Energy for Sustainable Development 85 (2025) 101652

Contents lists available at ScienceDirect

Energy for Sustainable Development

journal homepage: www.journals.elsevier.com/energy-for-sustainable-development

Anchor-based mini-grids: (Political) power beyond technology? The case of a mini-hydro scheme in Rural Zambia

Nandi Mbazima [a], Xavier Lemaire [b,*]

[a] Energy Institute, University College London, Central House, 14 Upper Woburn Place, London WC1H 0NN, United Kingdom
[b] Institute for Sustainable Resources, University College London, Central House, 14 Upper Woburn Place, London WC1H 0NN, United Kingdom

ARTICLE INFO

Keywords:
Clean energy access
Anchor-based mini-grid
Mini-hydro Zambia
Impact of rural electrification
Rural energy community

ABSTRACT

An innovative approach to rural electrification advancement has been the development of the anchor-based business model for mini-grids, which adopts a novel approach to delivering electricity to different rural customer segments to achieve a commercially viable project. Mini-grid research focusing on the anchor-based model is gaining traction within the scholarly literature. However, studies largely examine the technical and economic aspects of anchor-based systems and lack an intricate focus on their social and political elements, particularly with respect to understanding the post-implementation development reality of operationalised anchor-based mini-grid projects in achieving sound and equitable electricity access.

Through a qualitative study, this paper presents the results of a case study of a hydro anchor-based mini-grid in remote rural Zambia, that examines the outcomes and proceedings that materialised within the district following the mini-grid's implementation, from a social perspective. Key stakeholder interviews and ethnographic techniques were employed to collect data from the suite of social actors that reside within the mini-grid system, and thematic analysis and critical realism were analytical methods employed to gain insights into the workings of the system, interrelations of the actors, and the underlying mechanisms at play. The results demonstrate that power structures and dynamics, as well as gender and cultural ideologies, are two important mechanisms at play, where various forms of power are particularly significant elements that permeate from the anchor-based system and political power itself is inherent to the anchor-based system.

Introduction

Background

Currently, 773 million people globally lack electricity access, concentrated predominantly in rural Sub-Saharan Africa (SSA) (The World Bank, 2022). For rural and last-mile communities, decentralised mini-grids play an important role in reaching these customers. The mini-grid market has risen from approximately 400 mini-grids in 2009 to approximately 1850 mini-grids in 2019 in SSA (Sustainable Energy for All, 2020). According to the World Bank, there were 3174 mini-grids installed in Africa in 2022, connecting 27 million people to electricity through 6 million connections (ESMAP, 2022). Comparatively, 45 million people were connected to electricity through solar home systems in 2022, while 599.8 million people remained without access to electricity in 2022 (International Energy Agency, 2023). However, to accelerate the pace of rural connections and make progress on SDG7, mini-grid solutions through a panoply of business models are required that not only leapfrog traditional energy technologies but also consider the different local contexts within unelectrified populations. Where innovative approaches have emerged, these are creating service delivery options that confront conventional pathways to electrification (Vanadzina, Mendes, et al., 2019; Vanadzina, Pinomaa, et al., 2019).

A novel approach to rural electrification that has arisen is the anchor-business-consumer business model (herein referred to as the anchor-based model or anchor system), which has been implemented with success in rural India and is gaining traction in East and Southern Africa (Climate & Development Knowledge Network, 2015; Kurz, 2014; Palit & Sarangi, 2014a). The anchor-based model hinges on the premise that supplying electricity to creditworthy rural consumers with high, consistent energy needs – anchor customers – can financially sustain private sector rural energy initiatives. The anchor customer is a business or institution physically established in a rural area that possesses the technical capacity to consume large amounts of electricity consistently.

* Corresponding author.
E-mail addresses: n.mbazima.17@ucl.ac.uk (N. Mbazima), x.lemaire@ucl.ac.uk (X. Lemaire).

https://doi.org/10.1016/j.esd.2025.101652
Received 4 November 2024; Received in revised form 14 December 2024; Accepted 2 January 2025
Available online 16 January 2025

By securing a reliable and substantial revenue stream from anchor customers, rural energy developers can make it economically feasible to electrify customers with lower energy demands (Fig. 1).

Traction for the use of anchor customers for mini-grids for energy access began to develop in the early to mid-2010s, not only around industry anticipation around the anchor-based business model's potential to effectuate bankable rural energy projects (GSMA, 2013, 2014; Kurz, 2014), but also with the emergence of anchor-based projects being implemented (Daniel et al., 2014; Palit & Sarangi, 2014a). This includes energy developer-anchor client partnerships between OMC Power and Bharti Infratel in India (Tenenbaum et al., 2014), DESI Power – also with mobile tower companies – in India (Roach & Ward, 2011; Daniel et al., 2014), and Gham Power with Ncell in Nepal (Craine, 2015; GSMA, 2017).

Within the rural energy access literature, studies on anchor-based mini-grids tend to primarily examine their technical and economic aspects, analysing the feasibility and viability of anchor-based systems and how they can be optimised (Banerjee et al., 2017; Bhattacharyya et al., 2019; Givens, 2016; Gómez, 2013; Ramchandran et al., 2016). While studies exist that explore the various social and socio-political aspects of mini-grids, investigating issues around gender, power relations, institutions, and politics (Ahlborg, 2018; Ahlborg & Boräng, 2018; Ahlborg & Sjöstedt, 2015; Balls & Fischer, 2019; Baraille & Jaglin, 2022; Osunmuyiwa & Ahlborg, 2019, 2022; Winther et al., 2018), they do so more broadly for the suite of mini-grid solutions that exist, and less so for studies that have a primary focus on anchor system development. Further, few studies examine the empiric outcomes of anchor systems post-implementation to assess how the outcomes that materialise facilitate bona fide and equitable access for rural populations.

As such, this paper aims to present the case of an anchor-based system in Zambia from a social perspective. While ZESCO, the state utility in Zambia, dominates electricity generation in the country, the generation capacity from IPPs, alongside some transmission and distribution activities, has increased significantly in recent years (Bayliss & Pollen, 2021). Private sector participation is seen as crucial for building sustainable renewable mini-grids (Bayliss & Pollen, 2021; Kapole et al., 2023). The paper employs qualitative interview and ethnographic techniques to understand the intricate relationships that take place between the system's social actors, and to understand end-user experiences following the advent of electricity with this model. This paper discusses the generative events that transpired, the mechanisms that were triggered, and the outcomes that materialised for the Zengamina anchor-based system.

Literature review

The anchor-based mini-grid model

There is much optimism within the grey and scholarly literature around the potential of the anchor-based business model to enable the development of commercially viable and resilient rural mini-grid systems (Banerjee et al., 2015; Beath et al., 2021; Falchetta et al., 2022; Gammon & Sallah, 2021; Kurz, 2014; Namaganda-Kiyimba & Mutale, 2020; Ranade, 2013; Roach & Cohen, 2016; Roach & Ward, 2011). The basic premise of the model is that a large entity located in a rural area that: 1) has a sufficiently large electricity demand, 2) has a continuous need for electricity over a sufficiently long period of time, and 3) is deemed to be creditworthy, can be leveraged by an energy developer to improve the economic viability of a rural project through cross-subsidisation and facilitate mini-grid connection of all types of rural customers within a given setting. Such conditions must hold to ensure a steady and sufficient revenue stream for the developer, to ensure that the project is commercially viable.

Three main types of customers are targeted: anchor customer(s), businesses, and rural community households. While the presence of the anchor customer is important to a bankable project's materialisation, all customer types have an essential role to play in the energy system. The businesses are important in consuming excess electricity (having a larger load demand than the surrounding households) stimulating local economic development, and conceivably developing to be future anchor loads in the area (thus helping to minimise the risk of anchor attrition); the customers – rural households that typically are the largest proportion of customers – are ultimately the main group targeted for electrification and, expectantly, improved quality of life (Ranade, 2013; Kurz, 2014; Williams et al., 2015; Ramchandran et al., 2016; Robert et al., 2017; Perez-Arriaga et al., 2019). See Fig. 2.

There are two main configurations of the anchor-based system that have been observed. The first configuration administers a traditional mini-grid set up that incorporates generation, transmission, and distribution infrastructure, with direct connections to all three customer segments; the second configuration additionally establishes an energy hub, through which community residents can access energy and electricity services through energy products (GSMA, 2014; Nique & Opala, 2014). The second configuration has been instituted by OMC Power in rural India, where energy hubs are built to provide lanterns and battery boxes to communities near where the mini-grids are located (Shah, 2015) (Figs. 3).

Within the developing country context, the anchor-based model has been successfully implemented in pockets of rural India as well as in several countries in East and Southern Africa. In India, for example, where the rapid expansion of the mobile telecommunication industry has taken place, private companies such as OMC Power, Husk Power, and DESI Power have installed solar- and biomass-powered off-grid renewable energy systems that power mobile telephone towers and rice mills as anchor consumers while powering surrounding businesses and community customers as additional customer segments (Bhattacharyya, 2014; Gómez, 2013; GSMA, 2013, 2014; Guarnotta, 2016; Palit & Sarangi, 2014b; Roach & Cohen, 2016; Tenenbaum et al., 2014). The high population density of rural India where potential anchors can be found near villages, and the advanced telecom industry, have aided the spread of anchor-based systems in India. In Africa, anchor-based mini-grid systems have been implemented in countries such as Tanzania (e.g., the Andoya hydro power project), Uganda (e.g., the Kabunyata solar PV mini-grid), Congo (e.g., Orange telecom towers)[1] and Zambia (e.g., the Zengamina hydro scheme), where a range of entity types serve as anchor tenants (International Finance Corporation, 2012; Kurz, 2014; Lane et al., 2018; Mugagga & Chamdimba, 2022; Payen et al., 2015).

From a financial perspective, the central element of long-term commercial viability of an anchor-based mini-grid project is the anchor tenant's ability to meet its financial obligation through regular payments, irrespective of the anchor entity that is employed; if not, the inherent value of the intended entity as an anchor client becomes negligible (Tenenbaum et al., 2014). Hence, the creditworthiness of a sought anchor tenant is crucial. Constraints to the expansion of anchor-based mini-grids relates to barriers to the influx of private investment, such as a non-conducive regulatory environment and the sparse availability of adequate creditworthy off-takers.

Trends in research

There are several areas of focal attention within the literature studying anchor-based systems. Some studies focus on assessing the technical and economic feasibility and viability assessments of anchor-

[1] See https://www.pv-magazine.fr/2022/07/13/en-rdc-bboxx-et-orange-se-rapprochent-pour-alimenter-les-tours-de-telephonie-en-energie-solaire/.

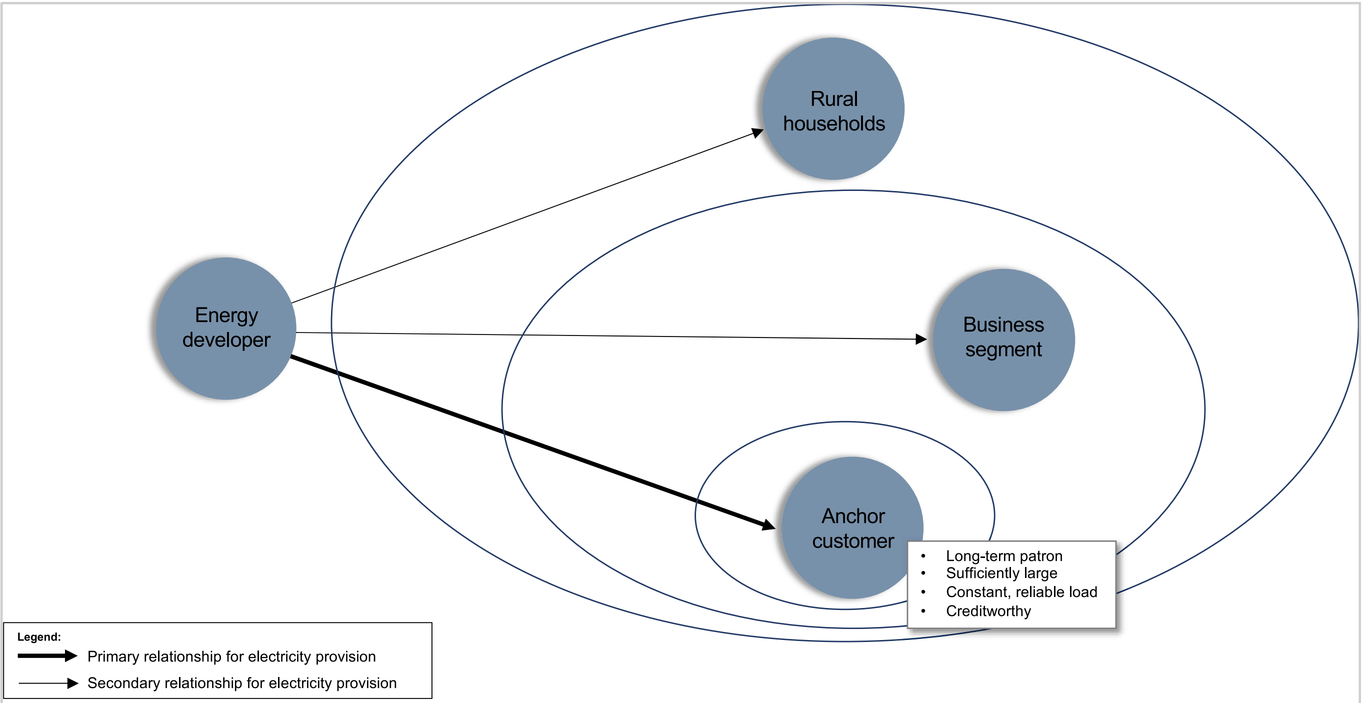

Fig. 1. The anchor-business-consumer model (The anchor customer consumes approximately 20–30 % of the electricity generated by the mini-grid). Source: Adapted from (Mbazima, 2024).

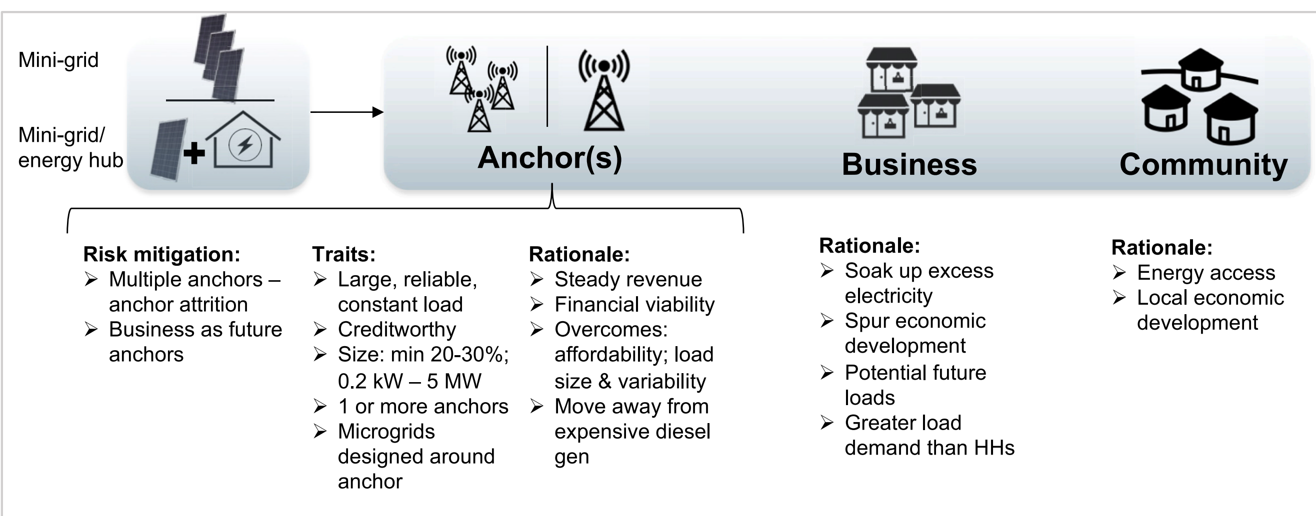

Fig. 2. Characterisation of the anchor-based model. Source: (Mbazima, 2024).

based systems (Ramchandran et al., 2016; Robert et al., 2017; Namaganda-Kiyimba & Mutale, 2020; Robert et al., 2021). They show that incorporation of an anchor load within a mini-grid can lower the average cost of the system and improve its revenue streams, where analyses considered anchors that assumed between 10 and 50 % of load factor.[2] There is some understanding that anchor customers assume at least 20–30 % of the mini-grid's generated electricity for commercial viability to occur (Bamberger et al., 2013; Robert et al., 2017). However, it is noted that subsidies may still be required to improve the financial viability of anchor-based mini-grid schemes (Ramchandran et al., 2016).

Studies have also empirically examined various forms of demonstration projects of mini-grids designed and developed around an anchor customer for rural electrification (Gammon & Sallah, 2021; Lukuyu et al., 2020; Njogu et al., 2017). Lukuyu et al. (2020) examine the potential impact of implementing charging infrastructure for electric fishing boats as an anchor load for an island mini-grid in Uganda, while Gammon and Sallah (2021) similarly investigate the prospect of an electrified taxi cab fleet, acting as an anchor, to generate a commercially viable mini-grid model in the Gambia. While study researchers were

[2] Bhattacharyya et al. (2019) in their study conduct a financial analysis of a solar PV mini-grid that considers an 80 % anchor load. However, they determine that at that load factor, in the operating context of their scenario analysis, project viability will require significant subsidy support (Bhattacharyya et al., 2019).

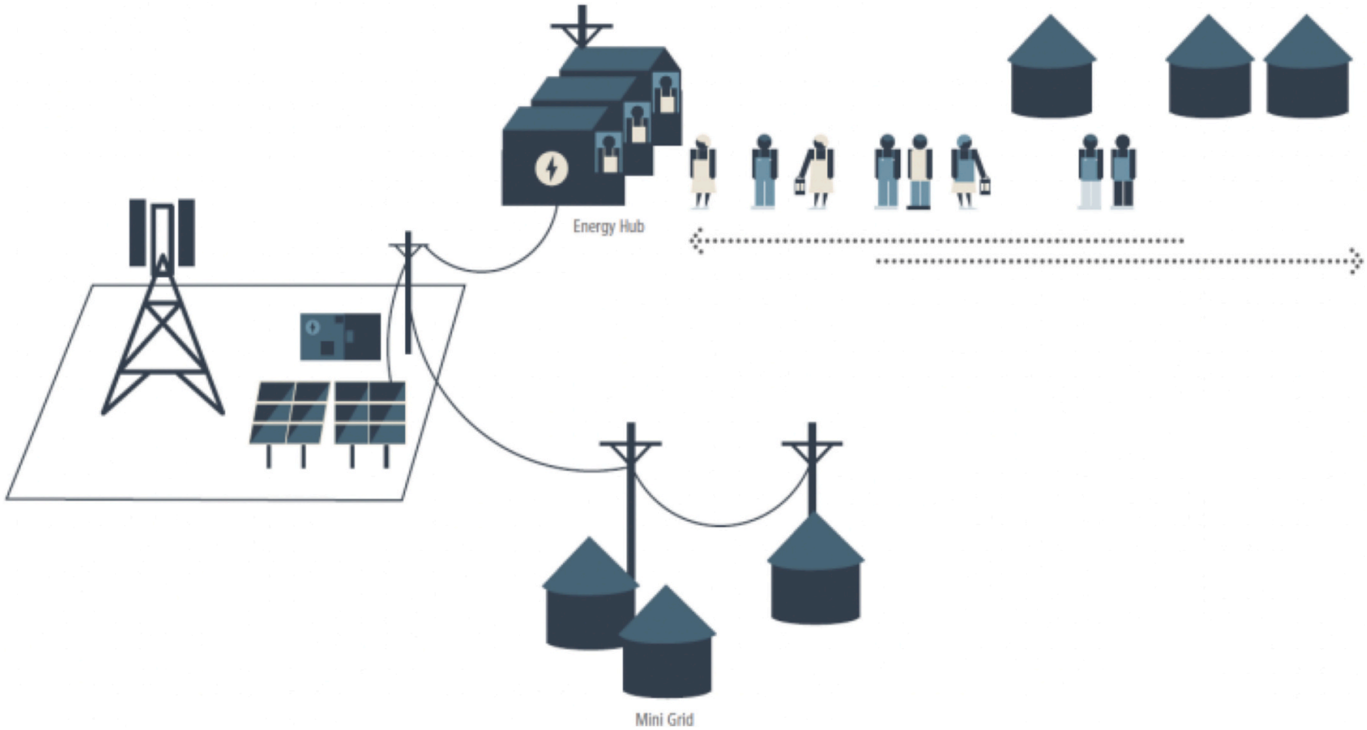

Fig. 3. Mini-grid vs. energy hub configuration.
Source: (GSMA, 2014).

able to obtain technically viable results, commercial and economic viability can vary and depends more specifically on a number of factors, such as access to finance, cost of equipment and fuel costs. Njogu et al. (2017), examining an existing but early-stage community-developer mini-grid model in Kenya with the national utility company as an anchor client, find that access to finance, capacity building measures, and strong community partnerships are important for project and financial sustainability. Thus, an enabling environment through supportive policy and market measures is critical.

While there are numerous authors that explore the social and cultural aspects of rural mini-grid and off-grid energy systems, considering end-user needs and aspirations, expectations, and experiences (Gollwitzer et al., 2015; Ogeya et al., 2021; Osunmuyiwa & Ahlborg, 2022; Pedersen & Nygaard, 2018; Ulsrud et al., 2011; Winther et al., 2018), few studies in the literature do so specifically studying implemented anchor-based mini-grids. This paper thus aims to provide a contribution to this research area, looking specifically at the case of an anchor-based mini-grid in rural Zambia.

Theoretical background

This research employs the Technology Innovation System (TIS) framework to study the development of the anchor-based mini-grid system and the interactions between the different social actors that exist and commune within it. TIS, according to Hekkert et al. (2007), looks to analyse the relationships and activities of the dynamic processes of (and between) actors and institutions centred around specific technologies, that engage with those technologies. This is predicated on the notion that innovation systems are a critical factor in technological change, and necessarily shape them. That is, technological change is not static. Such systems are also industrially and geographically agnostic.

The concept of power, an important concept in political economy, is widely debated and contested in social and political theory, and scholars have explored various conceptions of power. Common themes include power as a causal force, a collective capacity, and a discursive tool (Bachrach & Baratz, 1962; Dahl, 1957; Foucault, 1991; Giddens, 1984; Latour, 1984; Lukes, 2005). These ongoing debates add complexity to understanding and analysing power in empirical research, as different theoretical perspectives offer contrasting views on its nature and exercise. A focus on power as a causal force often centres on agency, where individuals or structures possess the capacity to influence. This is intertwined with debates on power and real interests, power and resistance, domination, hegemony, and violence (Foucault, 1979; Giddens, 1984; Lukes, 2005). This study aligns with the causal perspective of power, where it is possessed and exercised by individuals or shaped by social structures. It acknowledges the interplay between agency and structure in shaping power dynamics and social change, particularly with respect to technological interventions within the context of the energy transition.

Several authors have used the TIS approach to study the development and diffusion of mini-grid electricity in rural societies and looked to understand political economy factors, where this has looked to examine various structures and processes within existing and/or new organisational networks and institutional arrangements (Blum et al., 2015; Fillol et al., 2022; Ogeya & Lambe, 2025). For these studies, the TIS has been used to identify and explain the diffusion rate of mini-grids and how they can be improved, and to assess the performance of mini-grids and ways in which policy adjustments can help overcome identified barriers. This study recognises the TIS as a framework to investigate the complex relationships among social actors and the experiences of end-users in the context of anchor-based electrification in rural North-western Zambia.

Research design and methods

A case-study approach

A case study approach was employed to examine the empirical events and outcomes that take place within an implemented and operationalised anchor-based system in rural north-western Zambia. Yin (2018) posits that case study research constitutes an ideal methodological approach when the objective is to examine a contemporary phenomenon within a real-world context over which the researcher exerts limited or no control. A socio-technical perspective highlights the unpredictability of technological interventions, emphasising the role of human actors in their development and outcomes. Understanding such social and socio-technical phenomena requires studying them in their natural context. Additionally, case study research is well-suited for contemporary events, as demonstrated by the active anchor-based mini-grid project in this study. Further, the underpinning research questions of the larger research project that engendered the findings of the case study presented in this paper – functional "how" and "why" questions – necessitates a case study methodology that explores a phenomenon in its context to better understand its workings and outcomes and conducts explanatory research to determine the causes of its manifestations (Yin, 2018).

Three primary reasons underpin the selection of this Zambian anchor-based mini-grid project – the Zengamina hydropower project. Firstly, most anchor-based projects in SSA are chiefly in East and Southern Africa, offering a suitable context for empirical investigation. Secondly, my familiarity with Zambia's environment, while acknowledging potential biases, provides valuable insights into cultural nuances, local authority dynamics, and geographic considerations. Thirdly, the Zengamina case was one of two case studies that were examined for a wider doctoral research project, the other being the Shiwang'andu hydropower mini-grid project, where the two Zambian cases offered an opportunity to investigate the impact of variation in set-up (e.g. between anchor type and technology type) on the outcomes of anchor-based systems for rural electrification. The Zengamina scheme, as a private sector-led project, offers important insights for efforts to stimulate private sector investment and participation in rural electrification undertakings.

The Zengamina project, located in Ikelenge district in Zambia's north-western province, was commissioned in 2007 (Fig. 4). A privately owned and operated mini-grid, it was developed as a 0.75 MW run-of-the-river scheme to serve multiple anchor clients (a mission hospital, telecommunication tower, and large commercial business), existing small businesses, and rural households within the district. Its preliminary objective was to provide sustainable and low-cost electricity to Kalene Mission Hospital, which had been relying on costly diesel-generated electricity before the advent of the Zengamina scheme, but also to serve the surrounding communities that largely were living without power. At the time of study in 2019, the Zengamina hydropower scheme provided electricity to 740 customers – including anchor customers, social service establishments, large and small enterprises, and residential households. As of 2023, the Zengamina project provides electricity to 1039 customers (Energy Regulation Board, 2023; Rea & Kabiru, 2023).

The Zengamina hydropower scheme was at the time of study, the oldest of only two anchor-based mini-grid schemes that had been established in Zambia, the other being the Shiwang'andu hydropower scheme, a state-led and operated project.[3,4]

Given the complex nature of the research inquiry, a qualitative case study approach is most suitable. This necessarily involves a multi-method approach, including in-depth interviews and ethnographic observations, to explore the relationships between communities, interest groups, and socio-political influences. By using multiple methods, data triangulation strengthens the validity of the findings and deepens the understanding of the case study. In-depth interviews were conducted with policy and non-policy stakeholders at various levels. The aim was to comprehensively understand the context, activities, perspectives, and nuances of social actors. Interviews were conducted in person or via video conference and were recorded with consent. Where necessary, translators were used to facilitate communication. All interviews were transcribed by me as the primary researcher.

Data collection

Qualitative data collection methods were used, including conducting in-depth interviews and employing ethnographic techniques (direct and participant observation) at the project site. 63 semi-structured interviews were conducted, which allowed the collection of open-ended data while still adhering to the scope of data required for collection.

The analysis employed a multi-level analytical framework, considering micro-, meso-, and macro-level factors, where the process of selecting participants differed for the units of analysis for each of the levels.

The primary focus was on the meso-level, examining the social dynamics and outcomes between the various social actors involved. These include the energy developer, rural community members, small and commercial businesses, and other direct beneficiaries who are impacted by the implementation and operation of the mini-grid system. The micro-level analysis zoomed in on specific rural communities, considered as subsets within the larger meso-level system. This allowed for a more in-depth exploration of the social impacts on community members who are the primary beneficiaries of the energy access and livelihood improvement initiatives.

At the meso-level, information on power plant beneficiaries was gathered directly from relevant officials. While specific personal details were not provided, the data was sufficient to represent the range of end-users served. Interviews were conducted with representatives of the energy developer, anchor clients, and commercial businesses. For rural community members, small business owners, school and hospital administrators, and local government and cultural authority officials, door-to-door visits were conducted to ensure fair representation across all community areas within the project boundary. Local government stakeholders were also interviewed through door-to-door visits. Thus, the selection of rural community participants at the micro-level was integrated into the broader meso-level participant selection process.

The macro-level analysis examined the broader socio-political context of the country, including relevant actors like government officials, civil society organizations, and universities. Interviews were directly solicited with pertinent stakeholder groups including government and non-government entities.

Table 1 illustrates the distribution of the various participant types interviewed.

Data analysis

A triumvirate of analytical methods was used to probe the data and answer the study questions: thematic analysis, discourse analysis, and critical realist methods. Thematic analysis was used to identify the patterns and demi-regularities that prevail within the social fabric of the mini-grid system to create a detailed narrative account of the outcomes, processes, and dynamics that exist within the system. Discourse analysis was superimposed analytically to further understand participant motivations, perceptions, attitudes, and decisions related to the proceedings that take place within the system. Critical realist methods were subsequently employed to investigate *why* the observed outcomes, processes and dynamics materialise. This empirical analysis thus provides a holistic understanding and explanation of the evolution of the Zengamina project following its inception and commissioning. The research process is summarised in Fig. 5.

[3] As a privately-owned and managed mini-grid project, the Zengamina project is less unencumbered by the government responsibilities and judgements that feed into the decision-making processes of mini-grid administration. The residents of Ikelenge district were largely unelectrified before the advent of the scheme, so this project is amenable to studying the direct effects of an anchor-based mini-grid electrification.

[4] The Shiwang'andu hydro power project is a 1 MW scheme located in Muchinga province in the northern part of Zambia and commissioned in 2012. See (Mbazima, 2024) for further details.

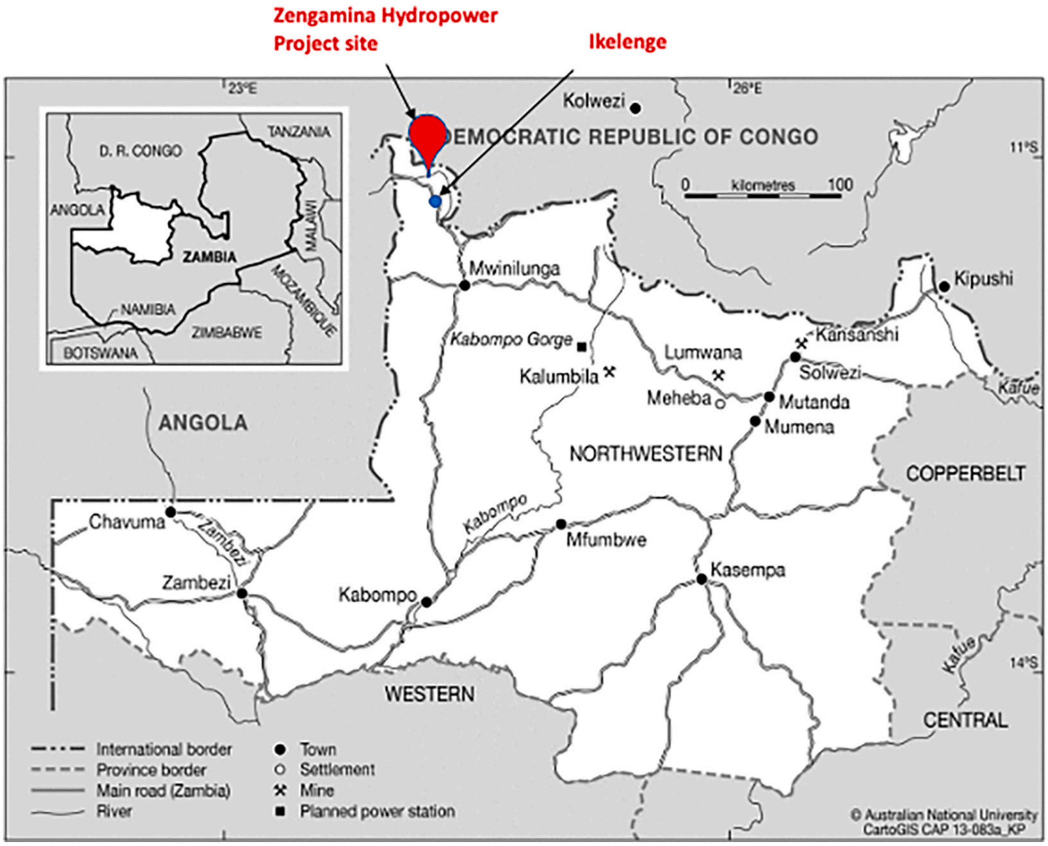

Fig. 4. Geographical location of Zengamina hydropower project.
Source: Adapted from (Phillips, 2019).

Table 1
Interview distribution by actor type, analysis level, and language interviewed.

Category	Type	Frequency
Actor Type:	Anchor	4
	Energy Developer	3
	Government Stakeholder	3
	Hospital	1
	Large Business	1
	Non-Government Stakeholder	4
	Rural Community Member	31
	School	7
	Small Business	9
Analysis Level:	Micro	31
	Meso	25
	Macro	7
Language:	English	50
	Bemba	11
	Bemba/Nyanja	1
	Lunda	1

Ethical considerations

This research adhered to the ESRC Code of Ethics and received ethical approval from the BSEER Research Ethics Committee at UCL. In addition to UK ethical approval, local ethical approval was obtained from the HSSREC at UNZA. Informed consent was obtained from all participants in this study, either in written or verbal form. Prior to participation, each participant was provided with a Participant Information Sheet and a Consent Form, and the details of these documents were discussed to ensure a full understanding of the study's purpose, participant rights, potential risks, and confidentiality measures. To maintain anonymity, personal and sensitive data was anonymised, and each participant was assigned a unique participant ID. Any publications or workshops arising from this study will continue to uphold strict confidentiality. To further safeguard participant data, the project was registered with the Data Protection Office, a Data Protection Impact Assessment (DPIA) was conducted, and UCL insurance was acquired to address potential contingencies throughout the fieldwork period.

Limitations of the data

The fieldwork was conducted in the fourth quarter of 2019, just prior to the COVID-19 pandemic. Due to subsequent travel restrictions, additional fieldwork was not possible in-country, which was a generalised ban on all research activities. In 2023, additional data was obtained from the project's directors to at least understand the scope of changes to the project from a service delivery perspective. Based on the data received, there was an uptick in the total number of customers who were receiving electricity from the Zengamina mini-grid from 740 to 1039 customers between 2020 and 2023. However, this was largely attributed to an increase in the number of metered residential customers and small enterprises. While there was an absolute increase in the number of end-users in these categories, the proportion of customers in these categories against the total number of customers served remained the same (95.7 % in 2020 vs 95.4 % in 2023). The number of anchor customers remained the same in this timeframe. Thus, even accounting for temporal changes and related sensitivities, the conclusions of this paper pertaining to the distribution and exercise of power remain valid. Notwithstanding, it is accepted that there may be variations or additions to the findings that could come from analysing more up-to-date data. Further research can build upon the existing data to boost validity and explore further lines of inquiry.

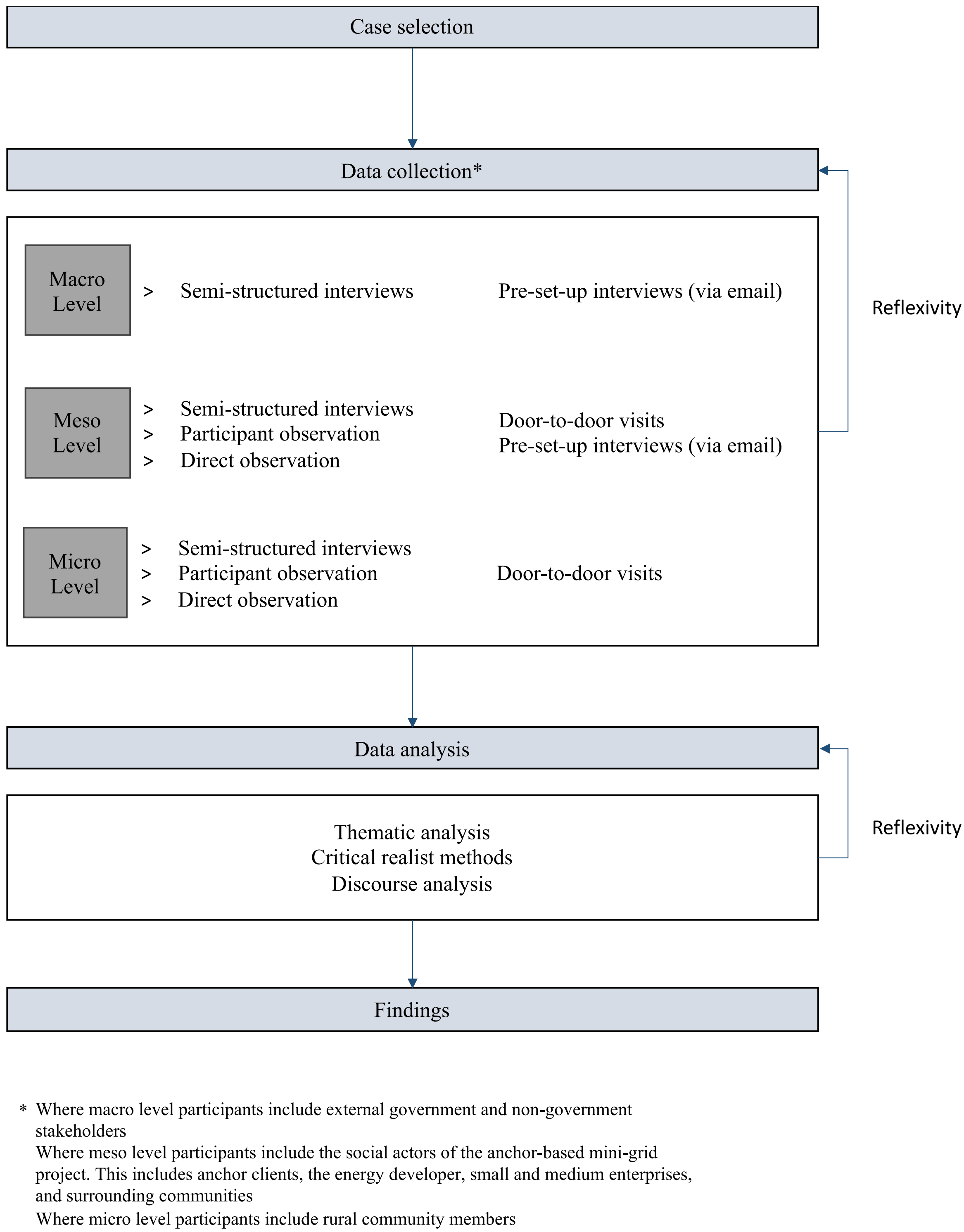

Fig. 5. Case study research process.

Findings

The workings of the Zengamina Hydropower project

The Zengamina scheme was set up as a run-of-the-river hydro mini-grid project, commissioned in 2007 as an independent private power producer (Figs. 6-7). The initial motivation for the project's development was to provide low-cost sustainable power to the Kalene Hill Mission Hospital to expand and sustain its medical services. However, the project was modified to include the electrification of the surrounding communities and businesses and extend the benefits of electricity use to the wider populace. The project initially sought to provide electricity services to the hospital, two telecommunication towers, and a commercial farm as anchor clients. Today, the project provides electricity to three priority customers – anchor customers – that together consume 45 % of the electricity generated, and this enables cross-subsidisation of tariffs for the different customer segments. The highest tariffs are borne by the anchor customers, followed by small and large enterprises, and

Fig. 6. Bird's eye view of the Zengamina hydropower scheme.
Source: (North West Zambia Development Trust, 2013).

Fig. 7. Powerhouse structure with generation machinery at Zengamina hydropower station.
Source: (Mbazima, 2024).

the lowest tariffs paid by community establishments and local residents (Energy Regulation Board, 2019).

Following the advent of the Zengamina project, six important generative events can be identified that were realised within the Zengamina anchor mini-grid system that together culminates in the processes and outcomes that materialise post-implementation. These are: 1) consultations and engagements with the community; 2) pre-construction and construction of the hydro project; 3) the hydro system as an "infrastructural organism"; 4) connection to the hydro system; 5) expansion and creation of SMEs; and 6) a change in schema and new way of life. These events materialise consecutively, although they can overlap, at the heart of which lies the *infrastructural organism* – the 'living' hydro power structure that includes the physical elements, social objects, and interactions involved in the day-to-day operation and management of the mini-grid (Fig. 8).

Consultations & engagements with the community

A mandatory requirement of all energy infrastructure projects in Zambia is community consultation with local residents and intended beneficiaries, to create awareness and sensitisation around the implementation of such projects. This was the initial process that started to develop a relationship between the energy developer and the local community that would feed into various succeeding events and interactive dynamics between the two social groups. At Zengamina, this process provided the conditions through which not only *trust* began to manifest through interrelations between the two social groups through a mode structure in which formal discourse could take place, but also established *hope and optimism* from the community standpoint in the welfare and livelihood benefits the power station would bring. This is also a cogent argument for the heavy involvement of local community members in the preconstruction and construction phases of the hydro project, which was instrumental in the project's fruition.

Pre-construction and construction of the hydro project

Local labour was heavily involved in the pre-construction and construction phases of the Zengamina scheme, including mostly general and some semi-skilled men and women who participated in bush clearing, digging, blasting, bricklaying, and other civil work activities. This took place over three years from 2004 until 2007, when the hydropower plant was commissioned, where labourers worked on average six days a week during this time. From the energy developer's perspective, this process embodied unification among residents; this is expressed in the following excerpt: *"The whole scheme had taken shape and was well advanced with little or none of the normal civil engineering resources that would be available in the UK, such as mechanised equipment and a skilled and experienced workforce. Most of these local people had never had any paid employment in their lives and certainly had not constructed anything like this before. However, they were constructing this major project using only basic tools and minimal mechanical assistance, all guided by one or two engineers who gave their time voluntarily. […] This was hot, heavy, noisy and*

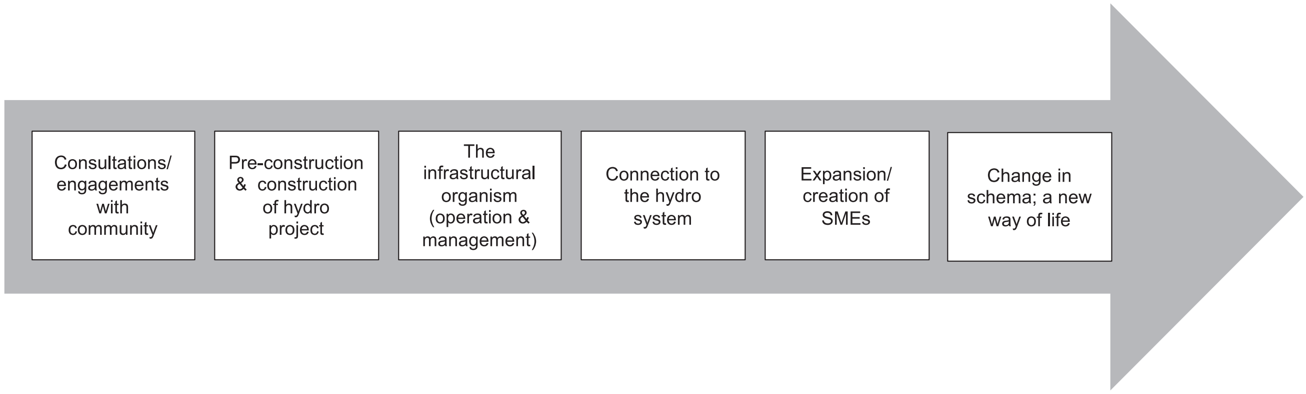

Fig. 8. The generative events within the Zengamina anchor system.
Source: (Mbazima, 2024).

very dusty work. At the other end of the canal in the header pond area, a group of women were hand-sieving crushed rock, all singing in rhythm with the backwards and forwards swinging of the sieve. It was wonderful to see their happy, smiling faces and listen to them as they worked so enthusiastically. Already, I felt that it was a tremendous privilege to be a small part of this project and to be present to witness the work as well as to see the tangible benefit it was already bringing to the local community in proding them with employment and a pride in what they were helping to create" (North West Zambia Development Trust, 2006, p. 3).

From the community perspective, there were aspirations of a better way of life for residents with the possibility of electricity access:

> *"In fact, most of works at Zengamina hydro power plant, was done locally. Yes. The only thing which we just saw was that the blasting they would bring the blasters, but they brought someone, trained in blasting then with the locals. Then, ladies, gents were employed. Local people were doing the works, and that's how it moved. I saw it being done, and, I saw it coming out. Before electricity, before Zengamina, life was not good for Kalene. Life was not good for the community. Coz the community here had not even experienced any day of having power in the community. They had been seeing it when they moved out of the area, how... when it came for, the moment it came out, the community also started benefiting, and life became easier." – Interviewee 33b.*

There is a confluence of viewpoints in this regard that there was enthusiasm and affirmative expectation that in realising the hydropower project, livelihood improvement would follow. The foregoing events of community consultations and engagement that prospered an initial robust developer-community relationship, to build a sense of trust that developed into heavy local participation in the construction of the hydro mini-grid project, is ratiocinated to have engendered the conditions of hope and optimism within the environs of the project.

The hydro system as an "infrastructural organism" and connection to the hydro system

The successful working of the hydropower system to deliver adequate electricity service provision depends on the decisions and actions of the social actors who operate the system in conjunction with the physical performance of the system's infrastructure (this includes the physical set-up of the generation, transmission, and distribution components). How the system altogether (socio-technically) performs may affect the outcomes that are realised within the system, but is also itself affected favourably or adversely by exogenous factors, such as concerning the level of water availability due to weather variability. Within the Zengamina project boundary, the functioning of this infrastructural organism has had a marked effect on the local community's ability to access and use electricity: some can get and remain connected to the hydro system – the *'always connected'*; some can initially get connected but eventually are disconnected from the hydro system – the *'disconnected'*, and some are unable to connect to the hydro system and attain the benefits of electricity usage – the *'unconnected'*. Each segmented group navigates electricity access (or lack thereof) differently.

While the *'always connected'* can sustain electricity access to the Zengamina scheme, there are still wealth disparities within that group that create varied perceptions about how electricity provision is brought to bear. The *'always connected'* include anchor clients, traditional chiefs, and government representatives, but the larger proportion of this group are community members who largely assume agrarian work as farmers, working a subsistence life to support themselves and their families and hoping that any surplus produce can be sold for income. There is a strong collective consciousness that the more affluent among them have discernible clout on electricity use and the proceedings that take place within the community. This is not just assumed by the "less-affluent" populace, but by the affluent beneficiaries themselves.

For the *'disconnected'* and *'unconnected'* segments of the population,[5] the physical set-up of the grid has resulted in the spatial movement of people within the project domain with respect to how they receive or would like to receive electricity. This has led to two occurrences: the first being the effect of separation experienced between those who receive access to electricity and those who cannot, and the second being that the migration of residents to new areas with the district, in an attempt to attain electricity services, has produced an altruistic appreciation of the populace all benefiting from electricity use, but also a sense of apprehension that there is now greater competition for resources within a given area. What emerges from these activities is a sense of segregation by those who do not benefit at all – the *'unconnected'* – but also those who do, with respect to new dynamics that come into play with new geographical arrangements. Additionally, participants – particularly those that are unconnected – reported a sense of frustration around a delay with not being given timely access to electricity services:

> *"Because she paid for that one, and she has been not attended to, on time. So she has long to wait for that pole to be separated. So, so she's saying Zengamina is not all that serious, to the customers" – Interviewee 48.*

> *"Because as you can see there are houses behind, more especially behind us, that are looking for the services also. But they are not yet connected. They started requesting for the power, some are even five years. They've just been struggling. They haven't been attended to." – Interviewee 17.*

[5] To provide a sense of the proportion of electrification in Ikelenge district, the estimate of the population of Ikelenge in 2019 can be calculated to be 41,811 (based on population information from the Zambian 2010 and 2022 Censuses of Population and Housing). According to Liu et al. (2019), approximately 30,000 people benefitted from electricity connections made in 2019 from the Zengamina mini-grid.

In Ikelenge, where a delay in service delivery has built up frustration and dissatisfaction sentiments, this has led to the set-up of illegal connections to syphon off electricity. This is, however, also because of residents who set up illegal connections because they fundamentally cannot afford the costs of attaining and sustaining these services. It emerged that a seeming lack of enforcement by the project operators on this issue enables the interlaced network of bona fide and illegal connections to persist:

"And also the wiring, no one is checking the wiring of these houses. All the meters are being bypassed and all sorts of stuff. So it's... I wouldn't want to be in [his] position [...] Because, his situation is now, they will put power lines in adjacent to his, uh, and ... it's difficult, because he, when he allowed all these house connections, there's been no policing" – Interviewee 53.

Interviewee 25: "At times, I've seen those who are not connected tapping into the electricity from those which are connected.
Interviewer: Okay, but with the knowledge of the people who are connected?
Interviewee 25: Yes [...].
Interviewer: Okay. But if you do that then, who pays for the electricity? The people who are connected?
Interviewee 25: Mmmm, the people who are connected, but again, even the one that taps also contributes [to his neighbour]".

Expansion and creation of SMEs, a change in schema, and a new way of life

The materialisation of a hydro-powered mini-grid in Ikelenge society has ultimately seen some elemental shifts in the community lifestyle and shifts in daily patterns. For instance, it has resulted in the replacement of the daily manual husking and grinding of maize into mealie meal – a staple food in Zambia that is ground, prepared, and eaten every day – by its processing through hammermills. This has freed up constructive time that can be used productively for alternative activities, particularly where this work is largely assumed by women who largely function within the "unpaid economy" (work associated with the household, productive work and community work) (Johnson et al., 2019, p. 170). Further, prevailing ingrained structures of cultural and social ideologies can influence how women can benefit from electricity use. Some participants raised the issue of the need for women empowerment and the need for it to take effect within the community to improve the equitability of benefits for end-users.

Through six generative events, certain conditions were triggered that include trust and optimism, power shifts, lack of enforcement, segregation and dissatisfaction, and lifestyle shifts and patterns (Fig. 9). These have together shaped societal actors' perceptions, attitudes, and actions, and altogether trigger the mechanisms of coercive power and power differentials as well as culture and gender ideologies; these are discussed in turn in the following section.

At the interface: a discussion of the significant relationships observed between the social actors of the anchor-based mini-grid

As Norman Long submits, the 'social interface' is the juncture where discrepancies in values, interests, knowledge, and power between social groups are most pronounced (Long, 2001). The empirical analysis of the Zengamina anchor-based project reveals a complex interplay of diverse interests and motivations among the key actors of the mini-grid system. The realisation of these interests is contingent upon the distribution of knowledge and power, which varies across the different actors. These power dynamics, characterised by disparities in knowledge and influence, significantly shape the actions and outcomes within the system. The most significant findings from these relationships pertinent to understanding the power interactions between the actors of the anchor-based mini-grid are discussed in this section.

Interactions with anchor tenants

Anchor tenants for the Zengamina project have a strong historical connection to the region and have played a pivotal role in initiating the mini-grid. This connection between the anchor client and the project developer could potentially impact the power dynamics within the system. Anchor customers are driven by the economic advantages of grid-based power over alternative sources like diesel generators or solar panels. Although the developer professes impartiality in power allocation, informal channels suggest that anchor tenants may retain priority access during periods of capacity constraints.

Interactions with energy developers

Regular interactions between the project developer and beneficiaries are facilitated through physical connections and disconnections of domestic and business establishments to the mini-grid, payment of electricity bills, and organised communication channels between the mini-grid company and its customers. In Ikelenge, representatives of the mini-grid company engage in regular payment collection activities from

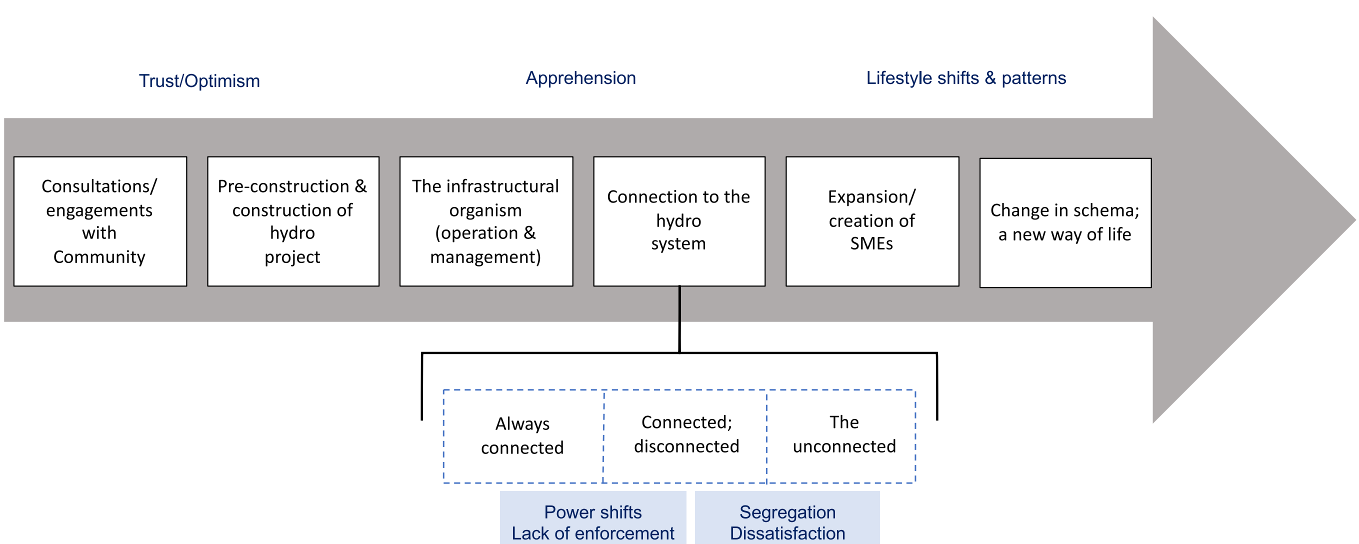

Fig. 9. The generative main events and manifested conditions, in the Zengamina anchor-based system.
Source: (Mbazima, 2024).

connected customers. These representatives possess full access to the payment information of their assigned customers and are responsible for transferring the collected funds to the company's main office. This practice confers significant authority and control upon the representatives, who can potentially leverage their knowledge of customer account transactions. Moreover, rural customers often lack a comprehensive understanding of their billing statements, creating a knowledge disparity that can be exploited by the representatives.

Formal communication channels between the relevant actors are often considered unreliable and exacerbates the issue. Customers may seek resolution through service agents, the main office, or direct interactions with company representatives. Despite these avenues, many rural and small business customers' complaints and requests remain unaddressed, leaving them feeling marginalized and powerless.

Rural community members also interact with trained staff members of the energy company during the formal application process for electricity provision. However, the physical presence of the infrastructure (or lack thereof) can facilitate informal connections, where some residents bypass the official process and establish illegal connections to the power lines. This can result in unpaid electricity consumption or increased costs for legitimate customers. Those who are unable to access these informal connections are left waiting, creating a social divide within the community.

Interactions with SMEs

The daily interactions between SMEs and their customers can foster community resilience. During power outages, businesses, particularly those selling perishable goods, must find innovative solutions to mitigate losses. Some shop owners collaborate with rural community members to sell their products directly, often at discounted prices, to prevent spoilage and maintain revenue. This strategy not only helps to mitigate losses but also strengthens the bond between the businesses and the community, demonstrating the power of local networks.

Interactions with (and between) community members

Within communities, social exchanges and trade, facilitated by electricity access, occur regularly. A significant portion of the rural population remains unconnected to the electricity grid, primarily due to pending applications or affordability constraints. This coexistence of connected and unconnected households results in both cooperative and conflictual dynamics. Cooperative behaviours include sharing electricity, often involving negotiated payments. Conflictual situations, though infrequent, may arise from minor incidents such as theft or disputes over resource sharing.

Interactions with government stakeholders

Government representatives stationed within the anchor system interact less frequently with other social actors regarding the day-to-day operations of the mini-grid. Their primary role involves pre-implementation engagement with local leaders and community members to secure buy-in and address concerns. In Ikelenge, the perceived inadequacy of the mini-grid's capacity has prompted government consideration of extending the national grid, leading to discussions with the energy developer on potential synergies and cooperation.

The mechanisms triggered within the Zengamina anchor-based mini-grid

Power dynamics and power differentials

Via precedence anchor client relationships. Inherent in the anchor mini-grid business model is a reliance on an anchor client or a set of anchors to enable the financial viability of the mini-grid system. Thus, such systems may raise issues of priority related to the distribution of electricity among the different customer bases (i.e., the anchor clients, businesses, and rural households). At the Zengamina project, there is a perception among beneficiaries that some customers are given undue preference over when power is given or the share of power that is given. In this case, power dynamics become perceptible during load-shedding incidences. For instance, a representative of the pineapple factory, considered an anchor entity when in operation, conveys:

> *"So I'm busy communicating to [him] to ask him if he can trip the power in the morning, as we are chopping [pineapples] and putting them into the dryer, then we have power in the afternoon until 22 hours. [...] So he was like he would have communicated before he sent the message [about load shedding] to customers. Because if they change [the load shedding] schedule again, they'll say 'Zengamina, you're [not being serious]" – Interviewee 52.*

This consumer understands his position of authority, and his ability to modify electricity service delivery, during periods of constrained capacity, to suit his business operations. Further still, such beneficiaries can employ alternative electricity options – such as diesel gen-sets and solar home systems – in the event of load-shedding incidences. Where the hydro system is the sole option for electricity access, load-shedding incidents coupled with shifts in electricity availability can increase the variance in how electricity is accessed and who gains.

What the interviewee is explaining in this extract is that they can arrange a conducive time period in which load-shedding by the mini-grid developer can be carried out, so that their business is not unsuitably disrupted. As a result, the business can strategically plan its business operations to keep down cost and productivity losses. While the pineapple factory maintains this especial interaction with the energy developer Zengamina Power Limited (ZPL), not all electricity consumers have such a corresponding relationship. Messages are in principle sent out to all electricity users ahead of load-shedding periods, but for this small business baker, load-shedding incidences have had a particularly detrimental impact on his business:

> *"Ah, but the challenges we are facing is only on, eh, the way power goes. Yeah, the way power goes. Sometimes today they'll give you a notice, tomorrow they won't. So as a result, at the bakery, we normally go in [batches]. There are a lot of bread, there are a lot of buns, they're damaged. [...] We just have to throw them away, so it becomes difficult. It becomes a challenge to us" – Interviewee 45.*

He goes on to explain that his complaints about his difficulties to ZPL are not fully considered:

> "*Yes we've been complaining, yeah. The complaints have been taken. Sometimes you find that there even has bread inside [the oven], without notice you even [lose] power. Then when you say okay just give us 30 or 40 minutes, so that we can be done with our products, they just say 'uh uh, this is an emergency problem, we didn't know that the power will go'" – Interviewee 45.*

The issue of absent alerts about load-shedding incidences and complaints about load-shedding ramifications is echoed by other participants who were interviewed, including rural community members, where the associated experiences of these consumers have built a perception of an energy service provider that does not fully subsume the needs of the customers it serves.

Via the privilege of alternative source capabilities. Wealthier residents and some establishments in Ikelenge district can limit or avoid the disruptions of load-shedding given their ability to adopt and switch to other modes of power to enable uninterrupted electricity provision. Kalene Mission Hospital, an anchor client for ZPL, employs diesel gen-sets to facilitate the continued use of equipment and systems that require electricity. Sakeji School, located approximately 20 km away from the hospital, also possesses additional power sources that include diesel gen-sets and standalone solar systems. They are used to power some of the school's activities through load-shedding events – such as its cafeteria meal service, lighting, and printing and charging services – but also to independently sustain the needs of certain buildings, such as the computer laboratory for students. For these residents, the introduction of a hydro mini-grid has meant the opportunity to shift away from expensive or unsustainable sources of energy that have been employed to maintain day-to-day necessities. Yet, this choice accessible by some customers also highlights the division between those who have and do not have the ability or privilege of continued power – **wealth disparities** – to sustain electricity benefits through load shedding incidences and avert any adverse implications.

Via implications of decisions made by the energy developer. While the introduction of a long-term source of hydro-generated electricity has revolutionised the lives of many Ikelenge residents, not all rural community members are connected to the mini-grid. While there remains a segment of the population within the project vicinity that is unconnected due to affordability issues, there are also residents who want and relay their ability to afford electricity but are not receiving the service given a lack of cognised effort from the energy developer, in the eyes of these residents:

> *"The [issue] that he's speaking [about], since from here to the hydro [power station], it's ten kilometres. So there's a nearby village, those nearby villages, especially Musongwa, which is about seven kilometres from here. Ya, they need electricity, very much. But they've never been given the opportunity to have electricity. […] I don't know the reason, that's why he's… people are complaining to say, "why are you not giving us electricity?"" – Interviewee 06.*

Illegal wires tapped along legal transmission lines are sometimes configured with the consent of end-users who have been set up by ZPL, with costs shared between the two parties. Thus, unconnected communities can be subservient to the actions of the energy developer which can inadvertently disadvantage intended recipients.

Gender and culture ideologies

Traditional and gender norms within Ikelenge society were important themes that emerged concerning how the benefits of electricity from the Zengamina mini-grid are received and enjoyed by residents within the project setting, but also concerning why, for instance, certain outcomes such as productive use of energy has not materialised.

There is a strong sense of distinction in the roles that women and men each assume within the local communities. Routinely, in the environs of the different villages, women were at the helm of the household activities and work being done, such as cooking, pounding maize into mealie meal, tending to chores around the house, and being at home with children, while men who were present around the home were generally the elderly, retired or typically idle (home from work or on leave). By and large, within this setting, women are commonly accustomed to running and managing a household, while men are habituated to duties such as tending to fields as farmers or running bakeries and grocery stores as business owners – acting as the financial provider for the household. The well-defined roles of men and women within these local communities are representative of how local community members also perceive their distinct functions, outlooks, duties, or responsibilities. For instance, in explain the history and development of Kalene Mission Hospital, one interviewee expressed:

> *"Despite [him]being a man, it's like there were more of ladies than a man in the hospital. So, um, as usual, they had their own vision, and their vision was clinical care, and not infrastructure development." – Interviewee 33.*

And these outlooks extend through the generations of current working men and women to the prospects of younger boys and girls, but there is a recognition that women empowerment would not just lessen gender inequality, but would also be beneficial for community members in maximising the benefits that can be accrued from having a hydropower station that provides them with electricity.

> *"And the most effective are the girls. Because every girl goes to school as a secondary issue. You know, I have met with fathers to say okay, he comes and he says 'okay, I need a loan for my son' and I say, 'your son's aptitude is lower than your daughter's.' 'No I want to put my son through' […] I'm trying to change the mindset to say girls are not a commodity. And we still have that in Zambia. They're like a commodity. […]. You know, they're so much brighter." – Interviewee 53.*

There is an evident perception that the differentiation of roles within these rural societies where women and their duties are deemed subservient in narratives and efforts to increase electricity access restricts compelling progress in rural contexts. The literature has demonstrated that such cultural and gender doctrines can influence the behaviours and choices that rural residents make concerning increased and equal access to electricity; such social structures are recognised within the contexts of the Shiwang'andu and Ikelenge communities, and thus serve to influence the magnitude of the effects engendered by the arrival of the hydro mini-grids.

Electrification outcomes in Ikelenge district

The arrival of electricity from the Zengamina mini-grid has brought about several benefits and challenges to Ikelenge community members that are not uncommon to outcomes of mini-grids that have been reported for mini-grids implemented under alternative business models (see for example, Ahlborg & Sjöstedt, 2015; Carabajal et al., 2024). For the Zengamina scheme, electrification has brought about substantial positive socio-economic impacts and precipitated certain challenges to Ikelenge's inhabitants[6]; the ensuring subsections illuminate the most pronounced outcomes established through the data collection and analytical process.

'From darkness to light': Most local residents in Ikelenge district were living without any steady form of electrification before the development of the mini-grid. The advent of electricity has resulted in the ability to attain basic electrical needs such as lighting and phone charging and has resulted in significant positive change. As one resident explains:

> *"But the biggest impact that it's had [is] for the community. {…] And I don't think anywhere else in the world actually realises the impact, of electricity, that it can bring. […] [We used] woodstoves. Those are charcoal irons. Um, up until six years ago we were ironing the clothes with those (points to manual iron plates that had to be manually heated up). Stuff like that, people don't have any idea. […] Yeah, you know, the main thing is that it's looking after the local community. It has revolutionised a lot of people's lives" – Interviewee 33.*

Electrification is now used for applications such as cooking, lighting, heating, ironing, refrigeration, "entertainment",[7] and e-learning. This has generated co-benefits that could not have been acquired without electricity, such as carving a path for additional subjects such as Computer Studies being part of the school curriculum, and night schooling that has been taken up by residents in the area.

The movement of people: An unanticipated outcome following the development of the mini-grid project was the spatial movement of people within and outside the project's infrastructural boundaries to be within proximate access to transmission lines and poles. This was

[6] The participants who took part in this study represent a range of stakeholders that include rural community members, small business holders, large commercial business members, anchor energy system developers, and local government officials.

[7] "Entertainment" was described by participants as the use of devices such as radios and television sets which can be enjoyed in group settings.

perceived to be both positive and negative by local community members who were interviewed, where some residents viewed this type of migration as constructive given their position that the electrification scheme should provide welfare benefits for everyone; other residents perceived that the resettlement activity would result in heightened competition for land, products, and services.

Other positive outcomes: The development of small-scale enterprises, job creation, and opportunity cost and cost savings are other notable outcomes that were observed to materialise by those who are connected and receive electricity. Electrification has enabled the proliferation of small businesses such as welding, hammermilling, the opening of barbershops and hair salons, and entertainment businesses – businesses that are now easier to open, run, and provide a greater service offering on a more economical electricity source. A substantial job creation occasion took place during the pre-construction and construction phases of the mini-grid project, with several job opportunities persisting for local community members during the current operation and management stage of the project. Electricity use has resulted in important cost savings and alternate and productive use of time that, at the Zengamina hydro scheme, has included time saved through refrigeration capabilities, and productivity gains through extended study hours for children and adults due to lighting.

Despite the significant positive impacts that the Zengamina mini-grid brought to Ikelenge inhabitants, there are certain prevailing challenges that exist within the system, some which present grievances for electricity consumers, and some which are pertinent to the set-up of anchor-based systems.

Illegal connections and the 'unconnected'**:** For many rural residents in Ikelenge, electricity access remains elusive for two main reasons. The first is due to affordability, where many unconnected residents simply cannot afford the cost of connecting to the mini-grid and sustaining the cost of electricity services. The consideration by the developer of flexible payment structures and the availability of microfinance options may potentially alleviate this issue. The second is due to a perceived delay or lack of service delivery by keen residents who have requested a connection to the mini-grid.

This has resulted in a contiguous network of unauthorised cables that have been set up adjacent to the formal electricity transmission lines that have been erected, where residents syphon off electricity and gain access to the benefits realised by formal customers. This is a source of contention for the developer, but similarly a frustration for residents who are eager to benefit from electricity access; an improved understanding of the nuanced and heterogenous needs and hardships of residents can help refine how to deliver a more flexible service delivery offering.

Loadshedding**:** During the time of site visits, the mini-grid had several load-shedding events that meant that it had to deliberately shut off the provision of power supply to some segments of its customers along certain sections of its grid infrastructure. This was due to low water supply from weather pattern variations that then engendered power constraints. Particularly, these types of occurrences in the anchor-based system are where one may observe the clout of the anchor tenant; in the Zengamina mini-grid, it was observed that an anchor client strove to influence, not the share of power available, but the timing at which power was available to optimise on how its business could perform. Whether or not its exertion of power was productive in that instance, it brought to the fore the special relationship that exists between the energy developer and the anchor tenant.

Productive use of energy**:** An anticipated outcome of the anchor-based business model is that it instigates productive uses of energy (PUE) – motive power – in the rural setting in which it is implemented, to spur localised economic and social development. However, PUE was absent within the district and was not brought about by the introduction of the Zengamina mini-grid. While this research assignment did not endeavour to inquire in detail the grounds for why PUE did not materialise, key questions arise: Is there a set of requisite conditions, notably related to gender, that need to exist for PUE to emerge? In the presence of such a set of requisite conditions, is there a desire within the anchor-based system for PUE to take place? This would be important to probe in future research.

Fig. 10 depicts the phenomena that occurred within the Zengamina anchor-based system.

Discussion

In the delivery of a rural mini-grid through an anchor-based business model, the Zengamina scheme has attained an important economic benefit for the system. It has enabled cross-subsidisation of tariffs for the different customer segments that it serves, which works to provide a high but stable tariff for the anchor client that counterbalances the lower tariffs paid by rural residents and smaller businesses. This is important in counteracting financial impediments that typically arise from serving low-income rural dwellers without the assistance of ongoing grants or subsidies, as is buttressed by the literature that affirms the economic advantages of implementing anchor-based systems, particularly where anchor loads attain an electricity demand of at least 20–30 % (Zengamina's anchor clients consume 45 % of the electricity generated) (Bamberger et al., 2013; Robert et al., 2017).

Examining the development of the Zengamina anchor-based mini-grid demonstrates that several effects are engendered beyond the aspirations of delivering a financially sound electrification project. Power dynamics are present within the anchor-based system that manifest in several ways. Distinct to the anchor system, priority is given to the anchor clients during times of power constraints by virtue of the preceding anchor-client relationship that has been established during, and is inherent in, the set-up of the system. This leverage of the anchor client is recognised by community members and businesses within the district, where this type of power is perceived as a privilege that affects electrification affairs but also other aspects of Ikelenge's social life. Power dynamics also manifest through the relationships that take place between the developer and its beneficiaries (mainly concerning end-users who are categorised within the 'community' customer category) and through wealth disparities with respect to interrelations between types of community members (between those who can and cannot afford alternative electricity sources).

While these forms of power are not specific to the anchor-based system (see Ahlborg, 2018), they are established empirical findings in the Zengamina project, particularly when discussing balance and fairness of electricity use. This point is also of value to the other mechanism triggered within the Zengamina project – that of gender and culture ideologies, that can tilt the balance of power within households such as through decision-making abilities, that then in turn affect the equitability of electricity use. The fieldwork has highlighted that political power, thus, is an ineliminable theme within anchor-based systems, and there needs to be an integral attentiveness to where it is held, how it can be interpreted, how it can be employed to influence service delivery on all fronts within the confines of the anchor-based system.

At the time of data collection in 2019, three anchor clients were attained and three anchor clients still exist today, although there has been an increase in the number of customers connected that the Zengamina mini-grid serves since 2019 (See Table 2 and Table 3). ZPL has also partnered with Virunga Power, a renewable energy company, to expand the mini-grid's reach to supply electricity to every resident in the district, with the mini-grid expected to increase its capacity from 0.75 MW to 1.4 MW (Liu et al., 2019). As the expansion on the Zengamina scheme continues, there is an opportunity to internalise the power dynamics and relations that have emerged to refine and reshape the development process within the structural operation of the business model and improve the livelihoods en masse of the local communities.

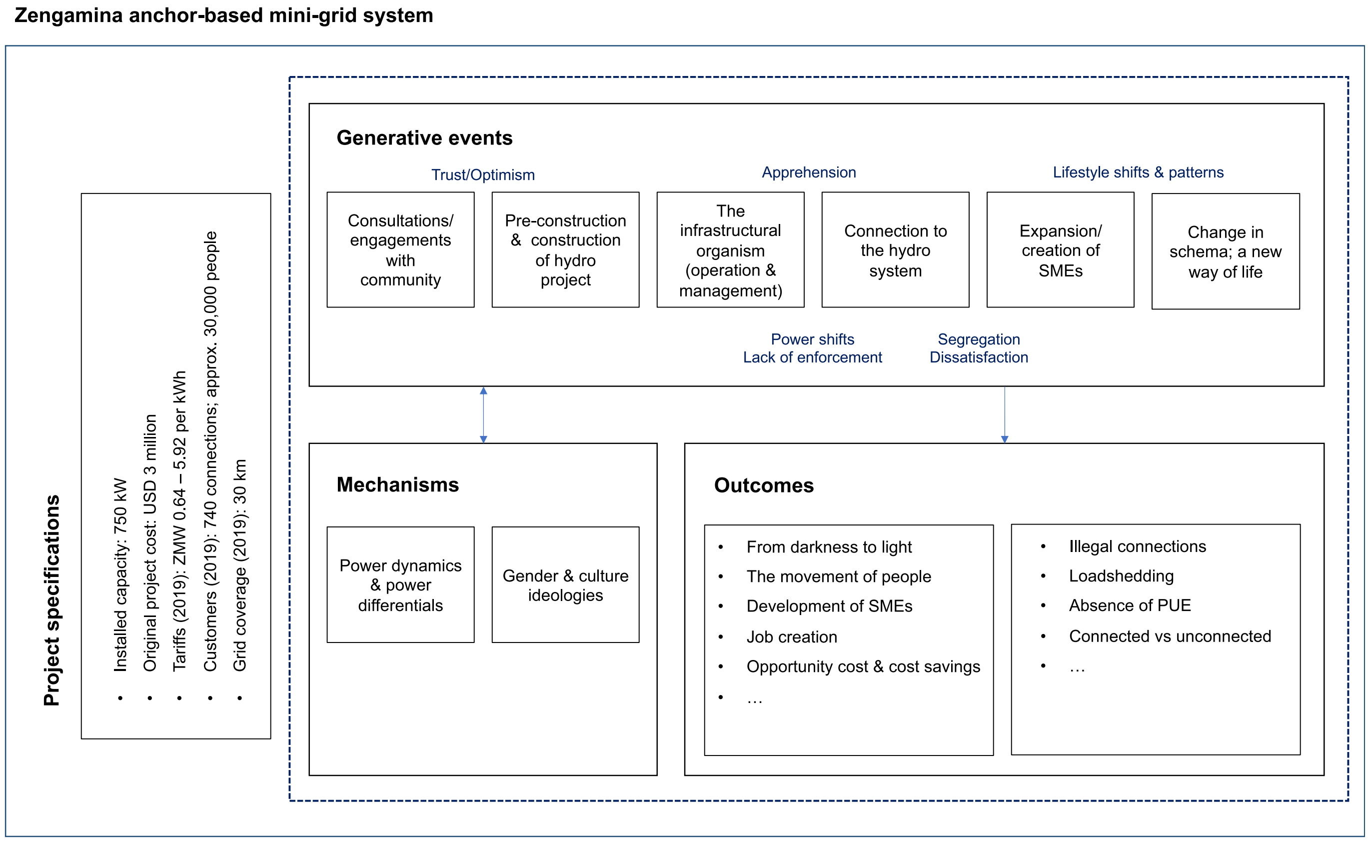

Fig. 10. Proceedings materialised within the Zengamina anchor-based system.
Source: Adapted from (Mbazima, 2024).

Table 2
Total number and proportion of customer base at Zengamina hydro mini-grid, 2019 and 2023.

Category	Total (2019)	Percentage (2019)	Total (2023)	Percentage (2023)
Residential	671	90.7	814	78.3
Small Enterprise	37	5.0	177	17.0
Community Services	6	0.8	20	1.9
Large Enterprise & Institutions	23	3.1	25	2.4
Priority Commercial User	3	0.4	3	0.3
TOTAL	**740**	**100**	**1039**	**100**

Source: (Energy Regulation Board, 2020; Rea & Kabiru, 2023) (Data also obtained via email correspondence (D Rea and P Kabiru 2023, personal communication, 20 November 2023).)

Table 3
ZPL Customer base and proportion of electricity consumption, as of 30th June 2020.

Category	Total	Percentage	Share of annual electricity consumption (%)
Residential	671	90.68	34
Small Enterprise	37	5.00	6
Community Services	6	0.81	4
Large Enterprise & Institutions	23	3.11	11
Priority Commercial User	3	0.41	45
TOTAL	**740**	**100**	**100**

Source: (Energy Regulation Board, 2020)

Conclusion

This paper has presented the empirical case of the Zengamina hydropower scheme in north-western Zambia to provide an understanding of the realised outcomes and the social proceedings and workings that take place within an implemented anchor-based mini-grid system, serving to contribute to a literature that documents from a social perspective the concrete results of operational anchor-based projects. This is a reality for the Zambian case in Ikelenge district, and similar studies can advance whether these findings are replicated in other anchor systems, given their context-dependent nature.

This paper has detailed the development of the Zengamina scheme by providing a progression of the generative events that materialised through the electrification of its target beneficiaries. It emerges that political power is an important social undercurrent that is ingrained in but also stems from the development and operation of the anchor-based business model. This sheds light on the importance of parity in consideration paid to both the social and economic elements of such interventions if the intended aim is to secure fair electricity access.

Future work could further explore the different facets of the power relationships between the different social actors, to provide a better understanding of the contentions and confluences of actor mandates and motivations, and where opportunities for harmonised action may exist. Where this research effort was largely carried out in a qualitative manner, future research can employ a mixed-methods approach to providing a more comprehensive socio-technical understanding for how the interaction of the technical elements with the decisions and actions of social actors may constrain or support intended aspirations. Based on the findings of this paper, it is a worthwhile endeavour to examine the effects of the social and cultural contexts of electricity interventions, at a general level, but also within the distinct environs that each mini-grid business model constructs, to better understand the real achievements of existing energy access undertakings.

CRediT authorship contribution statement

Nandi Mbazima: Writing – original draft, Visualization, Validation, Methodology, Investigation, Data curation, Conceptualization. **Xavier Lemaire:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Funding

Additional funding for the research and the writing of this paper has been provided by the UKRI-GCRF "Energy Democracy and the Politics of Energy Transition in African countries" research project [grant ES/T006285/1]. The support of the Economic and Social Research Council (ESRC) is gratefully acknowledged.

Declaration of competing interest

This note to confirm none of the authors has any conflicts of interest to disclose concerning this study.

References

Ahlborg, H. (2018). Changing energy geographies: The political effects of a small-scale electrification project. *Geoforum, 97*(September), 268–280. https://doi.org/10.1016/j.geoforum.2018.09.016

Ahlborg, H., & Boräng, F. (2018). Powering institutions for development—Organizational strategies for decentralized electricity provision. *Energy Research and Social Science, 38*(February), 77–86. https://doi.org/10.1016/j.erss.2018.01.011

Ahlborg, H., & Sjöstedt, M. (2015). Small-scale hydropower in Africa : Socio-technical designs for renewable energy in Tanzanian villages. *Energy Research & Social Science, 5*, 20–33.

Bachrach, P., & Baratz, M. S. (1962). Two Faces of Power. *The American Political Science Review, 56*(4), 947–952. https://doi.org/10.1017/S0003055406222561

Balls, J. N., & Fischer, H. W. (2019). Electricity-centered clientelism and the contradictions of private solar microgrids in India. In *, 109(2). Annals of the American Association of Geographers* (pp. 465–475). https://doi.org/10.1080/24694452.2018.1535312. Routledge.

Bamberger, M., et al. (2013). Evaluating the economic and equity impacts of decentralized rural electrification program in India. *South Asian Journal of Evaluation in Practice, 1*(1), 25–43.

Banerjee, S. G., et al. (2015). *The power of the mine: A transformative opportunity for Sub-Saharan Africa*. Washington, DC. https://doi.org/10.1596/978-1-4648-0292-8.

Banerjee, S. G., et al. (2017). Double dividend: Power and agriculture nexus in sub-Saharan Africa. Washington, DC. Available at: https://openknowledge.worldbank.org/entities/publication/a2cdf12c-a9b0-5ee3-8020-0b77d9f3687d.

Baraille, T., & Jaglin, S.. The solar repair trade in Nairobi (Kenya): The blind spots of a "sustainable" electricity policy. *http://journals.openedition.org/tem*.

Bayliss, K., & Pollen, G. (2021). The power paradigm in practice: A critical review of developments in the Zambian electricity sector. *World Development, 140*, Article 105358. https://doi.org/10.1016/j.worlddev.2020.105358

Beath, H., et al. (2021). The cost and emissions advantages of incorporating anchor loads into solar mini-grids in India. *Renewable and Sustainable Energy Transition, 1*, Article 100003. https://doi.org/10.1016/j.rset.2021.100003

Bhattacharyya, S. C. (2014). Viability of off-grid electricity supply using rice husk: A case study from South Asia. *Biomass and Bioenergy, 68*(0), 44–54. https://doi.org/10.1016/j.biombioe.2014.06.002

Bhattacharyya, S. C., et al. (2019). Solar PV mini-grids versus large-scale embedded PV generation: A case study of Uttar Pradesh (India). *Energy Policy, 128*(December 2018), 36–44. https://doi.org/10.1016/j.enpol.2018.12.040

Blum, N. U., Bening, C. R., & Schmidt, T. S. (2015). An analysis of remote electric mini-grids in Laos using the Technological Innovation Systems approach. *Technological Forecasting and Social Change, 95*, 218–233. https://doi.org/10.1016/j.techfore.2015.02.002

Carabajal, A. T., et al. (2024). Social and economic impact analysis of solar mini-grids in rural Africa: A cohort study from Kenya and Nigeria. *Environmental research, infrastructure and sustainability : ERIS., 4*(2), Article 025005.

Climate & Development Knowledge Network. (2015). Testing synergies in distributed renewable village power in Africa. Available at: https://cdkn.org/sites/default/files/files/Project-Completion-Report.pdf.

Craine, S. A. (2015). Modern design principles for investable village power projects. *Boiling Point: A Practitioner's Journal on Household Energy, Stoves and Poverty Reduction*, 67.

Dahl, R. A. (1957). The concept of power. *Behavioural Science, 2*(3), 201–215. https://doi.org/10.1002/bs.3830020303

Daniel, S., et al. (2014). Microgrids for Rural Electrification: A critical review of best practices based on seven case studies. In *Microgrids for Rural Electrification : A critical review of best practices* (p. 122). United Nations Foundation.

Energy Regulation Board. (2019). *Call for comments on Zengamina Power Limited's Application to revise electricity tariffs and connection fees* (pp. 1–4). Lusaka.

Energy Regulation Board. (2020). *Statistical Bulletin: January to June 2020*. Lusaka. https://www.erb.org.zm/wp-content/uploads/files/statBullet2020.pdf.

Energy Regulation Board. (2023). *Statistical Bulletin: January to December 2022*. Lusaka. https://www.erb.org.zm/wp-content/uploads/statBullet2021.pdf.

ESMAP. (2022). *Mini grids for half a billion people: Market outlook and handbook for decision makers*. Washington, DC: The World Bank. https://openknowledge.worldbank.org/entities/publication/b53273b6-b19a-578e-8949-8dc5c7a3cd79.

Falchetta, G., et al. (2022). Harnessing finance for a new era of decentralised electricity access: A review of private investment patterns and emerging business models. *Energy Research and Social Science, 90*(February), Article 102587. https://doi.org/10.1016/j.erss.2022.102587

Fillol, L. T., Honkapuro, S., Annala, S., Pinomaa, A., & Dibaba, H. (2022). Analysis of private mini-grid development for rural Rwanda. In *2022 IEEE PES/IAS PowerAfrica, PowerAfrica 2022*. https://doi.org/10.1109/PowerAfrica53997.2022.9905374

Foucault, M. (1979). The history of sexuality. In Robert Hurley (Ed.)*, Vol.1. An introduction*. Allen Lane.

Foucault, M. (1991). In Paul Rabinow (Ed.), *The Foucault reader*. Penguin.

Gammon, R., & Sallah, M. (2021). Preliminary findings from a pilot study of electric vehicle recharging from a stand-alone solar minigrid. *Frontiers in Energy Research, 8*. https://doi.org/10.3389/fenrg.2020.563498

Giddens, A. (1984). The constitution of society: Outline of the theory of structuration. In *The constitution of society: Outline of the theory of structuration*. Polity Press.

Givens, R. (2016). *The Anchor-business-community model for rural energy development: Is it a viable option?* Duke University. https://dukespace.lib.duke.edu/dspace/handle/10161/11940.

Gollwitzer, L., et al. (2015). *Institutional innovation in the management of pro-poor energy access in East Africa*.

Gómez, A. R. (2013). *From gap to opportunity: The A-B-C telecom mini-grid model for East Africa*. KTH. http://www.diva-portal.org/smash/record.jsf?pid=diva2:656764.

GSMA. (2013). Service over technology: Defining the role for mobile in energy access. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/02/Service-over-Technology-CPM-White-Paper.pdf.

GSMA. (2014). Mini-grids: Reducing risks and costs through the anchor customer business model. Available at: https://www.german-energy-solutions.de/GES/Redaktion/DE/Publikationen/Praesentationen/2015/2015-03-19-iv-mini-grids-09-gsma.pdf?__blob=publicationFile&v=7.

GSMA. (2017). *Gham power: Finding a replicable model for mobile-enabled micro-grids with Ncell in Nepal*.

Guarnotta, R. (2016). *Optimal power flow and pricing mechanism for bipolar DC distribution grids*. Delft University of Technology.

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change, 74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

International Energy Agency. (2023). Access to electricity improves slightly in 2023, but still far from the pace needed to meet SDG7 – Analysis - IEA. Available at: https://www.iea.org/commentaries/access-to-electricity-improves-slightly-in-2023-but-still-far-from-the-pace-needed-to-meet-sdg7 (Accessed: 9 November 2023).

International Finance Corporation. (2012). From gap to opportunity: Business models for scaling up energy access. Washington, DC https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/publications_report_gap-opportunity.

Johnson, O. W., Gerber, V., & Muhoza, C. (2019). Gender, culture and energy transitions in rural Africa. *Energy Research and Social Science, 49*, 169–179. https://doi.org/10.1016/j.erss.2018.11.004

Kapole, F., Mudenda, S., & Jain, P. (2023). Study of major solar energy mini-grid initiatives in Zambia. *Results in Engineering, 18*(July 2022), Article 101095. https://doi.org/10.1016/j.rineng.2023.101095

Kurz, K. (2014). The ABC-Model: Anchor customers as core clients for mini-grids in emerging economies. Berlin. Available at: https://www.german-energy-solutions.de/GES/Redaktion/DE/Publikationen/Praesentationen/2015/2015-03-19-iv-mini-grids-05-giz.pdf?__blob=publicationFile&v=8.

Lane, J., et al. (2018). Mini-grid market opportunity assessment: Zambia. Available at: https://greenminigrid.afdb.org/sites/default/files/gmg_zambia-final_.pdf.

Latour, B. (1984). The powers of association. *The Sociological Review, 32*(S1), 264–280. https://doi.org/10.1111/j.1467-954X.1984.tb00115.x

Liu, D., et al. (2019). *Word small hydropower development report 2019: Case studies*.

Long, N. (2001). *Development sociology: Actor perspectives*. Routledge.

Lukes, S. (2005). *Power : A radical view* (2nd ed.). Bloomsbury Academic.

Lukuyu, J., Muhebwa, A., & Taneja, J. (2020). Fish and chips: Converting fishing boats for electric mobility to serve as minigrid anchor loads. In *Proceedings of the 11th ACM International Conference on Future Energy Systems* (pp. 208–219). Association for Computing Machinery. https://doi.org/10.1145/3396851.3397687.

Mbazima, N. (2024). *A social analysis of rural electrification through anchor-based mini-grid systems: A case study of Zambia*. Unpublished Ph. D. Thesis. University College London.

Mugagga, R. G., & Chamdimba, H. B. N. (2022). Mini-grids as the vehicle to rural development in Uganda: A review. *Advances in Phytochemistry, Textile and Renewable Energy Research for Industrial Growth*, 246–255. https://doi.org/10.1201/9781003221968-34

Namaganda-Kiyimba, J., & Mutale, J. (2020). Designing affordable rural community microgrids. In *2020 IEEE PES/IAS PowerAfrica, PowerAfrica 2020* (pp. 1–5). https://doi.org/10.1109/PowerAfrica49420.2020.9219953
Nique, M., & Opala, K. (2014). *The synergies between mobile, energy and water access: Africa*. Available at https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/04/MECS_Synergies-between-Mobile-Energy-and-Water-Access_Africa.pdf.
Njogu, M., Kimathi, P., & DaSilva, I. (2017). Community-developer business model promoting social energy enterprises (Case study of Mutunguru 7.8MW community driven small hydro power project). In *IEEE AFRICON: Science, Technology and Innovation for Africa* (pp. 1143–1148). IEEE. https://doi.org/10.1109/AFRCON.2017.8095643.
North West Zambia Development Trust (2006) NWZDT News: January 2006 - Newsletter of the North West Zambia Development Trust. Available at: moz-extension://2580d43b-1a1f-4b99-8a0b-086f5121297b/enhanced-reader.html?openApp&pdf=http%3A%2F%2Fwww.nwzdt.org%2Fwp-content%2Fuploads%2F2010%2F02%2FNWZDTnewsletterJan06_75dpi.pdf (Accessed: 4 May 2022).
North West Zambia Development Trust. (2013). Zengamina Hydro Project. Available at: http://www.nwzdt.org/?page_id=22 (Accessed: 5 April 2022).
Ogeya, M., & Lambe, F. (2025). The political economy of mini-grid electricity development and innovation in Kenya [Article]. *Renewable and Sustainable Energy Transition, 6*, Article 100092. https://doi.org/10.1016/j.rset.2024.100092
Ogeya, M., Muhoza, C., & Johnson, O. W. (2021). Integrating user experiences into mini-grid business model design in rural Tanzania. *Energy for Sustainable Development, 62*, 101–112. https://doi.org/10.1016/j.esd.2021.03.011
Osunmuyiwa, O., & Ahlborg, H. (2019). Inclusiveness by design? Reviewing sustainable electricity access and entrepreneurship from a gender perspective. *Energy Research and Social Science, 53*(March), 145–158. https://doi.org/10.1016/j.erss.2019.03.010
Osunmuyiwa, O. O., & Ahlborg, H. (2022). Stimulating competition, diversification, or re-enforcing entrepreneurial barriers? Exploring small-scale electricity systems and gender-inclusive entrepreneurship. *Energy Research and Social Science, 89*, Article 102566. https://doi.org/10.1016/j.erss.2022.102566
Palit, D., & Sarangi, G. K. (2014a). Renewable energy-based rural electrification: The mini-grid experience from India. New Delhi. Available at: https://unepccc.org/wp-content/uploads/2014/09/renewable-energy-based-rural-electrification-the-mini-grid-experience-from-india.pdf.
Palit, D., & Sarangi, G. K. (2014b). Renewable energy based mini-grids for enhancing electricity access: Experiences and lessons from India. In *International Conference and Utility Exhibition 2014 on Green Energy for Sustainable Development, (March)* (pp. 19–21). https://doi.org/10.1109/ICDRET.2014.6861705
Payen, L., Bordeleau, M., & Young, T. (2015). Developing Mini-grids in Zambia: How to build sustainable and scalable business models?. Available at: https://answers.practicalaction.org/our-resources/item/developing-mini-grids-in-zambia-how-to-build-sustainable-and-scalable-business-models/.
Pedersen, M. B., & Nygaard, I. (2018). System building in the Kenyan electrification regime: The case of private solar mini-grid development. *Energy Research and Social Science, 42*, 211–223. https://doi.org/10.1016/j.erss.2018.03.010
Perez-Arriaga, I. J., et al. (2019). A utility approach to accelerate universal electricity access in less developed countries: A regulatory proposal. *Economics of Energy & Environmental Policy, 8*(1). https://doi.org/10.5547/2160-5890.8.1.iper
Phillips, C. (2019). Why Zambia's North-Western Province is NOT the 'new Copperbelt' – Margaret O'Callaghan. Available at: https://copperbelt.history.ox.ac.uk/2019/10/21/why-zambias-north-western-province-is-not-the-new-copperbelt-margaret-ocallaghan/.
Ramchandran, N., Pai, R., & Parihar, A. K. S. (2016). Feasibility assessment of Anchor-Business-Community model for off-grid rural electrification in India. *Renewable Energy, 97*, 197–209. https://doi.org/10.1016/j.renene.2016.05.036
Ranade, M. (2013). "A-B-C" model for Off-grid Energy Solutions. Available at: https://www.unescap.org/sites/default/files/Session_10_Monali_Ranade_0.pdf.
Rea, D., & Kabiru, P. (2023). *Email communication with Nandi Mbazima, 20 November*.
Roach, M., & Cohen, I. (2016). Mobile for development utilities - African Solar Designs: Trialling the community power for mobile model in Kenya. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/05/M4D-Utilities-African-Solar-Design-case-study.pdf.
Roach, M., & Ward, C. (2011). Harnessing the full potential of mobile for off-grid energy. Available at: https://www.gsma.com/mobilefordevelopment/resources/harnessing-the-full-potential-of-mobile-for-off-grid-energy/.
Robert, F. C., Frey, L. M., & Sisodia, G. S. (2021). Village development framework through self-help-group entrepreneurship, microcredit, and anchor customers in solar microgrids for cooperative sustainable rural societies. *Journal of Rural Studies, 88*(March 2020), 432–440. https://doi.org/10.1016/j.jrurstud.2021.07.013
Robert, F. C. C., Sisodia, G. S. S., & Gopalan, S. (2017). The critical role of anchor customers in rural microgrids: Impact of load factor on energy cost. In *2017 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)* (pp. 398–403). IEEE. https://doi.org/10.1109/ICCPEIC.2017.8290401.
Shah, R. (2015). *Mobile for Development Utilities - Assessing the opportunity to improve energy access: Ncell in Nepal*.
Sustainable Energy for All. (2020). *State of the Global Mini-grids Market Report 2020: Trends of renewable energy hybrid mini-grids in Sub-Saharan Africa*. Asia and island nations. https://www.seforall.org/publications/state-of-the-global-mini-grids-market-report-2020.
Tenenbaum, B., et al. (2014). *From the bottom up: How small power producers and mini-grids can deliver electrification and renewable energy in Africa, DIRECTIONS IN DEVELOPMENT Energy and Mining*. Washington, DC. https://doi.org/10.1596/978-1-4648-0093-1.
The World Bank. (2022). Tracking SDG7: The Energy Progress Report 2022. Washington, DC https://www.worldbank.org/en/topic/energy/publication/tracking-sdg-7-the-energy-progress-report-2022.
Ulsrud, K., et al. (2011). The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems. *Energy for Sustainable Development, 15*(3), 293–303. https://doi.org/10.1016/j.esd.2011.06.004
Vanadzina, E., Mendes, G., et al. (2019). Business models for community microgrids. In *International Conference on the European Energy Market, EEM*. https://doi.org/10.1109/EEM.2019.8916368
Vanadzina, E., Pinomaa, A., et al. (2019). An innovative business model for rural sub-Saharan Africa electrification. *Energy Procedia, 159*, 364–369. https://doi.org/10.1016/j.egypro.2019.01.001
Williams, N. J., et al. (2015). Enabling private sector investment in microgrid-based rural electrification in developing countries: A review. *Renewable and Sustainable Energy Reviews, 52*, 1268–1281. https://doi.org/10.1016/j.rser.2015.07.153
Winther, T., Ulsrud, K., & Saini, A. (2018). Solar powered electricity access: Implications for women's empowerment in rural Kenya. *Energy Research and Social Science, 44* (March), 61–74. https://doi.org/10.1016/j.erss.2018.04.017
Yin, R. K. (2018). *Case Study Research and applications: Design and Methods* (6th ed.). Thousand Oaks: SAGE Publications, Inc.. Available at: https://us.sagepub.com/en-us/nam/case-study-research-and-applications/book250150. (Accessed 2 October 2019).