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Sizing isolated mini-grids in Kenya: risk transfer to deal with multidimensional uncertainties and constraints

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Abstract

Isolated mini-grids (MG) can be an efficient option for rural electrification worldwide. Nonetheless, a large share of MG fail after a few years and inadequate sizing has been identified as a major risk. Academia, public authorities and funding agencies tend to consider the sizing of mini-grids mostly from a technical and economic angle, looking to optimize performance for MG developers and operators with tools such as HOMER. This paper proposes a different approach. We study the strategies adopted by different MG stakeholders to deal with their own uncertainties and constraints in the sizing process. Based on field work in Kenya, we detail how MG funders and regulators transfer risks to private MG developers and operators. As a result, the latter face risks regarding demand estimation, funding and regulatory aspects when sizing MGs. In turn, they adapt their methods and business models, sometimes transferring risks to end users. While flexible sizing might be a solution, we show that regulatory and funding issues limit MG modularity, leading low-income customers to eventually bear the consequences of ill-suited sizing.

Highlights:

- MG sizing goes beyond technical and economic optimization
- Equilibrium between production capacity and electricity demand is only transitional
- Regulatory and financial environments are ill-suited for mid-term flexibility needs
- Stakeholders try to transfer the risks of MG sizing to each other
- Customers are the ones to eventually bear the consequences of unsuitable MGs

Keywords: mini-grids, Africa, Kenya, sizing, sustainability

Word count: 7566

List of abbreviations:

- AMDA: Africa Mini-grid Developers Association
- CAPEX: Capital Expenditure
- DFI: Development Finance Institutions
- EPRA: Energy and Petroleum Regulation Authority
- GIZ: Gesellschaft für Internationale Zusammenarbeit (“Society for International Cooperation” in English)
- KOSAP: Kenya Off-Grid Solar Access Project
- KPLC: Kenya Power and Lighting Company
- MG: Mini-grid
- NGO: Non-Governmental Organization
- OPEX: Operational Expenditure
- PV: Photovoltaic
- REA: Rural Electrification Authority
- REREC: Rural Electrification and Renewable Energy Corporation
- RBF: Result-Based Financing
- SHS: Solar Home Systems
- SDG: Sustainable Development Goals

1. Introduction

Six hundred million sub-Saharan Africans lack electricity [1]. In rural areas, only 25% of them have access to electricity [1]. The decreasing cost of photovoltaic (PV) panels [2] makes solar off-grid systems cost-competitive for these areas [1], [3], [4] compared with grid extension. International programs such as Sustainable Energy For All [5], the Green Mini-Grid Program [6], Power Africa [7], and Lighting Africa [8] favour three kinds of off-grid solutions to reach the seventh UN Sustainable Development Goal (SDGs) [9], dedicated to energy. These solutions are: Solar Home Systems (SHS) and stand-alone systems for scattered households and single users such as schools, and mini-grids¹ (MGs) for large, dense villages. Compared with SHS and stand-alone systems, MGs can supply a relatively large amount of energy for productive activities such as welding, pumping or milling. Therefore solar MGs have become a mainstream option for rural electrification: more than 2000 MGs have been installed in sub-Saharan Africa [12] and the International Energy Agency estimates that off-grid MGs are the best option to electrify more than 200 million people on this continent [1] by 2030.

In addition to their cost-efficiency for rural areas, solar MGs are more environmentally-friendly than diesel technologies and can have fewer potential drawbacks than large utility-scale solar plants [13]–[16]. Literature on energy justice in the Global South highlights how large solar projects may lead to dispossession of land [14]–[16], lower revenues [16] or higher gender inequality [13] for communities near power plants. As illustrated in Rajasthan [15] or Burkina Faso [16], the benefits of large-scale projects tend to be reaped by large companies to the detriment of local communities. On the other hand, the relatively small size of MGs reduces land-grabbing risks. When designed in a participatory way [17], MGs may improve living conditions for the local community [18] and be more suitable for users' needs [19]. Unlike SHS [20], MGs may also favour the sharing of responsibilities and knowledge on the energy supply [19].

However, MGs can also face challenges [17]. Some authors show that MGs may experience tariff related-conflicts [21], degradation of goods [21] or restraints on electricity appliances [16]. Moreover, numerous MGs have low reliability and/or a shortened lifetime compared to their expected 20-year lifespan, with a critical threshold of around six years [22], [23]. The low longevity of MGs results from multiple factors such as a lack of qualified technicians, difficulties estimating demand, low profitability and equipment breakdown [21], [24]–[26]. Several of these issues are related to MG sizing [24]: undersized MGs deteriorate rapidly as electricity over-consumption damages components such as batteries [27] while oversizing may impair their financial viability [28] (cf. Appendix 1).

Sizing consists in defining the power capacities of the off-grid MG regarding both energy production and storage to ensure that production is always equal to consumption at the local level. It includes choosing the number of solar panel and batteries, and deciding whether to add a diesel generator. Proper MG sizing is crucial for two reasons. First, sufficient capacity must be installed to ensure a reliable electricity supply for users but not too much, to minimize costs. Secondly, even if, from a technical point of view, the MG production and storage capacities can be extended or decreased over time, in practice it is difficult to do this in the medium-term, especially in financially constrained contexts². MG sizing thus seems relatively irreversible after the MG is installed, evidencing that sizing is not only a technical issue.

¹ Most solar MGs are made of solar panels, batteries, genset, etc. In off-grid MGs, the MG distribution network is not connected to the main electricity grid. Some authors distinguish nano, pico, micro and mini-grids depending on their size, relationship with the main power grid, AC/DC power, etc. Given the lack of consensus on this terminology [10], [11], in this article we use the term “mini-grid” for systems between 5kW and 1MW.

Numerous tools and guides have been produced by international institutions and academics, among others, to help developers size MGs, i.e. calculate the number of photovoltaic panels and batteries needed to electrify a community at minimum cost [31]–[37]. All these guides present similar steps. First, the MG developer estimates the electrical demand to draw a load curve, with visits and on-site surveys in the community. These surveys assess electricity-intensive activities, existing alternatives, such as SHS or diesel generators (genset), and potential users’ ability and willingness to pay. The developer also quantifies solar radiation and shading patterns with a view to supplying this demand [38]–[40]. Finally, the developer collects financial data, such as the costs of physical assets (e.g. PV panels, inverters, distribution grid), operation and maintenance, and capital, among others. These data feed numerical models, ranging from simple Excel sheets to highly detailed software, such as the well-known HOMER [41]–[44]. Extensive academic literature explains how to increase the accuracy of these simulations, reduce computational time and improve the robustness of results [45]–[50]. Most of these models look for “optimal sizing”, i.e. the configuration with the lowest levelized cost of electricity, but some include other indicators such as investment costs or environmental impacts [51]–[54]. A MG business model is eventually built from these estimates.

Considering the abundant literature on this topic, one might think that the sizing of a MG is well understood and poses no problem. With this in mind, one can guess our surprise when one of our interviewees, referring to the sizing of a MG in Kenya, declared that “*we were very lucky because reality appeared quite close to our estimate.*” It is unexpected to hear that sizing is merely a matter of “luck” despite multiple sizing tools and decades of feedback. The process to translate the results from sizing models to the field is an issue that has not been studied in the scientific literature to the best of our knowledge. Many stakeholders intervene in the MG design and funding, and might influence MG sizing to match their own constraints and objectives.

In this paper, we therefore propose moving away from envisioning sizing as mere techno-economic optimization involving only the developer. Instead, we study the process of sizing as a way for stakeholders to deal with the risks surrounding MG sizing: which strategies are adopted by the different stakeholders to face their own uncertainties and constraints in the sizing process? How these strategies impact the other stakeholders? Based on field work in Kenya and insights from management studies, we detail how MG funders and regulators transfer risks to private MG developers and operators. As a result, the latter face risks regarding demand estimation, funding and regulatory aspects when sizing MGs. In turn, they adapt their methods and business models, sometimes transferring risks to end users. While flexible sizing might be a solution, we show that regulatory and funding issues limit MG modularity, leading low-income customers to eventually bear the consequences of ill-suited sizing.

The remainder of the paper is structured as follows. Section 2 reviews insights from management studies. After describing our methodology and the Kenyan context (section 3), we detail how developers face constraints designing MGs (section 4). In 4.1, we show how these constraints result in uncertainties related to demand estimation, funding and regulatory aspects. Sub-section 4.2 analyses how public and private developers adapt their methods and business models to deal with uncertainties and conflicting constraints. Results are discussed in section 5, concluding that MG design is mostly considered as a one-shot process due to the unsuitable regulatory and funding context, causing most risks to be transferred to developers and operators, with repercussions for low-income rural customers.

² For example, in Senegal the government performed an extensive study in 2020 to calculate financial needs to rehabilitate and expand the capacity of existing MGs [29]. Nonetheless, recent calls for investment are dedicated to the main grid or new infrastructures, instead of improving existing MGs [30].

2. Insights from risk management studies

MGs are expected to play a key role in Africa's electrification but they receive only 1% of electricity investment [55]. Whereas large grid-connected production plants attract private investors and lenders, the MG sector still relies heavily on grants from foreign governments and Development Finance Institutions (DFI). Scholars have identified multiple barriers for MG investments. Gregory and Sovacool [56] show for example the complexity of the financial context of electrification with fifteen issues that negatively impact investors. They advocate for financial, political, and technological governance schemes to be implemented by governments and funding agencies. Other authors highlight the low profitability, the lack of a clear regulatory framework and the high level of technical, financial and social risks associated to MGs [24], [25], [57], [58].

Risk management for investment projects has been extensively studied, with methods based on real options [59], [60], adaptive pathways [61], [62], and stochastic dynamic modelling [63], among others. Building on the idea that, as a project progresses, uncertainties and available options decrease (cf. Midler curve [64]), these methods look for the best time to take irreversible decisions such as investment. As an example, uncertainties on MG sizing disappear after the system installation, while the relative irreversibility of the energy capacity reduces the possibilities of adapting electric production to demand. Risk management relies on the definition and quantification of the uncertainties surrounding a project, therefore requiring a good knowledge of the "known unknowns" [65]. "Known unknowns" refer to identified risks and their impacts, such as the arrival of the grid at a MG location, a risk that can be anticipated to some extent [66].

On the other hand, these methods are not suitable for "unknown unknowns" such as 100-year storms damaging electricity networks, because their low probability of occurrence usually excludes them from risk analysis [65]. These events act as "surprises" [67], whose causes and consequences can hardly be anticipated. However, specific forms of organization or project management, such as parallel projects [65], "agile" methods [68] or "resilient" management, can help to cope with "surprises" [66]. The idea is to rely on well-established partnerships and communication to respond quickly [67], [68]. Such methods have burgeoned in software development and computing but may also be used for infrastructure building through incremental design with frequent tests and evaluation by future users [69].

When risks materialize, coping strategies also require a common goal among stakeholders and cooperation in adversity. However, a large number of projects, such as private MGs, gather entities with potentially competing objectives. Cooperation issues have been widely studied in the literature on stakeholder theory. Ward and Chapman [70] stress how multiple stakeholders increase the level of uncertainties as each stakeholder influences the project based on their hidden vested interest. Methodologies exist to identify stakeholders and define ways to deal with their expectations [70], [71]. Our analysis of the MG ecosystem in Kenya defined five main stakeholders: MG developers, operators, users, regulators and funders.

MG developers are the primary organization (usually a private company, a non-governmental organization or a public utility) that initiates and advances the project up to the MG commissioning. They look for seed funding, design the MG, obtain licenses from the regulators and install the MG. They then hand over the MG to the operator. This second actor (usually a private, public or community-based organization) sells electricity to the customers and maintains the system in working order by means of what are called "cost-reflective tariffs." Thirdly, customers, or MG users, are composed of households, small businesses or community services (a health centre, school, public lighting, etc.) connected to the MG. The fourth type of stakeholders are the regulators. Regulators refer to national public institutions overseeing MG compliance with norms and standards related to

electricity tariffs, quality of service or environmental impacts. In Kenya, the main regulator is EPRA, the Energy and Petroleum Regulatory Authority. Finally, funders can be public or private institutions providing grants, equity or loans for the MG [55]. In practice, a single entity can have more than one role, being for example the MG developer, operator and partial funder through equity. MG ecosystems are thus composed of stakeholders with different roles and objectives.

3. Methodology and Kenyan context

Before presenting our methodology, we summarize the evolution of rural electrification in Kenya to better understand the specificities and stakeholders of this country.

Kenya is a particularly interesting country in which to study MGs due to its long-term experience with off-grid electricity and its variety of MG actors. Up to the 1990s, electrification was mostly a public matter. The Republic of Kenya promoted the electrification of rural areas to foster economic activities; basic infrastructure such as electricity was promoted as a way to develop “rural trade and production centres” with the final objective of slowing migration from rural to urban areas [72]. The national electricity company, Kenya Power and Lighting Company (KPLC), directed both urban and rural electrification. In 2004, the Ministry of Energy acknowledged the little progress in rural electrification rates and announced the creation of the Rural Electrification Authority (REA) to speed up the process. At the same time, the Ministry recognized off-grid technologies as suitable options for rural electrification. These technologies were already prevalent in the country, with an estimated 200,000 SHS nationwide, installed by private actors following “aggressive marketing” [73]. In line with the privatization trend promoted by international aid agencies and donors worldwide [74] and enacted in 1997 through the Electricity Power Act, the Ministry of Energy announced a framework for “independent power distributors” in areas far away from the grid.

The period after 2006 consolidated private and international actors for rural electrification, with major programs such as Lighting Africa (World Bank) in 2014 and the installation of international companies such as Powerhive and Powergen in Kenya. The public sector was redesigned with the 2019 Energy Act that created the Rural Electrification and Renewable Energy Corporation (REREC) to replace the Rural Electrification Authority (REA), and the Energy and Petroleum Regulatory Authority (EPRA) instead of the Energy Regulatory Commission (ERC). The EPRA supervises the sector and develops MG regulations³.

To understand this broad sector, we conducted 75 interviews with Kenyan and international actors, as well as on-site surveys on seven Kenyan MG sites, mostly in April/May 2022. MG were chosen according to three criteria: a longevity of at least five years to grasp demand evolution and operators’ strategies to cope with sizing-related challenges (see section 4.3); a diversity of MG operators and developers (public sector, international cooperation agencies, community cooperatives, NGOs, and international private companies); and an installed capacity of between 8kW and 650kW. Our interviews targeted the whole ecosystem of MGs from users to international funding agencies, including operators and developers, MG managers, public institutions, NGOs, and experts (see Table 1), using a snowball sampling approach. Interviews were conducted mostly in English with some exceptions in French and Spanish, following semi-structured guides adapted to the type of interviewee. Interviews lasted between 30 minutes and 2 hours and were mainly held face-to-face, with occasional phone or video calls.

Table 1. Interview characteristics. Source: authors.

	No. of interviews	Duration [hrs]
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³ In Kenya, the regulator EPRA drafted MG regulations, which were discussed with stakeholders in 2021. Official approval was still pending at the time of writing this article.

Funders (French Development Agency, ...)	5	5.3
Experts and consultants (IED, AMDA, researchers, ...)	13	15.3
Companies (Powergen, TTA, Renewvia, ...)	8	7.0
Managers from 7 MG in Southern Kenya	13	15.6
NGO (Practical Action)	1	0.8
Public Institutions (EPRA, REREC, KPLC, counties)	9	8.9
Users from 7 MGs in Southern Kenya and some SHS users	27	16.0
Total:	75	68.9

Interviews were transcribed and analysed using an inductive coding approach on QSR International’s NVivo [75]. We first indexed elements into large thematic categories. Based on this initial coding, middle-range theories were formulated regarding MG sizing methods, interactions between actors, and strategies to adjust sizing in the long term. The consistency of these theories was then tested through a second coding of interviews, with analytical codes. We also triangulated interviews with official documents such as the country’s development plan, the Kenyan Energy Acts of 2012 and 2019, and the draft MG regulations. We additionally attended or watched recordings of EPRA public events and conferences held by international institutions.

4. Results

4.1 Revealing the constraints around MG sizing: interdependence and instability of demand, funds and regulations

In this section, we analyse the constraints and uncertainties faced by MG developers during the sizing process, resulting from their interactions with other stakeholders. We look at three aspects affecting sizing: demand estimation, MG fundraising, and regulation around licences and tariffs. We show that these issues are concomitant and interdependent, leading to inherently “wicked problems” [76]. After this context analysis, section 4.2 explains how these three elements impact the sizing process.

4.1.1 The demand estimation conundrum

According to most sizing guides [31], [32], [35]–[37], three elements are needed to estimate the load curve required for MG sizing: the number of users; the number and types of electric appliances (e.g. TV, iron, boiler, etc.); and the time slots when these appliances are used. Household surveys estimate who wants to connect, what kind of appliances they would like to use, and when. Each of these elements is compared with the user's ability to pay, estimated on current households’ energy expenses, monetary revenue and future income, among other factors (cf. Appendix 1-2).

In addition to the usual challenges associated with household surveys, such as social desirability, which may lead users to overestimate their ability to pay for electricity (cf. Appendix 3-4), demand estimation for non-electrified users faces specific issues. The first of these is the demand for a service that does not yet exist (cf. Appendix 5) and which encompasses several aspects of life, such as daily activities (including cooking and lighting), leisure (TV and sound systems, among others), and collective and productive uses (for instance school, irrigation and shops) [77]–[79]. The second issue concerns rural users’ ability to pay: current and future income depends on a mixture of sources, such as fluctuating daily jobs, small-scale agriculture and occasional remittances from family [80]–[82] (cf. Appendix 6). The third difficulty is related to understanding the attractiveness of the MG compared

with alternative sources of energy (firewood, coal, paraffin, SHS) (cf. Appendix 7). Users may prefer these energy sources or alternate them with the MG depending on their price, flexibility and reliability, in a phenomenon known as “fuel stacking” [83], [84]. The last issue is survey extrapolation. Surveys are typically conducted over a few days and, as such, they hardly grasp demand variability at different points of time [85] (cf. Appendix 8). Some weekdays may require more electricity due to religious events or market days, while some months might experience a peak or trough in electricity demand due to harvest periods, rural-urban migrations or climatic conditions, among others [86]. Similarly, users’ ability to pay depends on seasonal expenses, such as school fees, holidays or celebrations. In the longer term, the economic characteristics of the community might also change. These demand variations are critical for MGs given that energy production and consumption should match at all times [26], [87].

As shown by Riva [88], the dynamics of electricity demand are related to many factors that cannot be fully measured or predicted. If the MG is functioning well, small entrepreneurs from other villages may relocate to within its perimeter, creating a “service centre” [89], while non-connected villagers might change their mind and eventually connect to the MG (cf. Appendix 9). Furthermore, electricity tariffs may evolve due to regulatory constraints and impact the demand (see section 4.1.3). All these factors combine to shape a multitude of uncertainties regarding the effective electricity demand and its evolution, and thus impact the sizing and the funding strategies for MGs.

4.1.2 Fundraising requires existing funding

In Kenya, the median capital cost of a MG is estimated at US\$ 2,102/kW [90]. A private off-grid MG in rural villages in this country typically ranges from 10kW to 60kW, representing an initial investment ranging from US\$ 21,020 to US\$ 126,000 [91], [92]. MG developers rarely have enough equity to self-fund physical assets; they must look for external funding such as grants and commercial debt.

As one of the SDGs, access to electricity attracts huge international aid funding. More than US\$ 1.3 billion has been committed for MG investments [90]. In Kenya, development agencies from Germany, the United Kingdom and France (Green MG program [6]), and the World Bank (Kenya Off-Grid Solar Access Project (KOSAP) project [93]) are some MGs funders. These actors often earmark MG budgets before their site is identified: developers must then find a site that matches funding instead of adjusting funding to the characteristics of the site (cf. Appendix 10).

Other kinds of subsidies, including result-based financing (RBF), are disbursed after achieving performance indicators, such as the number of connected households [94]. Developers must cover the costs and risks associated with physical assets, licensing, customer engagements, and so on, before being reimbursed. As such, RBF moves the risks to the developers since the funding agency will not disburse anything until the developer proves that households have been connected to the MG.

Lastly, commercial debt can be difficult to access because of the perceived risks associated with MGs. MGs are still a new kind of infrastructure and developers are relatively recent players. The sector is still looking for economically viable models [95] and Kenyan MG regulations are still being consolidated. For these reasons, MGs may be considered as risky investments [24] and lenders expect evidence of developers’ engagement to build their financial credibility. That is why lenders often expect developers to spend their own funding before approving loans:

“The lenders are very particular about this. They absolutely want you to put money in because if you don't put money in and the project fails, as you didn't put money in, you don't care. So the lenders will say to themselves: “If the project fails and you put in 20 million, you had better make it work because

if it fails, I get paid first, and you who put in your money, you won't get it back”.” (interview with a funding company representative, translated from French, April 2022).

Developing a MG thus requires pre-existing equity to leverage further funding or to be able to wait until funds are disbursed. Financial skills are also necessary to navigate funding temporalities and requirements, and to reassure banks on the project feasibility (cf. Appendix 11-12). Yet, even when developers manage to obtain funding, uncertainties remain in terms of capital cost due to inflation, the profitability required by investors, and changes in regulation, particularly that of tariffs [58], [96], [97]. This leads us to examine another critical element in the MG design: compliance with evolving regulations.

4.1.3 Negotiating licence and tariff approval among stakeholders

In Kenya, MGs are approved and supervised by different layers of public agencies. This section details the regulatory constraints on two critical initial stages in MG deployment: licensing and tariff setting.

The MG developer needs the validation of the targeted community, the relevant county and the Ministry of Energy before building the MG [98]. In practice, Kenyan authorities seem keen to approve as many sites as possible. Our interviewees from REREC and two counties stress strategies to attract MG investors rather than ones to discourage them, in a context of ambitious electrification goals with a modest public budget (cf. Appendix 13-15). In some cases, counties may facilitate community engagement for developers, building on their existing relationships with village leaders. This county approval is also compulsory for land issues when developers target communal land. In addition to contributing to electrification, private developers might be perceived as a source of funding by counties. During a public consultation for MG regulations in July 2021, one county representative pleaded for counties to receive a share of MGs' electricity fees. This request occurred in the wake of counties being given new mandates: the new 2010 Constitution devolved some electricity responsibilities to them, but the latter face limited budgets, staff and skills for implementing these duties [99]. The request was nonetheless discouraged by the regulator for fear that additional fees would be passed on to customers via tariffs.

Tariffs are the second major topic of negotiations between regulators on the one hand, and the MG operators and developers on the other. While the latter typically look for tariffs that will ensure maximum profitability, EPRA is also concerned by tariff fairness in the country and requires community approval of tariffs. The regulator first estimates the MG's costs and the corresponding “cost-reflective tariff” [100] using an Excel tool created with the German cooperation agency GIZ⁴. EPRA also benchmarks existing and proposed MG tariffs. The Excel sheet and the benchmark are useful not only for estimating tariffs but also for reducing tensions in tariff setting because of their perceived neutrality. The negotiation of tariffs can indeed be bumpy and continue after the MG is already operating, as reported in the case of two Kenyan MGs. EPRA may also ask for substantial tariff reduction, as reported by one operator who was requested to halve its tariff after the MG was already providing electricity (cf. Appendix 16).

While EPRA typically request low tariffs to “protect” communities, they see their role as protectors of the private sector as well. EPRA “protects both sides,” as this representative of the regulator explains:

“When we go for community engagement, we also take the opportunity to explain to them why their [MG] tariff is relatively higher than the KPLC tariff. Because in some cases, somebody will ask,

⁴ GIZ stand for “Gesellschaft für Internationale Zusammenarbeit” (“Society for International Cooperation” in English).

"Why are they [users connected to the public system] paying Ksh.20 and we are paying Ksh.70?" So we explain to them why, so that they also accept the tariff because it could be higher, but it's the best option. And then we try to compare with the other alternatives that they were using before the MG developer comes in." (interview with an EPRA representative, April 2022).

This interviewee highlights the public discourse on private MG tariffs: they are high compared with the public sector's harmonized tariffs but they remain the "best option" compared with "alternatives" such as SHS or diesel generators. The next section explains how constraints between estimates of MG demand, fundraising and regulation are often contradictory and simultaneous.

4.1.4 Juggling simultaneously with demand, funding and regulation settings

Electricity demand estimation takes place when users are expressing wishes for a good they are not familiar with, and for which tariffs have not yet been stabilized (cf. Appendix 17). Demand estimation, in turn, influences the design of the MG including sizing and financial arrangements: developers elaborate their business model considering a MG sizing that can match unknown future demand in a specific site that is sometimes not fully licensed by the regulator and local authorities. The regulator usually asks for the funding scheme of a MG before licensing, while funders typically request a valid licence as a proof of developers' credibility before providing disbursement (cf. Appendix 18). In short, demand estimation, funding, licensing and tariffs are interdependent and simultaneous.

Moreover, developers are not entirely free to define tariffs or site location. Tariffs are constrained by national players as the regulator arbitrates between profit maximization for private actors and tariffs as close as possible to those of the national operator (KPLC) to foster national equity among customers [101]. This tension between profitability and social goals also appears because operators are legally required to connect all willing customers, even those that are not profitable (cf. Appendix 9). Site location can also be influenced by counties' interests.

Developers are therefore faced with unstable and interdependent constraints. This can be described as a "wicked problem", understood as an ill-defined problem that cannot be divided in subproblems and solved with linear methods, and thus differing from those proposed in many sizing guides [76].

By imposing these constraints, funders and regulators try to protect themselves against default on payment or complaints from the community due to tariff or system unreliability. They report such risks to MG developers and operators, who are, at the same time, facing risks related to demand estimation.

4.2 Transferring constraints and uncertainties over time to other MG stakeholders

In this section, the strategies used by developers and operators to reduce their constraints are presented. We first clarify that constraints are more salient for private actors than for public ones, before going on to explain how private stakeholders adapt their methods and business models around such limitations.

4.2.1 Public MG have more leeway than private ones

Before delving into strategies to ease constraints, a distinction must be made between public and private actors. For public MGs, uncertainties regarding tariffs, licensing and fundraising are less salient or even inexistent [25], [102]. Firstly, public MG tariffs are known from the start since the same tariffs apply to the Kenyan grid and public MGs. Secondly, licence approvals follow a different process as public MGs and the national grid are both managed by KPLC, with no competition risks. Lastly, regarding fundraising, government agencies can access larger subsidies and cheaper credit facilities than private companies (cf. Appendix 19). Thus, the main uncertainty for public MGs comes from the demand estimation but this uncertainty is less than that affecting private MGs. Since the public sector first chooses the areas to electrify, it selects the most profitable sites, namely richer users and densely populated areas (cf. Appendix 20). The higher number of potential users smooths the consumption profile and approaches the mean typical load profiles that are often used for sizing assumptions, with no need to perform extensive household surveys.

Moreover, even though KPLC has a profitability objective, in practice, the rural electrification sector is heavily subsidized, with mechanisms such as a levy on 5% of nationwide electricity bills to contribute to rural electrification⁵. As subsidies compensate for losses, the public sector can afford MGs with a large share of costly gensets. These agile diesel-based MGs can adapt easily to almost every consumption profile, reducing the risk associated with demand estimation uncertainties.

However, in the private sector, subsidies are cautiously distributed (cf. Appendix 21). The State considers that the public levy should not be used to benefit private actors while development agencies seek to reduce subsidies to promote a market-based approach with competition among developers [104]. The quote below illustrates how an ex-member of a cooperation agency internally negotiated funding for a new MG project by justifying the need for blended subsidies and loans to support developers while maintaining a market-approach:

“We reached 70 MG but here again, it was a mixture of loans and subsidies because it was absolutely necessary. But we needed to justify that we would not distort the market” (interview with an ex-employee of a cooperation agency, May 2022; translated from French by the authors).

In the next section, private developers are revisited to analyse how experience and intuition are called on to cope with unstable parameters.

4.2.2 Experience and intuition to arbitrate between uncertain parameters

Despite the existence of recognized sizing models such as HOMER (cf. Figure 1), several of the interviewed developers devise their own (cf. Appendix 22-23). These “home-made” models are continuously improved using feedback from previous projects, comparing estimated and effective demand. Sizing models are also a way to explore assumptions related to the cost of capital with the discount rate, the equity-debt ratio, operating costs (especially fuel cost) and so on [105]. Developers can visualize how different assumptions affect the MG sizing. The models do not have “any judgement” according to one of our interviewees; the developer is the only one who can assess whether the MG sizing seems appropriate based on their “experience” and “intuition” (cf. Appendix 24-25).

⁵ This cross-subsidy might nevertheless be reduced in the future to lower electricity prices nationwide: a white paper from the Ministry of Energy published in July 2022 proposes reducing the levy by 50%. See [103] for more information.

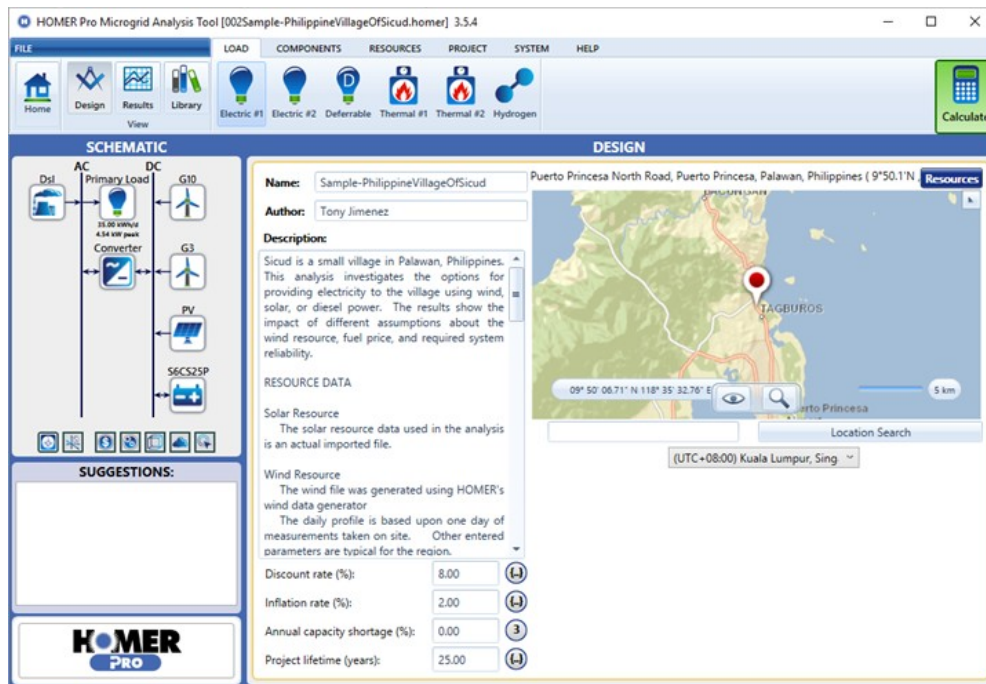


Figure 1. Illustration of HOMER Pro Software [105]

This hands-on knowledge builds on several years working in MG sizing, of “failures” and “successes” as described by one interviewee (cf. Appendix 25). Some experts observed that walking in a village is enough to grasp its economic potential and the appropriate MG sizing. Furthermore, developers often size MGs with security margins to cope with events such as long cloudy periods or demand peaks, based on their experience (cf. Appendix 26). Experience thus allows developers to move from “unknown unknowns” to “known unknowns”, building on previous challenges [106]. Security margins can entail installing more batteries for a 100% solar MG or adding a back-up diesel generator. The genset reduces the impact of demand uncertainties as it can easily be turned on and off, or used at a percentage of its capacity to avoid power interruption.

Genset versatility is thus a way to adjust electricity production to a varying demand and climate-related “known unknowns.” Nonetheless, gensets are costly to operate and maintain in the long run compared with renewable energy sources, whose capital expenditure (CAPEX) is high but operating expenses (OPEX) are low. Developers and operators need to adapt their business models to be able to balance short-term and long-term costs. The next section discusses how some developers and operators manage to circumvent constraints through the diversification of funding sources, complex financial arrangements, and innovative tariff schemes.

4.2.3 Customized private business models to circumvent constraints

Developers face conflicting constraints when choosing the size and energy sources for MGs. The security margin described previously may lead to oversizing renewable electricity production instead of relying on gensets, especially as funders prefer to invest in CAPEX rather than OPEX (cf. Appendix 27). OPEX, such as equipment replacement and maintenance, tends to be considered as sunk costs by funders [107]. Moreover, funders such as the German cooperation agency or the Green Climate Fund specifically promote renewable energy because of its lower carbon footprint. For these reasons, MGs might be oversized and renewable energy-oriented. At the same time, subsidies rarely

cover all the investment costs and the developers must find other funding through debt and equity (cf. Appendix 28). Investors usually expect a fast return on investment (3 to 5 years), which is difficult to achieve with capital-intensive renewable sources.

To solve this time-related issue, developers often have no choice but to combine different funding sources, as illustrated by the company Powerhive, which has installed 21 MGs in Kenya. This USA-based company managed to raise equity through investors, obtained grants from the Green MG program to fund physical assets, and leveraged smaller grants for specific electricity-related programs such as electric vehicles (see section 4.3.1). Table 2 illustrates how the company fundraises every year, with different actors, for various MG-related expenses.

Table 2. Powerhive funding (non-exhaustive) indicating funding uses, type, amount, date and origin. Source: authors, compiled from online media in June 2022.

What is being funded	Loans to buy appliances	Productive uses	33 electric vehicles	MG assets	Investments	Others
Type, amount, date and origin of funding	Loans for MG users: Unknown value, 2014 (Equity Bank of Kenya)	Leases and loans: US\$ 500K 2017 (USAID/Power Africa) Kuku Poa: unknown value (less than US\$ 300K) 2022 (Powering Renewable Energy Opportunities)	E-mobility: £175,176, 2020 (UK Aid, IKEA)	Output-based grants: Unknown value, total of 5.4m € for 10–15 MG, from Powerhive, Renewvia and RVE (Green Mini-Grid program)	First Solar: undisclosed value, 2013 ENEL: US\$ 12m Series A round, 2015 Diverse actors: US\$ 20m. Series A round, 2016 Toyota Tsusho: US\$ 9.3m. Series B round, 2019 Kouros: US\$ 9.3m. Series B round, 2019	Debt: US\$ 3m. 2018 Cryptocurrency: US\$ 23m. expected with Sun Exchange SUNEX, 2018

Constant fundraising is nonetheless time-intensive and requires specific skills and a high-level international profile⁶. Actors such as the African MG Developers Association (AMDA) support developers in designing their financial plans and obtaining subsidies. Initial MG studies can be very costly as some funders require validation from well-known international consulting firms (cf. Appendix 29). One of our interviewees, a former GIZ employee, considered that initial costs, and in particular feasibility studies before licensing, should be covered by subsidies as they do not always result in a successful MG (cf. Appendix 30). In that case, part of the investment risks would be transferred from the developers to the funding agencies. Still, small developers, especially national ones, find it difficult to enter the MG market [108]. In Kenya, most MG developers were created abroad. Powerhive, Renewvia and Powergen are originally from the USA, while TTA is from Spain and RVE.SOL from Portugal. Solinc, a national company, installs solar panels but does not develop rural MGs, focusing on less risky commercial and industrial uses. Other Kenyan actors (for example, Dream EP and Nirav Agencies Ltd.) are listed by Nygaard [91] but we were unable to find information on their recent activity. Moreover, many funding opportunities reach millions of dollars, excluding small players who cannot prove their credibility with a substantial project portfolio [102].

⁶ For example, Powerhive’s strategic advisors include one former UK Minister of State for Energy & Climate Change and the world-famous actor Leonardo DiCaprio.

From the funders' perspective, a MG portfolio decreases financial risks, as developers and operators can balance losses between their pool of (un)successful MGs. Large MG portfolios are an asset for negotiating lower capital costs, attracting more investors and eventually further increasing the developer's MG portfolio [14] (cf. Appendix 31).

Another strategy for decreasing risks entails making complex financial arrangements to separate OPEX from CAPEX. Specific financial structures split the entity that owns the physical capital (production and storage system) from the teams operating the MG (cf. Appendix 27). In that way, funders invest in the entity with a lower risk (physical capital) and developers can easily sell this entity when needed. International companies with existing teams may buy MG physical assets to develop their own MG portfolio. Thus, developers may specialize in physical assets using their design experience and large subsidy program, and then sell their MG portfolio to operators. MG developers may then achieve a fast return on investment without bearing the risk of long-term MG operation. This de-risking mechanism could lead to an institutionalized separation between MG developers and operators, with consequences on the sizing and longevity of MG.

The last strategy is related to in-kind donations and collaboration for development projects. Operators and developers can negotiate donations or services from the community at lower costs. For example, one operator explained that public lighting is granted for free in exchange for land on which to build the MG (cf. Appendix 32). Operators also sometimes make alliances with partners to develop “productive uses of energy” [57]. For example, IKEA Foundation and the UK cooperation agency funded Powerhive to develop a chicken-farming project entitled “Kuku poa” (“nice chicken” in Swahili). Vast literature details how such productive use of electricity could solve the viability challenge of MG operators while favouring local economic development [109]–[113], as expressed by an interviewed employee of one of the funding agencies:

“The whole business of rural electrification is based on the fact that you’re going to bring something to supply a light bulb or charge a phone assuming that electricity will develop the village economically. We are going to make people richer, so they are going to consume more and this is how you will make profits.” (interview with an employee of a funding agency, May 2022; translated from French by the authors).

Productive uses of electricity are diverse and encompass activities made possible by extending lighting time (e.g. tailors working after sundown), new activities directly related to electricity (e.g. printing services) or activities with enhanced productivity (e.g. solar-based water pumping for agriculture) [114]. The benefits of such “productive use of energy” are two-fold for operators and developers: they facilitate funding-leverage from the donor community and stabilize revenue thanks to an “anchor” consumer that is likely to pay regularly for a large amount of electricity [57].

4.2.4 Looking to influence the electricity consumption

As explained in section 4.1, energy demand cannot be accurately estimated *a priori*: it is a “known unknown” (cf. section 2). Developers and operators are aware of this uncertain demand and of the difficulties with changing the size of the system once installed. As a result, they plan tools to limit or stimulate the demand, either before the MG installation or during its operation.

To avoid situations where the MG production is unable to fulfil the demand, developers and operators can use power limiters or cap connections. Power limiters are particularly critical when users have the perception that the MG capacity is “infinite” and can bear heavy appliances such as welding machines, as the national grid does [115]. Another strategy is to voluntarily oversize the system in the short-term to anticipate unexpected demand growth and/or take advantage of subsidies for physical

assets (see section 4.2.3). In this case, the MG production is large enough to meet potential increased demand.

When a MG appears to be oversized compared with effective demand, operators can look to enhancing the desire for electricity (cf. Appendix 33-34). Strategies often involve marketing campaigns and community engagement approaches, sometimes relying on “ambassadors” as described by one operator. These are villagers who are particularly enthusiastic about electricity and promote its uses. Some of them sell electrical appliances on behalf of the operator and receive commission for successful sales. New customers may be found in the same locality or in the vicinity. In this case, customers are not connected to the MG but they may buy electricity as a service (phone charging for example). Operators sometimes closely follow up customers, enquiring why they did not recently buy electricity credits through automatic SMS or home visits. This is an attempt to better understand customers’ needs and constraints (cf. Appendix 35). From the users’ point of view, however, these reminders may be perceived as pressure to be a “good customer,” in other words a frequent, high-level electricity user. Pressure on customers is a way to transfer the MG’s financial viability risk from the operator to the customers.

Adjusting tariffs to increase or decrease demand is not an option according to the regulations, since tariffs must be approved beforehand by the community and the regulator (see section 4.1.3). Nonetheless, one operator interviewed explained how the regulations could be circumvented through a “bundle” system, allowing customers to buy electricity credits for a given period of the day or a whole week. In these bundles, daylight tariffs are cheaper to encourage consumption when the overall demand is low. The largest customers, defined as “residential premium,” also enjoy more attractive tariffs.

In practice however, even with these strategies, operators often face difficulties reaching “operational sustainability” (i.e. covering OPEX through tariffs [116]) and in particular having enough funds to replace faulty components, such as batteries and inverters (cf. Appendix 36). This seems to be the result of a gap between optimistic business designs and intertwined technical, economic and social challenges. For example, while lead-acid batteries (cf. Figure 2) are supposed to last for approximately eight years, they often last less due to hot temperatures or overuse. In this context, assuming that batteries will last as long as in laboratory conditions can be assimilated as an “optimistic bias” [64]. When batteries fail earlier than planned, the operator has often not raised enough funds to replace them. Another possibility is that users might pressurize the operator to decrease tariffs, as happened in two MGs that we studied, leading to a lack of funds to replace components. One MG studied experienced financial fraud as the electrician had tampered with the payment system. In all those situations, responsibilities are blurred in MG management, resulting in a lack of accountability [104].

MG technical problems and delays in fixing them damage customers’ trust in this technology. As power cuts become more frequent, users tend to disconnect from the MG and buy alternative systems such as diesel generators and SHS (cf. Figure 3). The customers potentially perform by themselves the modularity (i.e. increase in production capacities) that the MGs could not achieve.



Figure 2 (left). Due to funding difficulties, only 7 of the row of 12 batteries have been replaced, although replacing the whole row is technically recommended. Source: authors, fieldwork in Kenya, May 2022.

Figure 3 (right). The barbershop is connected to the MG but is also equipped with solar panels to cope with MG outages. Source: authors, fieldwork in Kenya, May 2022.

5. Discussion and conclusion

MG projects involve multiple actors who usually focus on one or a few aspects: funding, tariffs, reliability, sizing, and maintenance. Each aspect comes with specific uncertainties. Compared with multidisciplinary project teams focusing on a single common goal, this peculiarity leads to competing objectives and a compartmentalized view of uncertainties [64]. Each actor tries to reduce its own uncertainty by applying constraints on other actors [117] (cf. Figure 4). This is especially salient with lenders, who require developers to prove their creditworthiness by hiring costly international consulting groups, spending equity, or de-risking their project through complex financial schemes. Likewise, the regulator protects itself from the dissatisfaction of the population by imposing low tariffs and high reliability constraints on operators. As funders and the regulator seek to minimize their respective risks by transferring the uncertainties to the developer and operators, they affect the financial viability of MGs.

Even though one interviewee from the International Finance Corporation suggested that risks should be allocated to the actors who are best fitted to deal with them, in practice, developers and operators bear two types of risk. These parties are responsible for managing daily and long-term risks and can also be held accountable in case of problems. This situation goes against the ideal scenario of uncertainty allocation identified by Ward and Chapman [70]. In a MG project, accountability remains at the level of an individual organization instead of being built collectively, as would be more suitable in highly uncertain contexts [64].

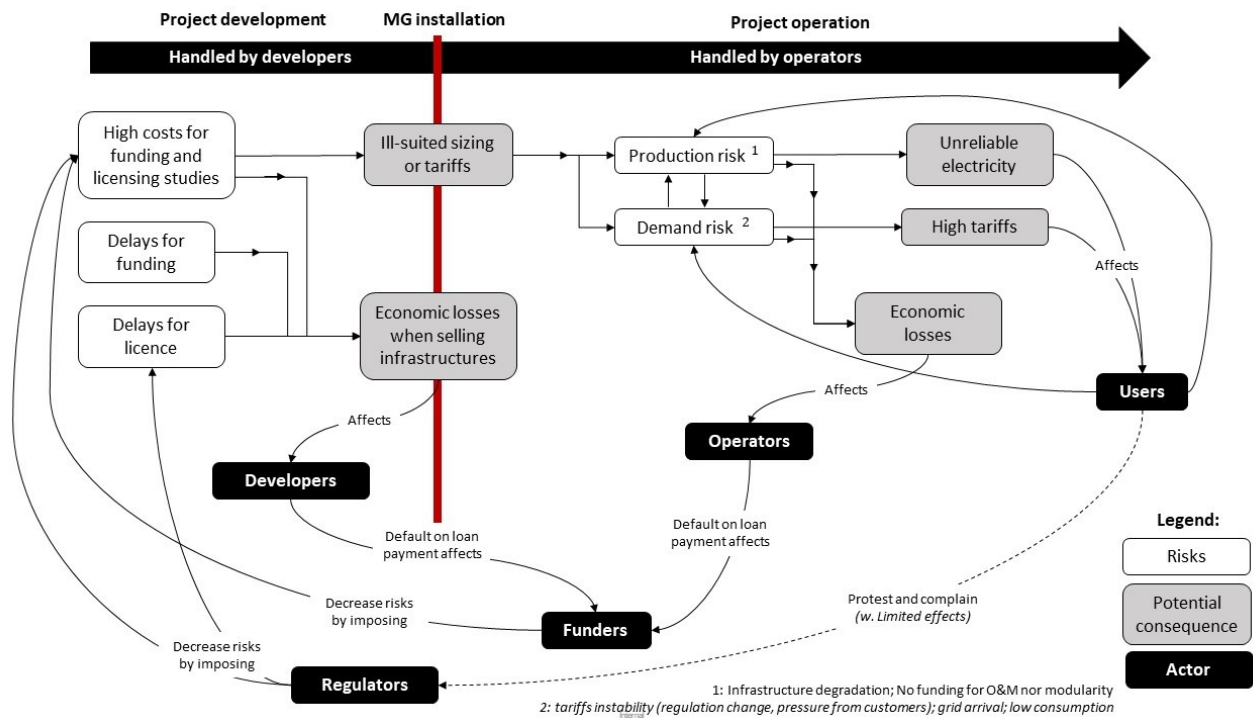


Figure 4. Summary of risks endured by each type of actor. For better readability, only the risks that we observed most frequently are represented. The dotted line represents an unlikely consequence.

Funders, regulators, developers and operators do not bear the same risks. Neither do they hold the same power. These actors can be divided into stakeholders and influencers, following Donaldson and Preston's theory [118]: influencers can influence the project but they do not have any stake in it, whereas stakeholders have stakes and may not have any influence. In the MG ecosystem, funders and the regulator can be seen as influencers. Funders receive numerous funding requests and their activity does not depend on a specific project. Regarding the regulator, even if private actors are seen as critical for accelerating the pace of electrification, KPLC and REREC remain the mainstream electricity actors. In short, MGs are at the heart of the business of operators and developers, while such projects are not vital for funders and the regulator. In addition, funders and regulators have more power as they intervene before sizing and investments materialize.

Developers and operators implement diverse coping strategies against risks such as multiple MG designing tools and trade-offs (section 4.2.2). These methods are well defined for known uncertainties (i.e. "known unknowns") but they may not be adapted to treat "unknown unknowns." For instance, betting on multiple potential funders and developing a solution that is location-flexible could increase the project resilience for MG developers, a strategy known as "parallel approach" ([65], cf. section 2). However, this strategy is difficult to implement as each location requires long and costly studies as well as the need to look for allies in each county and community. On the operator side, resilience may be difficult to build as operators arrive quite late in the project, when many decisions made are irreversible (cf. section 2 and the Midler curve). The installation of the MG is done as a one-shot event and modifications of the initial installation are not straightforward: MG commissioning greatly reduces uncertainty, but also flexibility to adapt. The only way for the operator to be more "agile" ([68] cf. section 2) may be to take on, as much as possible, the roles of developer and funder (through equity). In this way, the continuity of actors in the project could ease the management of uncertainties and increase responsiveness to "surprises" ([67], section 2).

Even the best sizing software and tools cannot anticipate effective demand, and less so how demand will evolve. At the same time, MG production capacity usually decreases as components age. Due to

these opposing trends, matching production capacity with electricity demand seems to be only a transitional equilibrium before or after an under- or over-sizing situation. Our research shows that regulatory and financial environments are ill-suited for this moving electricity demand and production. Tariff approval by the regulator may slow down or even prevent some demand-side management strategies, while grants and subsidies mostly target the early stages of project design. Unrealized demand expectations, the perception of equipment replacement and maintenance as sunk costs [107] and unclear accountability between developers and operators all contribute to degrading MGs. Eventually, customers are the ones to bear the costs of unreliable MGs by restricting their electricity uses or investing in more expensive systems like solar home systems and gensets. Customers also shoulder adaptation strategies such as demand stimulation or limitation, raising issues of energy justice for low-income customers [119], [120].

CRedit authorship contribution statement

Théo Chamarande: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Emilie Etienne:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Sandrine Mathy:** Writing – review & editing, Supervision.

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Declaration of Generative AI and AI-assisted technologies in the writing process:

During the preparation of this work the authors used DeepL in order to translate some of the quotes of our interviewees. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix

1. Mini-grid developer, May 2022

“The biggest challenge with mini-grids is how to size the mini-grids. The thing is, obviously, like for example, what we do at [company name], we usually do like initial surveys. So you try to understand what customers consume, what type of loads they have, that sort of thing. But the thing is, the moment you install the system, you can either install a very big system and unfortunately, once you go live and

the consumption is really low. And sometimes you can be very conservative and install a small system and once you go live, consumption is really high.”

2. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“And then there was a second phase where we said we were going to be more rigorous and really estimate the demand by analysing: Could people have fridges? [...] How many lamps per house? And that took about three days. We had a team of students who went out and actually visited each house.”

3. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“Initially, people are very enthusiastic about having electricity and they promise everything they can. But once the system is in place, not everyone connects on the same day because the cost of the subscription is a barrier for some.”

4. Mini-grid developer, April 2022; translated from Spanish by the authors

“So, it's also true that we thought that they were going to consume more on an individual basis and they have consumed a little bit less than what we had predicted. And well, as I said, we are in the process of acquiring new customers”

5. Mini-grid developer, April 2022; translated from Spanish by the authors

“When you work with a community, that has not had electricity, you never really know the energy that they are going to consume”

6. Mini-grid user, April 2022

“I usually use more power especially when the children are around when schools have closed. Because when schools are closed, almost eight showers, ten showers a day and that is energy consumption! But when schools are on, almost three or four from my young one and my better half.”

7. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“We also had to estimate the number of people who would switch to an autonomous system [Solar Home System], because at the time, that was also a question. A lot of people thought they would have their own system, and people didn't think that was a good thing, because Kenya Power wouldn't come along that quickly. There were people who had already started putting money in place, a budget, putting money aside. So I made an estimate and said to myself, “well, if 20% of people switched to an autonomous system, this is what we'd get”.”

8. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“And we covered, I think, 80% of the houses in those 3 days. The rest was just a projection. After that, I used a model with some estimates.”

9. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“And so, at the time, I believe, there was the bank. There was a bank in [village name]. The bank was a very big consumer. And this bank... it is so unfortunate. Because the day we were doing the sizing, the teams and everyone told me that they weren't going to be customers because they had a programme to have their own system. So, we designed the system without them in mind. They were excluded. But as soon as the system was up and running, they came to subscribe. Unfortunately, the rules governing concessions and the licensing are that you have to serve the area. You can't refuse a customer, so we had to give them a service contract.”

10. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“In the end, there was only one pilot project because the people who had designed the project had thought, and it was someone who had worked in Senegal before, at [name of the cooperation agency], who had designed the programme for Kenya, and I think his idea was for 10 kW or 20 kW systems. So he was thinking of at least three pilot projects. But in reality, when we chose the site, we couldn't afford to put 10 kW at [village name]. It would have been ridiculous. So that was that. So it was an arrangement from the outset, from the very inception of the project.”

11. Employee of a funding agency, May 2022; translated from French by the authors

“To raise debt, as we said, everything has to be bankable and the banker has to be risk-free. In other words, you have to be able to cover what we used to call “debt servicing”, which is the principal plus interest, you have to be able to cover it with guaranteed cash flow.”

12. Employee of a funding agency, May 2022; translated from French by the authors

“Another difficulty with them [international funding institutions] is that you'll say "according to Kenyan law, my environmental and social permit is OK. Kenyan law allows me to do this". They'll say "wait a minute, yes, that's Kenya. But what about World Bank standards? It's not the same authorisation". So your environmental and social study has to meet very specific standards and be recognised by very specific firms. You could find yourself saying, “I've done all my E&S [Environmental and Social] study and I have to do another one because it doesn't meet the lenders' requirements”. You're going to be back at it for another 5 to 6 months, and everything has to be absolutely perfect in terms of local authorisations.”

13. REREC employee, April 2022

“We are still struggling. So if you can recommend, even in your reporting, that investors walk to Kenya, [laughter] we will be very, very happy. Because power used to be a privilege in the past, but right now, it's a basic need. People can't live without it. And that is the pressure that we are feeling, all of us. Be it [private developer name], private investors or government investors, we are all under pressure to make sure that this much needed facility is available to the people.”

14. Employee of a county, April 2022

“Even the topography cannot even allow for the construction of the Kenya Power and Lighting Company. So they [private developer] just come as a relief and whatever they're doing, only their tariffs are not fine.”

15. Employee of a county, May 2022

“Because the energy plan is-- one of the objectives is to identify potential energy sources for potential area for investment. And one that is there of course, now it is easier to kind of bring on board organizations or company that can invest on that, on the energy.”

16. Mini-grid developer, April 2022; translated from Spanish by the authors

“And also, with the issue of tariffs, and in fact we are also in a negotiation phase with them right now, because they have asked us to lower the tariffs up to half. We are now studying it and we are going to make a counteroffer, because if we lowered the tariffs to the level they are asking for, we would not be able to survive”

17. Employee of a mini-grid developer association, May 2022

“But the main thing with any of the regulations that we are looking at now is that they basically, irrespective of what is required in them, the main issue is that they take over one year to approve one site. When you take the environment impact assessment, you take the tariff calculation, you take the licensing, you take all these things, you put them together and it's over one year of waiting per community.”

18. EPRA representative, April 2022

“From the feedback that we got from the developers, because they said, “It's very difficult to go to a financier with just the tariff approval without the license to get funding.””

19. Employee of a funding agency, May 2022; translated from French by the authors

“You, as the government, have access to cheaper debt, so it's going to cost less to build, and you have access to all the legal contracts you want with the government, because it's you. So you don't have to worry about getting a building permit or a concession contract in order, because you're the one doing it. So you can be sure that in the end, as a government, it will cost you less to build.”

20. KPLC employee, April 2022, referring to the maintenance of the distribution grid

“Priority is given to the high load areas. We look at of course what you'll get out of it in terms of billing. If you have an industrial customer who is out, even if it is one, you'll go to that area before going to domestic customers who will not give you a lot of returns. But also you look at the density of the population, if only one customer. But it depends also on the loading. High load customers are the main priority followed by high density areas then you go down to the rest.”

21. EPRA representative, April 2022

“in Kenya, it's very difficult to give money directly to a private developer from government coffers or to transfer money, because that will mean you're subsidizing a private developer directly which has been a challenge so far. So, we haven't overcome that challenge.”

22. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“Some operators with ambitions to do larger systems or to do a lot of systems will use Homer. Because it's well known, because there's a reputation behind it. There's a name, they'll say: "Oh yeah, it's Homer". And that's it, it's talked about everywhere, and so it creates a kind of credibility. But generally, they also have their models, made by hand, in which they've applied the judgement.”

23. Mini-grid developer, May 2022

“No, we do not use that [HOMER] because we have this tool that we developed internally and it's great”

24. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“No, we did it manually in Excel. On the one hand, I think it takes time. It's not optimal, but it still allowed us to be a little more precise and to use something that is a major asset, our judgement. The software doesn't have the judgement and the software repeats things that have happened elsewhere. And so the judgement actually allows you to put into the model the hypotheses that are those of the site itself.”

25. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“It's not really calculated [the discount rate used in the calculation of the electricity cost], but it's based on economic models, on historical inflation, in fact. And then, well, the figures sometimes come from World Bank estimates, from experts like me who have an intuition. And then they say something, and then everyone does what they say [laughs]. So it's basically their intuition. But often that intuition is very accurate. Because it's based on years of experience or failures, successes, and then finally, we say to ourselves, “here's a figure that's not going to distort the market”.”

26. Private developer, May 2022

“We will rather oversize the battery and make sure the PV size can charge it 100% each day. And it can also sustain the loads without PV for the next two days when it is 100%. I think that way you will have solved the problem.”

27. Employee of a funding agency, May 2022; translated from French by the authors

“Imagine your company wants to set up mini-grids in Kenya. On the one hand, it's going to have teams, the whole sales force, lots of employees. On the other hand, the lenders are going to ask for the assets, i.e. the mini-grid as such, to be legally separated into two different structures, the teams and the assets. In other words, you're going to have... let's imagine company X, it's going to have a

subsidiary with all the assets inside, all the mini-grid, and so that's going to be an empty shell where you're not going to have any employees. On the other hand, the balance sheet is going to be very interesting. Because on the assets side, you'll have all the money and on the liabilities side, you'll have all the money invested. And what people are going to ask for in particular is: "Yeah, I don't mind lending you the money, but I don't want to pay the salaries". It happens all the time. "I don't pay for OPEX, I don't pay people's salaries, I don't pay for the company's development. I'm prepared to give you money to pay for the assets"."

28. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

"A subsidy, if it has to be obtained, is useful and can sometimes be exaggerated in order to get the maximum subsidy. But when the operator is confronted with other types of financial instrument, such as loans, the operator knows that it will have to repay the loan, so it does what it has to do. The operator knows that he will have to repay the loan, so he is a little more careful about sizing to ensure that he has some useful capacity, i.e. capacity that can be converted directly into cash."

29. Employee of a funding agency, May 2022; translated from French by the authors

"So you go to them and say, "I've got my electricity purchase contract, and according to the contract, I'm obliged to start building in 3 months, because the government has undertaken to sign", and they say, "Hang on, hang on. I'm not sure your contract is bankable, because I want a lawyer to review it". And like these public institutions, they don't want lousy lawyers. No, they want the best, the very best, but with fees of at least \$30,000 a month. It was Gide and Norton Rose [Fulbright], Trinity, the guys who are in the top firms in Paris and London. They are very strong. They're very good, except that when it comes to justifying their fees, well, they're going to find things to complain about. Contracts are never perfect, so they'll say, "Well, that's that. Now you have to sign an amendment to the concession contract to the power purchase contract with the government to change this point, that point, that point", so you go back to negotiating with the local authorities."

30. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

"After that, there are other things that may also require subsidies. It's everything that's done upstream. Sizing studies are often money that operators put on the table and they're not even sure they're going to do the project because they don't have the licences. They don't have the certainty, but it's money put up front. And this money, because it's a risk that it might not be profitable to some extent, is a risk that should normally, in my opinion, be covered by subsidies. [...] In other words, the amount of studies that are required, [...] the level of consultants who can do such studies, their price, their costs, so it's quite expensive."

31. Employee of a funding agency, May 2022; translated from French by the authors

"If you tell them, "Here, I've got one mini-grid, two mini-grids", they won't have a solution for you, in fact you're too small. They're going to start thinking if you start talking about thousands of mini-grids, it has to be in the millions, you see. If you're under even 5 million, it's going to be very hard to raise debt or to get really attractive terms, because that's what we call the portfolio effect. You have to have a lot of mini-grids to reduce the risks. If you have ten mini-grids and only two of them fail, you're screwed. If you have a thousand and 20 crash, it's no big deal, it'll pass. And above all, if you want to raise debt to finance all your mini-grids, you need to have a lot, you need to start talking in

terms of millions. Because today, who has the money? Who lends money in Africa? It's not the commercial banks, the Kenyan banks, which don't have the skills. As I was saying, it's the international institutions.”

32. Mini-grid developer, April 2022; translated from Spanish by the authors

“The service we are giving to the community is free of charge because the community has also worked with us, they gave us the land where we have the photovoltaic plant. That land belongs to the community, but we use it and we don't have to pay for it. We give free light at night to the whole village. We set up streetlights and nobody pays for that light. This is the contribution that we give to the village as a way of saying “thank you”, because they have always collaborated.”

33. Employee of a private operator, April 2022

“In meeting the operation costs, that is the simple math that has been used in all those. You connect a customer; a customer pays let's say 300 or 400 in a month as in most cases with our customers. So 400 will not be enough out of the huge investment done to achieve a single customer. So, we need these customers to use more appliances. That's why we introduced such items as the electric pressure cookers to realise profits at a very fast rate.”

34. Mini-grid developer, Mai 2022

“Usually, the achievement of the demand that we expected is not reached in the timeline that we were expecting, so in those scenarios we do stimulate the demand using free projects”

35. Employee of a private operator, April 2022

“Going to-- usually I populate a list from the system about target customers. For example, I want to pay a visit, maybe they're customers who have never used electricity let's say for a month, and you try to know exactly what prompted them not to use this service for all this time. Is it sickness, is it school fees? Were they dissatisfied at a given time due to poor, maybe handling? So that you get them back on track. Another one is a site visit by technician to maybe solve a ticket. A customer has a positive account balance, no power in their house. Another visit should be maybe for interaction purposes, to reach out some sales targets or two can be by a technician to solve some tickets with the customers. Another one is maybe to go and see what the caretaker is actually doing with these customers. Is he or she making door to door visits? Is he or she actually knowing what customers are going through? Is it because these customers have forgotten the contact number of the company to request about the correct pay bill number? So we tend to teach these caretakers to be proactive in terms of their reporting and raising tickets with the customer care desk that is down here.”

36. Ex-employee of a bilateral cooperation agency, May 2022; translated from French by the authors

“When I carried out the design studies at the time, I knew that it could work for 2 or 3 years, but that beyond that, the capacity would have to be increased. [...] But then, there were budget limitations, so we thought that with the 70 cents as well, there would still be room to increase capacity. But unfortunately, or fortunately, we gave the contract when we handed [village name] over to the

government. The contract to maintain it was drawn up in accordance with the rules for inviting tenders. There's transparency and everything that comes into play, so it was the best bidder at the time in the market, the best bid technically and financially that won, and so in the end, I think it's [company name] who inherited the operations, the maintenance. But their price and their offer didn't really allow us to put a lot of money aside to have this increase in capacity three years later. So I knew that three years later, there would certainly be a problem.”

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