economic benefit from household appliances, demand, and consumption of energy should be included, and thus, WTP data based on revealed preferences can be produced for future studies. By combining both methods it is possible to further improve the quality of work and reduce the biases associated with WTP study methods. In future, it would be interesting to compare such finding with the other WTP and pricing methods, to make the findings more wide-ranging. Besides, future research could focus on studying a user-centric experience of a unit of service actual off-grid customers.

The future impact of this study can be the possibility of using a unit of service in assessing bundling public goods such as water, electricity, telecom, digital services, health services, etc. in rural areas' context. In addition, policymakers can incorporate such methods for appropriate incentives and subsides design in rural electrification programs.

CRediT authorship contribution statement

Henock Dibaba: Conceptualization, Methodology, Writing – original draft. **Iurii Demidov:** Visualization, Data curation. **Evgenia Vanadzina:** Supervision, Conceptualization, Methodology, Writing – review & editing. **Samuli Honkapuro:** Supervision, Writing – review & editing. **Antti Pinomaa:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Publication III

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The Prospect of Inclusive Business Model for Mini-Grid Development

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The Prospect of Inclusive Business Model for Mini-Grid Development

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***Abstract*— This paper aims to assess the importance of inclusive business models in rural mini-grid projects by analyzing the value chain of the mini-grid ecosystem. An inclusive business model is characterized by sustainability and aims to involve income-constrained groups in the value chain by providing solutions to neglected problems. Specifically, in the context of mini-grid development, an inclusive business strategy should aim to generate economic opportunities, promote local ownership and sustainability, and ensure that the benefits of electrification are accessible to the most marginalized communities. The objective of this study is to suggest approaches for mini-grid developers to foster inclusivity in their operations by addressing the social and economic hurdles experienced by underserved communities in rural areas of developing countries.**

***Index Terms*— Inclusive business model, mini-grid, rural electrification.**

I. Introduction

The International Energy Agency (IEA) reports that a significant population of 770 million individuals in Africa and Asia lack access to electricity [1]. The COVID-19 pandemic has worsened the prevailing issue of energy poverty in developing nations, and progress made over several years has come to a halt. Sub-Saharan Africa (SSA) has been especially affected, with the number of individuals without electricity access increasing for the first time since 2013. As a result, the region now accounts for 77% of the global population without access to electricity, up from 74% prior to the pandemic.

The utilization of mini-grids has been recognized as a pivotal means of tackling the pressing issue of electricity shortages in Africa. Mini-grids refer to power generation and distribution systems that provide and deliver electricity to a relatively limited number of customers, primarily situated in geographically remote areas. These self-sufficient systems may operate independently and standalone without connection the national utility power grid, or they can be interconnected with it.

The power capacity of mini-grids can vary, ranging from just a few kilowatts to several megawatts. Africa is reported to have the highest proportion of planned mini-grids, with over 4,000 mini-grids currently in the planning phase, as per the World Bank's data [2]. Compared to the primary grid and solar home systems (SHS), mini-grids are a more practical solution for off-grid areas with a substantial population density and demand. Often, extending the primary power grid to reach remote communities that consume minimal amounts of energy and reside in dispersed areas can be excessively expensive [3].

Despite their potential, mini-grids still encounter financial challenges that result in a lengthy payback time for the investment, due to the low electricity demand and the limited ability of communities to pay for electricity usage [3]. To improve their financial viability, one way is to stimulate economic activity within the community by involving users in different parts of the mini-grid value network. These actions enhance the delivery of the energy service and the use of output energy for productive use, highlighting an important business concept that prioritizes inclusiveness in its business model.

An inclusive business model differs from a conventional business model in that its focus is on providing economic opportunities to marginalized or low-income individuals by involving them in the value creation process and enabling them to capture a portion of the organization's benefits, rather than solely aiming to maximize profits for the company and its shareholders [4]. In the context of mini-grid development, an inclusive business strategy should create economic opportunities, promote local ownership and sustainability, and ensure that the benefits of electrification reach the most marginalized under-served communities [5].

To build a sustainable and effective mini-grid business model, it is crucial to incorporate inclusive business models into its fundamental components, including both the value creation and value capture systems [4], [5]. The value creation system encompasses the processes and partnerships involved in producing and delivering value, such as local ownership, demand-side management, energy storage, frequency regulation, and operation and maintenance (O&M). Meanwhile, the value capture system relates to the economic benefits and entrepreneurial activities that result from the mini-grid's business model, which includes various commercial and productive use activities.

For successful implementation, it is essential to engage with the local community through effective community engagement strategies [5]. This involves identifying and connecting with local businesses, building capacity and

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engagement, strengthening positive socio-economic impacts, and raising awareness of the benefits of mini-grids among end-users.

Moreover, the notion of inclusivity offers a promising resolution to a recurring research inquiry raised in previous studies (e.g. [6], [7]) regarding the conflict between economic and social factors in the advancement of mini-grids. Inclusivity presents a means of resolving, or at the very least attempting to address, the dilemma of balancing commercial profitability with socio-economic impact, which is often encountered in mini-grid initiatives. By facilitating the design, planning, and monitoring of business operations that serve to the unique requirements of financially disadvantaged populations, an inclusive business model may enable providers to generate revenues while simultaneously enhancing the living standards.

The aim of this paper is to assess in what way inclusivity can be implemented in a rural mini-grid ecosystem. The paper further provides exemplary mini-grids that integrate communities' involvement in the value creation and capturing process of their business. The paper is organized as follows: Section II gives the definition and history of inclusive business model. Possible activities that can be consider as inclusive in a mini-grid ecosystem are provided in Section III. Section IV provides exemplary cases of inclusive actions, and finally Section V concludes the paper output.

II. Inclusive Business Model

The World Business Council for Sustainable Development first introduced the concept of Inclusive Business in 2005. The idea of inclusiveness had already surfaced in the 1990s in relation to investment and international trade regimes. Inclusive business has evolved from previous business trends, including corporate responsibility, business ethics, and corporate citizenship. The main goal of inclusive business is to provide sustainable income opportunities for individuals who have limited economic capability [8].

The concept of inclusive business has become a significant part of the inclusive development approach. It aims to create sustainable and fair income opportunities for people who have low job market mobility. In 2015, the endorsement of Sustainable Development Goals (SDGs) prompted governments, investors, and businesses to adopt a sustainable, equitable, and inclusive economic model to address global issues. This endorsement reinforced the importance of the inclusive business concept, which plays a significant role in enabling businesses to create value for the bottom-of-the-pyramid (BOP) population by integrating them into their value chain. The BOP is a socio-economic class that includes low income and economically marginalized individuals, comprising two-thirds of the human economic pyramid [9].

Accordingly, business entities can integrate the BOP in their business model by providing employment opportunities as producers, suppliers, and distributors, while at same time making them clients and customers for the company's products and/or services.

III. Inclusivity in Mini-grid Business Ecosystem

A. *Value network of mini-grid*

The value network in mini-grids refers to the various activities that are involved in creating the technical and economic feasibility of the mini-grid development process [4]. Previously, the value network of mini-grids was limited to the developer, mainly comprising government and non-governmental organisations (NGOs). However, in recent times, the value network has expanded to include a diverse range of facilitators who are responsible for different aspects of the development process [4], [10]. These facilitators offer support activities such as software and analytics, or core activities like technical services, energy storage systems, digital payment technologies, civil work, and finance. The generic concept of mini-grid value network is shown in Fig. 1.

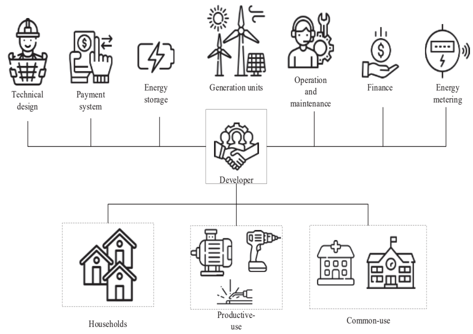

Fig. 1. Value network of mini-grid.

B. *Inclusive action in mini-grid business model*

To guarantee that the electrification of marginalized communities through mini-grid development is beneficial, an inclusive business strategy should prioritize economic opportunities, local ownership, and sustainability. Inclusivity should be ingrained in the mini-grid business model, with community participation in value creation and capture systems. Fig. 2 maps common and possible inclusivity actions by categorizing them into the value creation and value capturing sections of the mini-grid ecosystem.

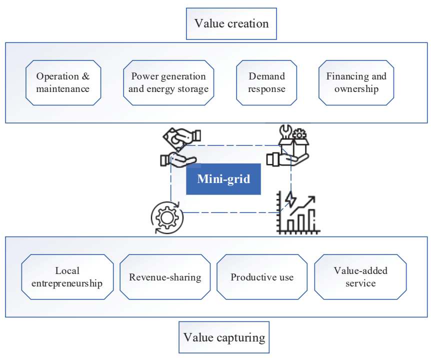

Fig. 2. Inclusivity in a mini-grid business ecosystem.

1) Value creation system of mini-grid

In the context of mini-grid development, the value creation system relates to the set of processes that are employed by the developer to deliver sustainable energy services and other related services. The involvement of communities in mini-grid value creation can facilitate inclusivity and promote the long-term viability of the project. Here are some examples of inclusive actions that can be taken to foster mini-grid value creation.

a) Power generation and energy storage as a service

Electricity (power) generation and energy storage as a service is a concept where community members can provide additional power generation and energy storage capacity to a mini-grid system through a well-defined service agreement with project developers. By increasing the power capacity, the system's flexibility is improved, which in turn allows for additional benefits to the community through increased income opportunities. Nonetheless, the integration of these units into the energy management system (EMS) is a necessary step for the implementation of such services.

b) Demand response programs

Demand response (DR) refers to a technique where consumers of electricity modify their energy consumption during peak usage periods to lower demand on the power grid and ensure electricity availability. Electricity providers usually offer DR programs to their customers, which allows them to enroll in such initiatives and receive financial rewards for decreasing their electricity usage during peak demand periods and low supply conditions. The deployment of DR programs in mini-grids can provide considerable financial gains to users by reducing their demand during high-consumption and low-energy generation periods, particularly in mini-grids that rely on intermittent energy source.

c) Operation and maintenance (O&M)

Ensuring the sustainability of mini-grid energy systems relies heavily on the efficient execution of their operation and maintenance (O&M) tasks. These activities are crucial in verifying that the system functions correctly and overseeing the technical aspects of electricity delivery. Although developers may oversee this phase, the community should be at the forefront of O&M efforts, given that most of these tasks occur within the village. To successfully attain the objective, it is crucial to establish a model that places great importance on engaging local residents as system operators. This approach entails organizing practical training sessions for a select group of individuals, equipping them with the essential skills and experience to operate and maintain mini-grid systems in collaboration with the primary operator. Through the implementation of this approach, community members who have undergone the necessary training can generate income while also contributing to the operation and maintenance of the mini-grid system.

d) Financing and ownership

The opportunity for financing and ownership of mini-grid holds the potential to serve as an empowering mechanism for financially secure members of local communities. This may include community cooperatives, local businesses, and anchor loads. This approach fosters cooperation and collaboration between stakeholders and the community while providing a means for community ownership. Sharing financial risks with the community mitigates investors' risks while giving the community a greater stake in the project's success. This collaborative approach promotes collective ownership and responsibility, motivating community members to take an active role in the project's development. Additionally, involving the community in financing and ownership provides other benefits, such as promoting sustainable development, increasing awareness of energy efficiency and consumption, and creating local economic opportunities. By tapping into the community's resources, stakeholders can leverage their expertise and skills to achieve shared objectives.

2) Value capture system of mini-grid

The value capturing system of a mini-grid projects concerns the economic gains derived from the mini-grid business model, where stakeholders participate in productive activities. To fully capture the value of mini-grid projects, community involvement is necessary, which can be achieved through local entrepreneurship, revenue-sharing mechanisms, productive use of energy, and value-added processing.

a) Promoting local entrepreneurship

To ensure the success of such training and support programs, mini-grid developers must collaborate closely with community members, local organizations, and government agencies to tailor the program to the specific needs and capabilities of the community. The program should aim to build on existing local resources and knowledge, thereby maximizing the potential for sustainable development. By providing targeted training and support to local entrepreneurs, mini-grid developers can facilitate the creation of a local ecosystem of businesses and services that can enhance community development and reduce dependency on external resources. Ultimately, this approach can help to ensure the long-term sustainability of mini-grid projects, promoting inclusive development and enhancing the well-being of the community.

b) Revenue-sharing mechanisms

In mini-grid systems, it's important to ensure that all stakeholders receive a fair share of the revenue and economic benefits generated. To achieve this, revenue sharing can be implemented through various mechanisms. One such mechanism is to involve the local community in revenue sharing. Under this approach, communities may allow the installation of mini-grid infrastructure on their land and receive a share of the revenue generated by the system in exchange. To facilitate this process, a community trust fund or a revenue-sharing agreement can be established. These mechanisms provide a transparent and accountable way to distribute revenue among the local community members. By involving the community in revenue sharing, mini-grid projects can promote equitable distribution of economic gains, which ultimately contributes to the socio-economic development of the community.

c) Productive use of energy

Productive uses of energy refer to the use of both electric and non-electric forms of energy, such as heat or mechanical energy, to promote socio-economic development in various sectors such as agriculture, rural enterprise, health, and education. By integrating the energy potential with other services, such as water or food services, through partnerships, it is possible to increase the overall value for all stakeholders involved and further promote socio-economic development. This approach allows for the creation of linkages between different sectors, ultimately leading to more holistic and sustainable development.

d) Value-added processing

To effectively implement this strategy, mini-grid developers need to collaborate with local entrepreneurs and farmers to identify the most viable value-adding opportunities in the community. This can involve providing training and support for product development, marketing, and distribution. Moreover, mini-grid developers should ensure that the pricing of electricity and pre-processed products is affordable and transparent, enabling local entrepreneurs to compete with metropolitan or international competitors. By facilitating the development of value-adding activities in local communities, mini-grid projects can enhance the social and economic benefits of electrification and contribute to inclusive development.

IV. Practical Examples of Inclusive Actions

Next, an analysis of selected case studies to illustrate the practical implementation of inclusive business models in mini-grid development is carried out. Most of the cases focus on the value capturing aspect of the mini-grid ecosystem.

A. Absolute Energy in Rutenderi village

Absolute Energy provides energy services mini-grid in the Rutenderi village of Bugesera district in Rwanda. The mini-grid provides to over 500 households and 40 entrepreneurial activities with a capacity of 50 kW. The system is owned by Absolute Energy, and they have designed a business model that supports the productive use of electricity. To better support local entrepreneurs, they partnered with Energy 4 Impact, an international NGO that provides support to business owners by delivering appliances, offering technical training, and promoting awareness of energy potential [11], [12].

B. ARC Power in rural Rwanda

ARC Power is a UK-based company providing sustainable electricity to rural Rwandan communities through mini-grid development. To support local communities, the company has built Solar Business Parks next to each mini-grid site. These parks will serve as battery-swapping stations for electric vehicles and provide entrepreneurs with customized spaces to run businesses, such as bakeries, tailors, milling stations, and welding shops. ARC Power has also partnered with Empowering Villages to provide basic business and entrepreneurial skills training to community members, helping them set up businesses, undertake business planning, and access loans for electric appliances [13], [14].

C. MeshPower in Nyakabungo

MeshPower, a UK-based company, provides clean energy to rural communities in Rwanda through solar-powered mini-grid systems that use AC/DC systems. They earn revenue by selling electricity, financing appliances, and providing internet access. MeshPower also offers Wi-Fi hotspots and asset-financing services. With DOEN Foundation support, they introduced an asset financing service based on "rent-to-own" lease plans with payment terms ranging from three to 12 months. The company promotes productive uses for electricity among customers, such as supporting welders, tailors, hairdressers, and others to increase their productivity and profitability [15].

D. Powerhive in Kisii and Nyamira

Powerhive, a US mini-grid developer, has developed a mini-grid system in the Kisii and Nyamira county of Kenya. Powerhive provides prepayment electricity to local households and micro-businesses in Kisii County, Kenya, using battery-backed systems. The company also offers a micro-financed poultry program, which has financed chicken brooders and houses, providing livelihood opportunities for around 130 people and generating a new income stream of $150-250 USD per person per month. Powerhive has also supported climate-resilient agricultural practices, including the adoption of less carbon-intensive cooking and the use of electric mills, motorbikes, and tuk-tuks [16], [17].

E. Jumeme in islands of Lake Victoria

Jumeme is a supplier of rural PV Mini-grid power in the Lake Victoria islands. They work together with local Tanzanian communities to catch Tilapia fish, which are highly in demand in Tanzania but mostly imported from China. The company freezes the fish on-site using mini-grid electricity, which helps to reduce post-harvest losses. By doing so, they eliminate the need for two stages of trading intermediaries and can deliver high-quality frozen Tilapia at a wholesale price to the capital city of Dar es Salaam. This optimized supply chain with frozen fish results in a reduction of overall transport costs, eliminating the middlemen on-site. Additionally, on-site freezing reduces water losses, leading to lower weight loss and higher revenues since less of the initially paid fish weight is lost [18].

F. Husk Power Systems (HPS) in Bihar

Husk Power Systems (HPS) uses renewable mini-grids to provide electricity to rural areas in India, Nigeria, and Tanzania. HPS operates over 120 sites, serving over 215,000 people. In Bihar, India, HPS's biomass power plants provide electricity to 30,000 households in rural villages. HPS has created job opportunities for over 500 people, including operators, electricians, and mechanics, from the villages it serves. The company has also generated jobs for independent plant owner-operators, contributing to the economic development of these areas [6], [19].

V. Discussion and Conclusion

This paper explores the benefits of inclusive approaches in mini-grid development. Inclusive practices must be integrated into key components to establish a successful and sustainable mini-grid business. This involves engaging the community in value creation and capture, power generation, energy storage, and ownership of the mini-grid network, creating economic and entrepreneurial opportunities. Early engagement and capacity building through training and skills development are necessary for community participation, successful operation, and maintenance, including job creation opportunities.

Inclusive practices can effectively address the identified conflict between commercial and social issues in previous research. Furthermore, inclusivity can improve and broaden the energy nexus by integrating it with other related industries such as water, agriculture, and industries. An inclusive business model may enable providers to capture revenues while simultaneously improving the livelihood conditions of their customers by offering a way to design, plan, and monitor business activities that address the specific needs of income-constrained groups.

Inclusive approaches can accelerate the trend of integrating energy access with related industries. An inclusive business model involves targeting actors from other sectors to build a system that sustains the community and increases overall profit. Case studies show inclusive actions like supporting entrepreneurial activities, training, financing, and productive use of resources. Developers must work closely with the local community to create and capture value from mini-grids.

However, it is important to note that despite the many potential benefits of inclusivity, there can also be negative effects that arise from some actions, particularly in value-added service models. For example, a developer's monopsony power over labor and raw materials can lead to price fixing, exploitation, and resource control in the long run. In addition, if a community relies heavily on value-added services for employment, there is a risk of unemployment if the business fails or slows down due to external factors. This can be particularly problematic if people have already given up their traditional risk-mitigation measures of generating income from other sources.

To mitigate such potential negative effects, the local government should develop legal and regulatory frameworks that benefit both the developer and the community, especially in addressing monopsony. Moreover, safety net systems should be designed to support affected individuals in case of job losses.

Future research should focus on gaining a comprehensive understanding of the diverse facets associated with these effects. Furthermore, there should be an emphasis on giving priority to the creation of efficient strategies aimed at mitigating these effects.

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Publication IV

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Measuring success: Evaluating the business model of rural mini-grid ecosystems

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Original research article

Measuring success: Evaluating the business model of rural mini-grid ecosystems

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ABSTRACT

In Sub-Saharan Africa (SSA), the challenge of widespread electricity access, especially in rural areas, persists, with approximately half the population lacking basic electricity services. To tackle this issue, decentralized energy resource (DER) technologies, including solar home systems and micro/mini-grids, have gained prominence, aiming to revolutionize the SSA energy landscape. This paper aims to introduce a framework for evaluating business models in the context of rural mini-grid ecosystems. Conventionally, developers of rural mini-grids are responsible for all aspects of the project, from conception to operation and maintenance. However, with the emergence of new private sector facilitators, value creation in this ecosystem has become more complex. As multiple stakeholders apply different business models and patterns to create and capture value, evaluating the efficacy of these models is critical. The evaluation framework presented in this paper draws upon various business model theories and evaluation approaches and includes indicators for assessing performance. To demonstrate the framework's usefulness, we applied it to six companies currently operating in rural mini-grid projects in Africa. Consistent evaluation of these business models is essential for adapting to changing conditions, identifying areas for innovation, and sustaining competitiveness, furthering the field of business model assessment. By bridging this gap between business model evaluation methodologies and rural electrification studies, this paper contributes to understanding the transformative effects of mini-grid projects, extending beyond traditional energy access metrics.

1. Introduction

In the Global South, particularly in Sub-Saharan Africa (SSA), the challenge of ensuring widespread access to electricity remains a significant issue. Approximately half of the population in this region lacks access to basic electricity service, with a notable concentration residing in rural areas [1]. To address this critical problem, the emergence of decentralized energy resource (DER) technologies has gained momentum, particularly in the form of off-grid solutions like solar home systems and micro/mini-grids [2]. These innovative approaches seek to revolutionize the energy landscape throughout SSA.

Solar home systems are particularly well-suited for sparsely populated regions with limited energy demands, serving various residential needs including lighting, household appliances, computers, and water pumps [3]. These systems typically operate at low power levels, usually under 100 W. Another pioneering strategy, the swarm grid, envisions the connection of individual solar home systems through peer-to-peer energy-sharing platforms [4]. Each home is equipped with a controller that is interconnected through cables, facilitating the sharing of power. The controllers actively monitor power flows, with energy payments being conducted through mobile money platforms. Mini grids, featuring generation units ranging from 10 kW to 10 MW, are particularly effective in areas characterized by high demand and population density but are challenging for the primary grid to reach promptly. In places where the main grid's expansion is cost-prohibitive and time-sensitive, mini grids emerge as an economically viable option [5].

The decreasing cost of technical components, such as solar photovoltaic (PV) panels and battery energy storage systems, has made mini-grids a cost-effective energy resource option. Moreover, technological advancements such as Radio Frequency Identification (RFID), Information and Communication Technology (ICT), Geographical Positioning System (GPS), Remote Sensing (RS), and data communications, including cloud and edge cloud computing technologies with 3G, 4G, and 5G technologies, have made it possible to enhance the energy

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utilization, digital payment options, and remote-control features of mini-grids. These features also enable communities to engage in economic activities using income-generating productive-use appliances and machinery, as well as digital tools and platforms [6,7].

Rural mini-grids in developing regions are commonly developed by government organisations, non-governmental organisations (NGOs), and private companies. The conventional value network of a rural mini-grids revolves around the developer, which is the centre of every process from initiating the project, to designing, procuring the different components, installing, and later operating the mini-grid after the project has been commissioned. With the newer generation of mini-grids, however, the value network is expanding, that is, new private-sector stakeholders (facilitators) have started to get involved in different parts of value creation processes. This value creation can range from supporting activities, such as software providers and analytics, to core activities, such as technical services, flexibility options, energy storage systems, digital payment technologies, civil work, and finance [6] (see Fig. 1).

As the value network expands, the business landscape for mini-grid projects in developing regions is undergoing significant changes. Previously, developers held responsibility for all tasks; however, in the current scenario, private companies have taken on a significant portion of these responsibilities. This shift has led developers to transition into roles that involve orchestrating overall development efforts while placing emphasis on community engagement and electricity sales [7]. The increasingly complex value network has also resulted in different stakeholders adopting various business model patterns to create and capture value.

In the ever-changing business landscape, it holds strategic significance for companies to consistently assess their business models, ensuring the refinement of their services and the sustenance of competitiveness [8]. This principle is equally applicable to organisations engaged in the realm of rural electrification and mini-grid businesses. Business model evaluation is a critical aspect of the planning process, enabling firms to determine the feasibility of their models in the current and future business landscape. This evaluation can be conducted before implementing a new business model or improving an existing one [9]. Furthermore, mini-grid developers and facilitators can evaluate their business operations to maintain service quality, reduce costs, increase profitability, and remain competitive in the market. Business model evaluation also enables such companies to identify potential risks and hazards and operate sustainably. Additionally, the evaluation results can help companies identify areas for innovation and product development.

In this paper, we emphasize the importance of a comprehensive evaluation of business models in rural mini-grids. This evaluation should encompass the assessment of collaborative efforts among various stakeholders who actively participate in community projects. The ultimate goal of such evaluations is to ensure the provision of affordable, reliable, and sustainable energy services that effectively support socio-economic activities within these communities, fostering both productivity and communal engagement. While several studies have outlined business model evaluation methods in Section 3.1, there is a limited number of evaluation methods available for rural electrification or mini-grids. Most studies on business models for mini-grids (e.g., [10–17]) tend to concentrate mainly on subjects like business model frameworks, ontology, commercial and social impacts, as well as socio-technological configurations. Furthermore, different international organisations' reports (e.g., [6,7,18–20]) provide studies regarding the implementation of mini-grids. The ongoing discourse surrounding mini-grids business model is multi-faceted, with a primary focus on the pivotal role of social enterprises in addressing energy access challenges in rural Bottom of the Pyramid (BoP) markets [10]. Simultaneously, there is growing acknowledgment of the technical and organizational complexities inherent in providing energy services in these underserved areas, often leading to conflicts between social and commercial objectives when configuring mini-grids [11]. At the heart of this discussion lies the critical issue of ensuring the sustainability of mini-grid-based social enterprises, which hinges on their ability to expertly design, manage, and operate the sociotechnical aspects of these systems, striking a delicate balance between technological efficiency and social impact [14].

Despite its paramount importance, the discourse on business models for rural electrification and mini-grids frequently lacks in-depth

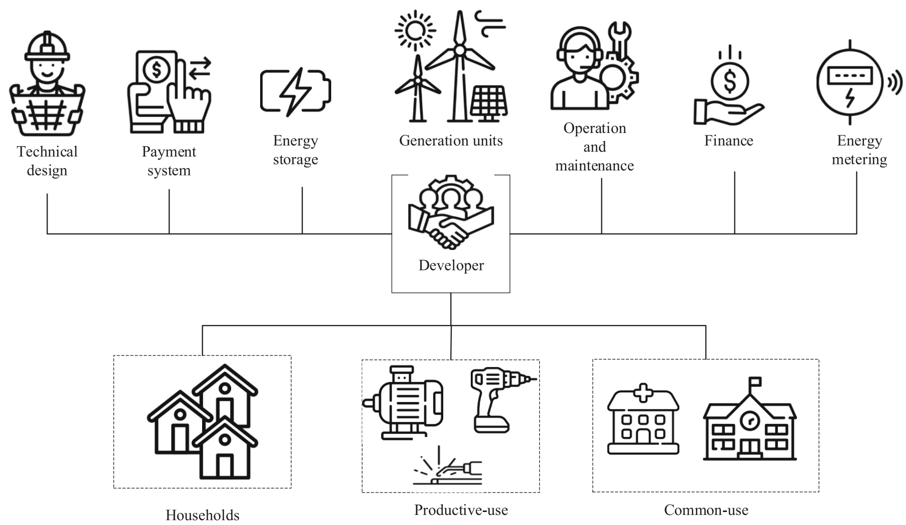

Fig. 1. Depiction of the latest mini-grid value network and its components. Source: *own compilation*.

discussions regarding evaluation. This gap emphasizes the necessity to establish a connection between the existing business model evaluation methodologies rooted in business disciplines and the specialized realm of rural electrification studies. Bridging this gap holds the potential to yield valuable insights into the effectiveness and sustainability of mini-grid business models and contribute to the field of business model evaluation.

Furthermore, the significance of addressing this research gap extends to the realm of impact assessment. By incorporating business model evaluation into the impact assessment process, it becomes possible to gauge the transformational effects of mini-grid and rural electrification projects on the livelihoods of the target communities. Such an approach enables a more comprehensive measurement of project impact, transcending the conventional metrics of energy access and infrastructure development. Therefore, it is necessary to identify evaluation indicators for the mini-grid business ecosystem that encompasses the roles of both developers and facilitators.

With this in mind, this paper aims to bridge the following research gaps with the following contributions:

- Identifying evaluation indicators for the mini-grid business ecosystem that assess the roles of developers and facilitators in evaluating the business model comprehensively.
- Provision of business model evaluation methodology for the rural mini-grid business.

The paper is organised as follows: the second section provides an overview of the business model and business model reviews the current microgrid business environment in developing countries. The third section provides business model evaluation concept and present related literature. The fourth section proposes a conceptual framework design for business model evaluation for the mini-grid business ecosystem. The fifth section presents an analysis of a case study from different mini-grid developers and facilitators based on the proposed evaluation method. Finally, the sixth section provides the discussion and conclusion of the paper.

2. Theoretical background

2.1. Business model and business model patterns

A business model describes how an organisation creates, delivers, and captures value [21,22]. The term "business model" was first mentioned in scientific literature in 1947 by Lang, and later by Bellman et al. in 1957 [23,24]. However, it wasn't until the 1990s, with the emergence of e-commerce and the New Economy, that the concept gained popularity [25]. The New Economy was characterized by a shift towards more online based and high-tech services, made possible by the increasing adoption of the internet and greater computing power. However, the term "business model" has been frequently misused and overused, leading to a vague understanding of its meaning [22,25]. In the late 1990s, the term was often used to compare the new e-business value creation to the traditional "brick-and-mortar" model. The interchangeable use of the term with other similar terms, such as strategy, economic model, and revenue model, further contributed to a lack of clarity around the concept [26,27]. The Osterwalder and Pigneur model, which includes value proposition, customer interface, infrastructure, and finances, has been widely accepted and tested [24]. Their definition of a business model as "*the rationale of how an organization creates, delivers, and captures value*" has become the standard [27–29]. This model provides a comprehensive framework for understanding and analysing business models and has been used extensively in both academia and industry [8].

Business model patterns are tested and proven models that can act as a base for innovating a new business model or improving an existing one [30]. These patterns are specific to different parts of a business model and can be combined to establish a new business model, fostering innovation and competitive advantage in the ever-changing business environment. For example, an internet trading company could use a digital service provider pattern to offer services to customers, a shared infrastructure pattern as the channel to reach customers, a freemium pricing mechanism to provide digital services for free and charge for premium features, and a brokerage fee pattern for revenue streaming [31]. By using established patterns and frameworks, organisations can innovate and improve their business models, creating more value for their customers and stakeholders.

2.2. Rural mini-grid value network and available business model

The classical value network of a rural off-grid system makes developers to be the centre of every activity of the development and operations [6]. These developers can be community cooperatives, government energy utilities, private investors, public-private partnership-based organisations and non-governmental organisations (NGOs) [10]. They coordinate the necessary finance and technology and establish relationships with different stakeholders. Developers have a first-hand or business-to-customer (B2C) relationship with off-grid users. Today, however, the value network is expanding, and new players are participating in new value creation activities. These stakeholders can range from original equipment manufacturers (OEMs) that supply hardware and software to the off-grid system to those who provide supportive activities, such as technical services, flexibility options, energy storage systems and finance, as illustrated in Fig. 2. They have a business-to-business (B2B) relationship with the developer and a business-to-business-to-customer (B2B2C) relationship with both developers and customers. For instance, companies such as Okra Solar[1] provide energy management and operation systems that enable to integrate individual solar home systems in a mesh grid; Sparkmeter[2] provides smart meters, energy management software and digital solutions for mini-grid systems; OXTO Energy[3] provides flywheel energy storage systems (FESSes) to rural mini-grids for stabilising the grid by frequency regulation; GnuGrid Africas' Credit Reference Bureau[4] (CRB) helps financial institutions and off-grid solar companies to identify high-risk borrowers by utilising credit information, thereby reducing the upsurge of high default rates in such informal sectors. Furthermore, other companies such as Zuhura Solutions[5] and Baridi[6] provide chilling and storage services for agricultural producers that require cold chain logistics. Such a trend had also been followed by companies—which once operated in a vertically integrated value chain—to break up their value chain and focus on their core business [6,32].

As the value network expands, it brings about a shift in the business environment of mini-grid initiatives in developing areas. Companies operating within the value network are compelled to adopt various business models and strategies to create and capture value. Table 1 outlines typical business model patterns employed in rural off-grid projects.

1 https://okrasolar.com/.
2 https://www.sparkmeter.io/.
3 https://oxtoenergy.com/.
4 https://gnugridcrb.com/.
5 http://www.zuhurasolutions.com/.
6 https://baridi.co.ke/.

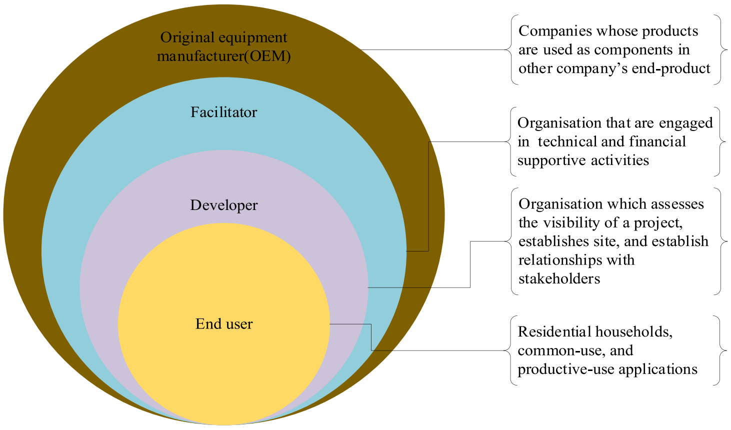

Fig. 2. Multi-tier mini-grid ecosystem. Source: *own compilation.*

Table 1
Example of mini-grid business model patterns.

Business model pattern	Description of the model	Specific business model area	Reference
Appliance financing	Offering appliances with credit to rural customers to prompt electricity demand	Financial viability	[33,34]
Revenue sharing	Sharing the total generated income with stakeholders to incentivise and maximise participation of rural communities	Financial viability	[35]
Anchor-Business-Community (ABC) Model	Reducing the risk of uncertain power demand by leveraging anchor customers first followed by businesses and community	Financial viability	[36]
KeyMaker	Enabling mini grid power-based rural manufacturers to be part of the value chain of product trading businesses	Value proposition	[12,37,38]
Energy-telecom-nexus	Providing integrated power, telecom and digital services using mini-grids and base stations to communities that lack mobile broadband coverage and electricity	Value proposition development	[38,39]
Energy-Food-Nexus	Enabling rural agriculture-based productive-use customer (agricultural cooperatives) to be the central load mini grid and complimenting household loads with excess power	Value proposition development	[40,41]
Split asset	Reducing the capital cost burden of the developer by dividing the financing of the generation and distribution assets between the developer and the government or community	Infrastructure	[42,43]
Pay-as-you-go	Enabling users to pay for the electricity they use when they need it	Payment method	[44]
Pay-as-you-store(chill)/ Chilling-as a-service	Enabling agriculture producers in the cold-value chain to pay for using cold storages when needed	Payment method	[32]

3. Business model evaluation

Business model evaluation is a systematic approach and procedure that is used to attain a quantifiable perception of a given business model [8,45]. The evaluation outputs can be used prior to the implementation of a new business model (ex-ante) or to improve an existing business model. The evaluation can benefit different stakeholders in the business environment by enabling them to recognize their strengths and weaknesses and evaluate their business performance. Furthermore, evaluation of a business model helps organisations to develop future goals and restructure their business for increased success and profit [46]. The evaluation process starts by setting the evaluation objectives. These objectives can be economic (profit earning, growth, survival to exist in the future, creation of new customers, innovation) or social (e.g., creation of employment, provision of fair prices), or a combination of different objectives. Based on the objective set, suitable indicators with a respective weight can then be developed. Indicators are markers of accomplishment or progress made towards achieving outputs of a work plan. In the case of a business model, the evaluation indicators are set to answer the evaluation questions and provide a useful insight about the business activities of an organisation.

3.1. Business model evaluation in scientific literature

The domain of business model evaluation methods has not received extensive examination, yet the scientific literature offers a wealth of proposed approaches. Within this literature, a diverse range of business model evaluation methods exists, tailored to specific domains and originating from authors with varied backgrounds. These diverse approaches are designed to evaluate a range of dimensions, including enterprise performance, entrepreneurship, innovation, and technology development. Together, they offer a comprehensive framework for assessing business models within the realm of scientific literature. While some existing methods concentrate solely on appraising the fundamental components of a business model, others go further by conducting comprehensive scenario analyses and rigorous risk assessments.

In the discussion that follows, we highlight some of these noteworthy approaches.

3.1.1. Business model assessment tools

Osterwalder and Pigneur [29] proposed a two-step assessment method: the first step assesses the business model blocks with respect to their degree of importance to the business model mapped with a business model canvas (BMC), and the second step evaluates each block with a strength, weakness, opportunity, and threat (SWOT) analysis. The evaluation outcomes are assigned quantitative values between −5 and + 5. Similarly, Batocchio et al. [47] presented a method for assessing the performance of start-ups by combining the BMC and the balanced score. The balanced score card is another strategic performance management tool used by organisations to identify and improve their services. Accordingly, for each BMC element, indicators are initially selected and then measured with a targeted set of values.

3.1.2. Indictor-based approaches

Mateu and March-Chorda [48] proposed eight indicators for evaluating an ex-ante business model, with a focus on managers and experts for assessment. Building on this work, Mateu and Escriba-Esteve [9] analysed and enhanced these methods and provided ex-ante business model evaluation techniques. They expanded the evaluation model to incorporate a broader range of stakeholders, including potential customers in the assessment design. Their evaluation framework includes intuitive weightings for each indicator, enabling a more comprehensive and inclusive evaluation process.

3.1.3. Stress testing and decision support

Haaker et al. [49] provides a business model stress testing and decision support system. The stress testing involves assessing business model elements regarding market scenario as well as regulatory and technology uncertainties. The decision support system helps companies in choosing the best-fit available business model from a financial point of view. Furthermore, Biloshapka et al. [50] developed a scaling matrix with four quadrants (looser, winner, giver, and taker) that include a company capture and what it provides for the customers. The authors also gave directions on how to move business models to the winning side.

3.1.4. Risk assessment methods

Tesch and Brillinger [51] identified and analysed the risk factors in a business model by mapping all actors within the value network from the value creator, value delivery and the end customer, as well as the value and delivery stream for a digital business model. The visual representation built by the authors enables identification of the risk-related factors and analysis of the role of partners, business owners and the efficiency and complexity of the value network.

3.1.5. Computational simulation methods

Groesser and Jovy [52] conducted a computational simulation modelling to test the viability of a business model in three different future scenarios, characterised by the introduction of a superior competing product, an increased contact rate and tightening supply. Moreover, Sharma and Gutiérrez [53] developed a business model evaluation framework for mobile commerce-related organisations. The authors use a business model framework to understand the dynamics of the digital business. The framework includes value proposition, interface and service platform, organisation model and revenue/cost. The paper identifies success factors for a viable business model that enables to support mobile-commerce in the IT service.

3.1.6. Weighting factors in analysis

Kayaoglu [8] proposes a dynamic business model evaluation tool that applies weighted indicators to each block of the business model at different hierarchical levels and criticality. This approach provides a clearer evaluation outlook of a specific business model by assigning different weights to indicators in each block. Additionally, Kayaoglu developed a software for business model evaluation that offers recommendations to users on adaptive measures to be taken at each business level, based on the proposed dynamic evaluation method. In a similar vein, Jaâfar Berrada [54] developed a comprehensive business model evaluation methodology as part of the H2020 European Project SHOW.[7] This methodology is intended to evaluate the business operations that support the deployment of shared, connected, and electrified automation in urban transport, in order to promote sustainable urban mobility in the EU region. The evaluation methodology assigns scores to the business/operating model based on the average value of all the goal scores, with each score weighted according to its importance.

3.1.7. Evaluating rural markets

In a more recent study into rural markets Zhang et al. [55] developed an evaluation framework for businesses operating in rural China. By identifying critical factors from case studies, two frameworks were proposed using open and axial coding. The firms in the case study were from manufacturing, agriculture, retail, telecom, and biotech sectors. By analysing the case studies, the authors identified the key indicators for measuring rural enterprises' business models and suggested key points that must be considered. Accordingly, the authors argued that rural market-based firms need to understand the consumption habits, preferences, and capabilities of the rural customers. The study also suggested that firms should engage in training and facilitating rural customers to also enhance the value creation process further.

A summary of the method described above can be found in Table 2 below.

Despite the importance of mini-grids in rural electrification, there appears to be a scarcity of evaluation methods available to assess such cases. This lack of evaluation methods highlights the need to develop new methods and identify relevant indicators for evaluating the mini-grid business ecosystem, which includes both the developer and facilitator's roles. By utilizing the above-mentioned evaluation methods, as well as additional user-centric indicators, our objective is to create a comprehensive methodology and evaluation framework that considers all actors within the mini-grid environment.

4. Proposed methodology

In order to achieve our research objectives, which involve assessing mini-grid business models, we propose a comprehensive approach that draws from the methods reviewed earlier. Our aim is to create a generic and replicable methodology applicable to various mini-grid ecosystems. To accomplish this, we outline a four-step process as illustrated in Fig. 3. Firstly, we will focus on identifying the key stakeholders within the value network, with particular attention to developers and facilitators. Secondly, we will carefully select relevant evaluation indicators that will help us gauge the performance of these business models effectively. Thirdly, we will assign criticality ratings to different components of the business models and weight factors to the evaluation indicators to ensure a well-rounded assessment. Finally, we will calculate an overall score based on the quantified data gathered through this structured process. This approach will enable us to systematically evaluate and compare mini-grid business models across different ecosystems.

Step 1: Classification of stakeholders

Evaluating the business model of rural mini-grids requires classifying the stakeholders based on their location in the value network and objectives. We propose a tier-based approach to evaluate the mini-grid business environment, as presented in Fig. 2. The tiers are set to distinguish the different stakeholders (players) in mini-grid development based on the organisation's main objective and proximity to the end user.

The developer tier is responsible for initiating the project and in some cases operating the mini-grids. These developers can be community cooperatives, government energy utilities, private investors, public–private partnership-based organisations and NGOs. They coordinate the necessary equipment, finance and technology and establish relationships with different stakeholders. Developers have a first-hand or business-to-customer (B2C) relationship with mini-grid customers. In

[7] https://show-project.eu/.

Table 2
Summary of business model evaluation examples.

Category	Subcategory	Methods	References
Business model assessment and enhancement	Two-step assessment	Combining BMC analysis and SWOT analysis to systematically evaluate and enhance business models.	Osterwalder and Pigneur [29]
	BMC and balanced scorecard approach	Using BMC framework with the balanced scorecard to evaluate start-up performance and identify key performance indicators.	Batocchio et al. [47]
	Ex ante evaluation	Proposing eight indicators for ex-ante business model evaluation, with a focus on managers and experts.	Mateu and March-Chorda [48]
	Inclusive ex ante evaluation	Expanding the Mateu and March-Chorda [48] evaluation model to incorporate a broader range of stakeholders and introducing intuitive weightings for each indicator.	Mateu and Escriba Esteve [9]
	Scaling matrix for guidance	Developing a scaling matrix to categorize companies and offer strategic guidance for business model enhancement.	Biloshapka et al. [50]
Risk assessment and mitigation	Value network risk analysis	Conducting risk factor analysis by mapping all actors within the value network to identify risk-related factors.	Tesch and Brillinger [51]
	Computational simulation modelling	Employing computational simulation modelling to assess business model viability under various future scenarios.	Groesser and Jovy [52]
	Mobile commerce model framework	Developing a comprehensive framework for mobile commerce business model evaluation, covering critical elements.	Sharma and Gutiérrez [53]
	Dynamic evaluation tool	Introducing a dynamic business model evaluation tool that applies weighted indicators to different hierarchical levels and criticality within the business model blocks.	Kayaoglu [8]
	Comprehensive evaluation	Creating a comprehensive business model evaluation methodology that assigns scores to business/operating models based on goal scores with weighted importance.	Jaâfar Berrada [54]
Rural market evaluation	Rural market business models	Developing frameworks to evaluate business models operating in rural markets, emphasizing critical factors derived from case studies across various sectors.	Zhang et al. [55]

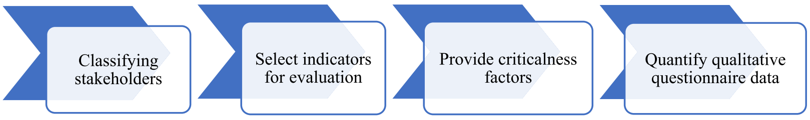

Fig. 3. Flow chart of the evaluation process.

this tier, organisations manage the finances (revenue and cost) and coordinate the necessary technical requirements to provide an uninterruptable power supply to the customers.

The second tier includes organisations and vendors that provide technology and services to mini-grid developers. These organisations can be energy management and efficiency software providers, smart metring suppliers, hardware suppliers, technical services (O&M), civil work, financial service providers, smart home appliance suppliers, productive-use (income-generating) machinery suppliers and energy storage providers. They have a business-to-business (B2B) relationship with the developer. In this tier, the organisation's main goal is to engage in one-time sale or provide ancillary services in short- and long-term periods to the mini-grids.

Step 2: Business model evaluation indicators

To evaluate the business ecosystem, we propose evaluation indicators in relation to the business model elements. As can be seen in Table 3, the evaluation indicators are divided into core indicators and sub-indicators. The evaluation indicators are adopted mainly from the

Table 3
Evaluation indicators for developers and facilitators.

Core indicator	Sub-indicator	Description	Stakeholders	
			Developer	Facilitator
Service offer	Adequacy	Acceptable amount of energy service	X	
	Affordability	Ability to provide affordable energy services	X	X
	Reliability	Degree of confidence in the energy system or appliances	X	X
	Safety	Ability to prevent dangerous and harmful effects on users	X	X
	Suitability	Quality or degree of providing the right type of service or product	X	X
	Environmental impact	Measuring the environmental impact of the service	X	X
	Gain creation	Ability to improve income and welfare by energy services	X	X
Financial status	Cost/revenue balance	Measuring the financial balance of operations	X	
	Cost reduction	Measuring taken to reduce and optimise costs	X	X
	Revenue increase	Possibility of increasing the revenue from the service or product sale	X	X
Customer segment	Consumption needs	Segmentation based on electricity consumption need	X	
	Consumption trend	Segmentation based on electricity consumption trends (behaviour)	X	X
	Consumption capacity	Segmentation based on electricity consumption capacity	X	
	Service needs	Segmentation based on the electricity service required	X	X
Customer relationship	Customer satisfaction	Inclusion of customer satisfaction	X	X
	Customer support	Availability of customer support	X	X
	Service improvement	Engagement in improving a better service for customers	X	X
Partnership	Relationship with stakeholders	Identification of the availability of key partners	X	X
	Depth of relationships	Measuring the degree of partnership	X	X
	New partnerships	Establishing new partnerships with other parties	X	X
Resource management	Resource availability	Identifying whether the resources needed are easily available	X	
	Resource utilisation	Degree of how resources are efficiently utilised	X	X
	Resource standardisation	Resources used according to the standards	X	X

BMC block elements presented in [29], user-centric business and marketing model development [56,57] and different rural electrification monitoring and evaluation guidelines and case studies [58,59]. In this paper, we only focus on the developer and facilitator tier for the evaluation, given that their business operation can have a significant effect on the overall energy ecosystem and its proximity to the end user. Besides, OEMs have more diversified customer groups other than mini-grids, for which their products are also suitable in other sectors.

As can be seen from Table 3, not all the indicators are shared by both facilitators and developers. In some cases, such as 'consumption need' and 'consumption capacity' indicators are mainly assigned to developers than to facilitators, considering that developers are the main responsible party for such tasks.

Step 3: Criticalness factor

The success of a business model hinges on its individual building blocks, but their relative importance in achieving overall success can vary in practical situations. For example, for mini-grid developers whose primary goal is to provide sustainable and affordable power supply, the "value proposition" block carries more weight than the "channel" block, which is focused on finding ways to reach customers. This means that even if both blocks receive the same score, their impact on the overall evaluation should differ based on their criticality.

To address this issue, we propose a critical level-based evaluation of each business model block utilized by mini-grid developers and facilitators in off-grid projects. Our approach involves a two-level analysis: first, we assign a criticalness level (0, 0.5, 1) to emphasize the level of importance of each business model block, following Kayaoglu [8] framework (see Fig. 4).

Step 4: Quantifying qualitative data

In this study, we quantify the questionnaire data to be able to retrieve numeric representation of indicators. The questionnaire comprises Net Promoter Score (NPS) and matrix types of questions. The mean values of the score values of sub-indicators are then used to calculate the overall score for the core indicator. A sample example from the questionnaire is presented in Table 5 as follows:

Other types of sub-indicator questions are designed within a matrix that asks respondents to evaluate the raw sub-indicators with column choices. Table 6 provides an example of questions from the questionnaire:

Our approach emphasizes the various attributes of the business model blocks rather than exact numerical values, and it is designed to be easily understandable. It is worth noting that assigning a numeric weight factor for evaluating different elements of a business model is subjective and depends on various factors such as the industry, the specific business, and the evaluation's goals.

We can then determine the aggregate mean score by utilizing the criticality factor associated with each indicator concept through the equations presented below.

$$Overall\ mean\ score = \frac{\sum_{i=1}^{n} (x_i * CFw_i)}{n} \tag{1}$$

where: xi = cumulative score of sub-indicators
n = number of sub-indicators
CF = criticalness factor

5. Case study

5.1. Sample

To further examine our proposed evaluation method, we investigate six companies that are engaged in rural electricity development projects. Two companies focus on development and operation, and the other four provide service as facilitators and OEMs in the value network. The investigated cases are presented in Table 7 below.

5.2. Data collection

For this study, we designed a survey that contains self-evaluation questions that are based on the evaluation indicators and sub-indicators mentioned in the above section. Questionnaires were sent to companies via Webropol. The questionnaire starts with general information about the companies and where they fit in the value network, followed by self-evaluation questions in relation to how they conduct their business activities. Questions about the companies' business

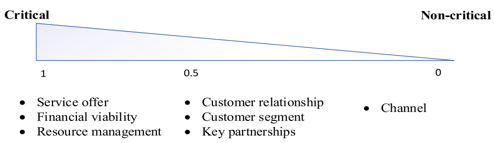

Fig. 4. Proposed criticalness level for the developers' business model.

Table 5
Sample sub-indicator questions.

Sub-indicator	Sub-indicator question	Score range
Adequacy and gain creation	– How do you rate your customers' typical satisfaction? – How do you rate the social benefits that your service is typically bringing to your customers? – How do you rate your organisation's ability to support the productive use of energy?	0 (not satisfied) and 10 (extremely satisfied) 0 (not beneficial) and 10 (extremely beneficial) 0 (unable to support) and 10 (able to support)

Table 6
Column choice-based sample questions.

Sub-indicator question		Score range
How do you rate the current state of power supply that your organisation typically provides for your customers?	Uninterrupted Power Adequate supply Affordability Safety Environmental impact	0 (below average) and 5 (top tier)

Table 7
Overview of the investigated cases.

Cases	Organisational role in the mini-grid ecosystem	Financial backing	Focus area	Countries of operation	Business model pattern use cases
Company A	Developer & operator	Loans, grants and result-based financing (RBF)	PV-based mini-grid development and operation in rural areas	Kenya	Pay-per-use as the revenue model with a fixed-rate pricing model and mobile money as the payment method
Company B	Developer & operator	Loans, donors and private investors	Hybrid solar photovoltaic- and battery-powered mini-grid plants	Kenya, Nigeria	Usage-fee as the revenue model and mobile money as the payment method
Company C	Facilitator & OEM	Private investors	Grid management solutions (smart meters, energy management platforms, digital solutions)	Nigeria, Uganda, Tanzania, Benin	Usage-fee as the revenue model and mobile money as the payment method
Company D	Facilitator & OEM	Loans, donors, and private investors	Mesh grid control asset management digital tool and geo-spatial-based project design platform	Cambodia, Philippines, Nigeria, Haiti	Usage-fee as the revenue model and mobile money as the payment method
Company E	Facilitator	Grants and private investors	Fintech services and a renewable energy aggregator platform for solar home systems and mini-grids	Nigeria, Ghana, Uganda	Pay-per-use as the revenue model for its agents
Company F	Facilitator &OEM	Grants and private investors, Result-based Funds (RBFs)	Energy management software providers, hardware suppliers, technical services (O&M), financial service providers, smart home appliance suppliers	Kenya, Rwanda, Togo, Nigeria	Pay-per-use as the revenue stream model, mobile money and instalment for payment method, consumption-based pricing

activities are divided into service offer, customer segmentation, customer relationship, resource management, partnership with stakeholder, financial status and the applied business model patterns. The questionnaire link can be found in the appendix section of this paper.

5.3. Data analysis

The data were initially examined in detail through a case-by-case (within-case) approach and later across cases. The analysis was carried out in two steps. First, we analysed the companies' generic responses to how they conduct their business, and second, we quantified their responses in relation to the proposed indicators.

5.4. Within-case analysis

In this section, we describe business activities as experienced by each individual respondent. The questionnaire responses are summarised in Table A1 in the annex section.

5.5. Cross-case analysis

In this section, we conduct a cross-case analysis for the cases based on Eq. 1. Table 8 presents a comparison of six companies (A through F) based on their performance on core indicators, which are service offer, financial viability, and resources management. The criticalness level for each of these indicators is 1, meaning that they are of high importance to the overall performance of the companies. The table also includes three additional indicators, which are customer segment, customer relationship, and partnership. These indicators have a criticalness level of 0.5, indicating that they are of moderate importance to the overall performance of the companies. The mean value for each indicator is also provided in the table. This gives an overall indication of how well each company is performing across all indicators. In addition, the table displays a colour gradient (red-green-yellow) to signify where values fall within a specific range.

5.5.1. Cross-case analysis for developers (company A and B)

According to the result, Company B scores higher than Company A on service offer, financial viability, and resources management. For example, Company B scores 0.90 on the service offer indicator, while Company A scores 0.73. Similarly, Company B scores 0.83 on the financial viability indicator, while Company A scores only 0.75. Furthermore, Company B has a higher mean value for the highly critical core indicators as compared to Company A. However, on the moderately important indicators, A and B have scores that are quite close to each other with mean values of 0.59 and 0.61, respectively.

Another interesting aspect revealed by the evaluation is that neither of the companies applies customer segmentation in their operation

Table 8
Evaluation score for case studies.

Core indicators	C.F Level	Company A	Company B	Company C	Company D	Company E	Company F
Service offer	1	0.73	0.90	0.90	0.85	0.78	0.85
Financial viability		0.75	0.83	0.85	0.78	0.73	0.83
Resources		0.93	0.96	0.89	0.96	0.96	0.89
Mean value		0.80	0.90	0.88	0.86	0.82	0.85
Customer segment	0.5	0.00	0.00	1.00	1.00	1.00	1.00
Customer relationship		0.93	1.00	1.00	0.93	0.93	1.00
Partnership		0.83	0.84	0.72	0.77	0.90	0.79
Mean value		0.59	0.61	0.91	0.90	0.94	0.93
Overall mean value		0.70	0.76	0.89	0.88	0.88	0.89
Overall mean with C.F		0.55	0.60	0.67	0.66	0.65	0.66

although both reported having diverse customer groups. Further, Company A's questionnaire response reveals that it's not fully capable of providing and satisfying customer needs. Additionally, prospects for market growth are limited in its area since the market is already saturated. On the other hand, Company B believes that there is room for growth in the rural electrification market and prospects to have an additional revenue stream.

5.5.2. Cross-case analysis for facilitators (Companies C, D, E and F)

The evaluation results also shows that Companies C, D, E, and F have similar performance on the service offer indicator, with scores ranging from 0.85 to 0.90. However, there are differences in performance on the financial viability indicator, with scores ranging from 0.73 for Company E to 0.85 for Company C. When it comes to the mean value for the core indicators, Companies C and D have the highest scores of 0.88 and 0.86 respectively, followed by Company F with a score of 0.85, and Company E with a score of 0.82. Moreover, it is noteworthy that all companies have obtained higher mean scores, exceeding 0.9, across the core indicators of moderate importance.

Moreover, all companies reported having established good partnerships with other stakeholders based on their questionnaire responses. However, it is worth noting that while developers can easily assess and compare the depth of their partnerships, facilitators may find it more challenging. This difficulty arises because facilitators offer different services in the value network, and the partnership requirements may differ for each service. Resource management is an area where all facilitators performed well, exhibiting proficiency in utilizing their physical, financial, and human resources. Regarding financial stability, while all companies had a positive outlook on the possibility of additional revenue streams, two respondents (Companies E and F) reported difficulty balancing their financial operations.

6. Conclusions and future perspective

The objective of this paper was to conduct a brief review of rural mini-grid business models and evaluation methods available in the off-grid energy systems sector. As the business environment in this sector is constantly changing, it is essential to have tools to understand and evaluate organizational performance.

Based on an analysis of the research gap in rural mini-grid business model evaluation methods, we introduced and tested a novel evaluation method. The presented method is designed to identify organisations by tier based on their position in the value network, followed by providing indicators that reflect the rural mini-grid business environment. The method proposes weighting and criticalness factors for each sub-indicator, enabling stakeholders to rank the indicators according to their importance for their organisation. These indicators were adopted from various business model theories, rural electrification guidelines, and marketing models, and the evaluation methodology was adapted from previous evaluation methodologies found in literature.

The proposed method was applied to analyse the business model of six companies, including two developers and four facilitators, operating in the rural mini-grid sector/market segment. Our findings showed that the overall scores of developers and facilitators do not differ significantly, but there are more variations in individual business model segments between companies. For instance, both developers lack segmenting their customers according to specific energy consumption behaviour, pattern, or demand, which could help organisations better understand their customer groups.

We argue that the proposed model makes contributions to science as it can provide better insight to evaluate rural cases compared to the current state of the art. Additionally, future research could analyse the mini-grid business environment that has customers, developers, and facilitators under one umbrella to evaluate overall business activities while analysing the individual effect of various business model elements on the operation. The evaluation results could also be compared with financial information (balance sheet or stock price) to check whether the performance in the business model evaluation correlates with the financial performance of companies. Another area of study could be to analyse different selection criteria based on the weighting and criticalness factor instead of intuitive assessment.

While the proposed evaluation method has the potential to provide valuable insights into evaluating rural mini-grid business models, there are some limitations to consider. One limitation to consider is that the proposed method was tested on a small sample size of only six companies, which may not be representative of the entire rural mini-grid sector. Further testing and validation of the method on a larger sample size could enhance its accuracy and reliability. In addition, the method relies on subjective evaluations by stakeholders, which could introduce biases into the results. While the proposed weighting and criticalness factors attempt to mitigate this limitation, there is still a possibility of individual opinions influencing the evaluation process. Furthermore, the method's applicability may be limited to certain contexts and may not be suitable for all types of rural mini-grid businesses. Other contextual factors, such as geographic location and regulatory environment, may need to be considered when using the proposed method. Lastly, it is important to note that the proposed evaluation method only provides a snapshot of a company's business model at a particular point in time. Business models are dynamic and can change rapidly, which means that the evaluation method may not be effective in assessing long-term performance or adaptability.

CRediT authorship contribution statement

Henock Dandena Dibaba: Conceptualization, Methodology, Writing – original draft. **Leticia Tomas Fillol:** Writing – review & editing. **Antti Pinomaa:** Writing – review & editing. **Samuli Honkapuro:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

The questionnaire used for this paper can be found online at: https://link.webropolsurveys.com/S/81D0D871CC7C6507.

Table A1
Summary of the case-by-case analysis.

	Service offer	Customer segmentation	Customer relationship	Key partnership	Resource management	Financial viability
Company A	The company's main service is to provide electricity. According to the company, the electricity supply is adequate and there are few power outages were recorded. In addition, the mini-grid systems are safe for customers and have a minimal amount of environmental impacts. However, the price of electricity for customers is quite high compared with grid connections.	The company does not apply any customer segmentation methods for its customers.	The company has very good relationships with its customers and gives personal assistance and self-service options to handle any requests.	The company has a very strong relationship with key stakeholders, especially with local government bodies, NGOs, technology providers and payment service providers.	Regarding resource management, the company utilises its financial, human and financial resources efficiently. It also responded that all its electrical equipment in use comply with international standards.	The company has difficulties in balancing its finance due to its revenue, but it is highly capable of optimising its costs.
Company B	The company's main service is to provide electricity for rural domestic customers. It also provides technical services and maintenance. The company considers itself to be highly capable of providing suitable and affordable energy supply to its customers.	The company does not apply any customer segmentation methods for its diverse customer groups.	The company has a good relationship with its customers and takes customer satisfaction measures into consideration to improve its service.	In the case of partnership with other stakeholders, the company has developed a very strong relationship especially with local government bodies, financial service providers, data collection partners and payment service providers. It also has a good relationship with other organisations such as NGOs, O&M partners and technology providers.	The company uses its financial and physical resources efficiently and complies with international standards.	The company has a balanced finical status, and it can optimise its costs.
Company C	The company's main service offer is to provide energy management software and smart meters for mini-grid and grid operators. The company regards its product and service to be highly efficient, affordable, and safe. Despite having lots of competitors in the market, the company is constantly acquiring new customers who are seeking the company's product and services. In addition, the company believes that there is room for growth in the future market.	The company applies customer segmentation methods for its customers based on the electricity demand, that is, utilities which serve under-grid customers and mini-grid developers for rural communities.	The company has a good relationship with its customers and provides self-service and automated services. The company is also highly engaged in improving its service to customers by taking customer satisfaction as an input.	The company has a strong relationship with other technology providers, payment service and financial service providers.	The company utilises its resources well in balance. Regarding resource management, the company utilises its financial and physical resources efficiently. The company's smart meters comply with international standards.	The financial status of the company is highly balanced, and it is highly capable of optimising its costs.
Company D	The company provides suitable services for its customers that is operational, affordable, and safe. The company strongly believes that its product improves productive uses and bring social benefits.	The company applies customer segmentation methods for its customers based on load requirement.	When it comes to customer relationship and satisfaction, the company has a good relationship with its customers and takes a customer satisfaction measures into consideration for improving its services.	The company has developed a strong relationship especially with local government bodies, O&M partners, technology providers. It also has a good relationship with financial service providers, data collection partners and payment service providers.	Regarding resource management, the company utilises its financial and physical resources efficiently; And all the company's electrical component in use complies with international standards.	The company is fairly balanced when it comes to its finical status, and it is highly capable of optimising it costs.
Company E	The company provides suitable and affordable services which bring satisfaction to its versatile customers. Its service also enables productive-use	The company applies customer segmentation methods for its customers based on electricity consumption need, trend (behaviour) and capability.	The company has established a good relationship with its customers and takes customer satisfaction measures into	The company has developed a strong relationship with different stakeholders including local government bodies, O&M partners,	The company utilises its financial and physical resources efficiently and can utilise additional financial and human resource if they are available.	The has challenges in balancing its financial situation but takes measures to optimise its costs.

(continued on next page)

Table A1 (*continued*)

	Service offer	Customer segmentation	Customer relationship	Key partnership	Resource management	Financial viability
	cases through its financial and digital service.		consideration to improve its service.	technology providers, financial service providers, data collection partners, payment service providers and NGOs.		
Company F	The company provides top-tier services for its customers and is highly engaged to improve its services. The company's system allows productive use via its distribution network.	The company applies customer segmentation methods for its customers based on electricity consumption need and social values.	The company has an excellent relationship with its customers and takes customer satisfaction measures into consideration to improve its service. The customer relationship includes personal assistance and automated services, and the company has established a long-term relationship with its customers through aftersales services.	The company has developed a very strong relationship with financial service providers and payment service providers. In addition, the company has a good relationship with other stakeholders including local government bodies, technology providers and O&M partners.	Regarding resource management, the company utilises its financial, physical and human resources efficiently.	The company has challenges in balancing its financial status and optimising it costs. However, the company strongly believes that there is a promising prospect of additional revenue stream in the coming future.

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