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Business models and access to finance for mini grid development in sub-Saharan Africa

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ABSTRACT

Drawing from a comprehensive literature review of publications from academia, industry, government and international institutions, this paper presents a critical analysis of the different business models and modes of finance for mini grids in SSA, alongside the operational risks and challenges faced by these emerging systems. First, we investigate the different business models that currently exist for mini grids in SSA, providing insights into the opportunities and challenges of each approach. Second, we identify access to finance as a prominent challenge to the expansion of 'third generation' or solar/ solar-hybrid mini grids in the region. In so doing, we explore the different configurations of actors, institutions and processes involved in the provision of finance and investment. Third, we examine key investment, regulatory and operational risks and challenges to the sector's current and future development.

Despite a notable growth in the deployment of solar and solar-hybrid mini grids in SSA and elsewhere, progress in bridging the rural electrification gap has been slow. More than 750 million people globally still lack access to electricity in the region, particularly in remote areas considered too poor to afford cost-reflective tariffs. As this paper argues, more clarity is needed between the enthusiasm expressed regarding the potential of mini grids and the level and quality of finance available for such systems.

While the literature points to hybrid ownership, partially subsidised models, a focus on anchor customers, and the bundling of projects into financial portfolios as the most promising business strategies, we argue that there is no one-size-fits-all solution for mini grid business models in SSA. An optimistic narrative towards private sector participation may not always translate into greater accessibility and affordability, particularly for geographically remote and low-income users. While the mini grid sector in SSA has grown significantly in recent years, securing adequate and appropriate external finance remains a key challenge.

Introduction

By 2023, 750 million people globally lacked access to electricity, most of them in sub-Saharan Africa (SSA), where 58 % of the continent's population lives in rural areas (IEA, 2024). Significant gains made in energy access worldwide between 2015 and 2020 have been undermined by the Covid-19 pandemic, Russia's invasion of Ukraine and global increases in the cost of capital (IEA, 2024). Progress in electrification has also lagged behind population growth. Based on 2022 projections, more than 500 million people will need to be connected for SSA to achieve the sustainable development goal 7 (SDG7) target of "access to affordable, reliable, sustainable, and modern energy for all" by 2030, of which 380 million connected to mini grid systems (ESMAP, 2022:35).

Despite the recent growth in the installations of solar and solar-hybrid mini grids, there is a disconnect between the enthusiasm

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expressed by energy and development institutions regarding the sector's potential contribution to the realisation of SDG 7, and the level of finance and investment currently provided for it. Commitments from development finance institutions (DFIs), including the World Bank, the French Development Agency (AFD), the African Development Bank (AfDB), the German Corporation for International Cooperation (GIZ) as well as Climate Investment Funds (CIF), currently dominate the financing landscape for mini grids in SSA and are meant to leverage private sector investments. However, according to estimations of ESMAP's Global Electrification Platform, of the $91 billion of investment required to connect 380 million people in SSA to solar hybrid mini grids, less than 10 % had been approved by 2022 (ESMAP, 2022:85).

The term mini grid refers to a low-voltage or medium-voltage generation and electricity distribution network which can operate in isolation from the main grid, but also connect to it should the network expand. The nature of a mini grid is such that power can be generated much closer to the point of consumption. Sometimes referred to as the 'missing middle' between the centralised electricity grid and solar home systems (SHSs), there is no clearly agreed definition of a mini grid in terms of size, generation capacity, customer base or energy source. It is a term through which the often-competing objectives of productive use, energy access and rural electrification have frequently been conflated (Baker et al., 2022; Sesan, Uduka, et al., 2024).

The falling price of solar technology and battery storage has greatly encouraged the growth of solar PV and solar-hybrid or 'third-generation' mini grids, as compared to previous systems, which were predominantly diesel and hydro-powered. Notably, the cumulative share of diesel in the total installed capacity of mini grids fell from 42 % in 2018 to 29 % in 2024, while the cumulative share of solar PV systems grew from 14 % to 59 % over the same period (Adamopoulou et al., 2024:28). ESMAP's latest data estimates that by 2024, 21,500 mini grids had been installed, serving a total of 48 million people, of which half in SSA (Ibid p22).

By way of illustration, Fig. 1 shows the increasing trend in solar mini grids in four different countries of the region.

While financial sustainability is often put forward as the most significant challenge for mini grid expansion and a project's long-term success (Moner-Girona et al., 2018; Ogeya et al., 2021; Tsuchiya et al., 2020), this will not be achieved without successful and scalable business models. With this in mind, our literature review firstly explores the different mini grid business models that currently exist in SSA, providing insights into the opportunities and challenges of each approach and illustrating these with case studies from different country contexts. Secondly, the review identifies access to finance as a prominent challenge to the further expansion of third generation mini grids in the region. In so doing, we explore the different configurations of actors, institutions and processes involved. Finally, we examine some of the key investment, regulatory and operational risks and challenges in the sector's current and future development.

Experience to date has shown that finding a balance between affordable service provision and adequate cost recovery is a key challenge for the financial viability of mini grids, particularly where the project serves low demand consumers with limited ability to pay in remote locations (Knuckles, 2016; Peters et al., 2019; Sesan, Uduka, et al., 2024). Various options have been put forward in this instance,

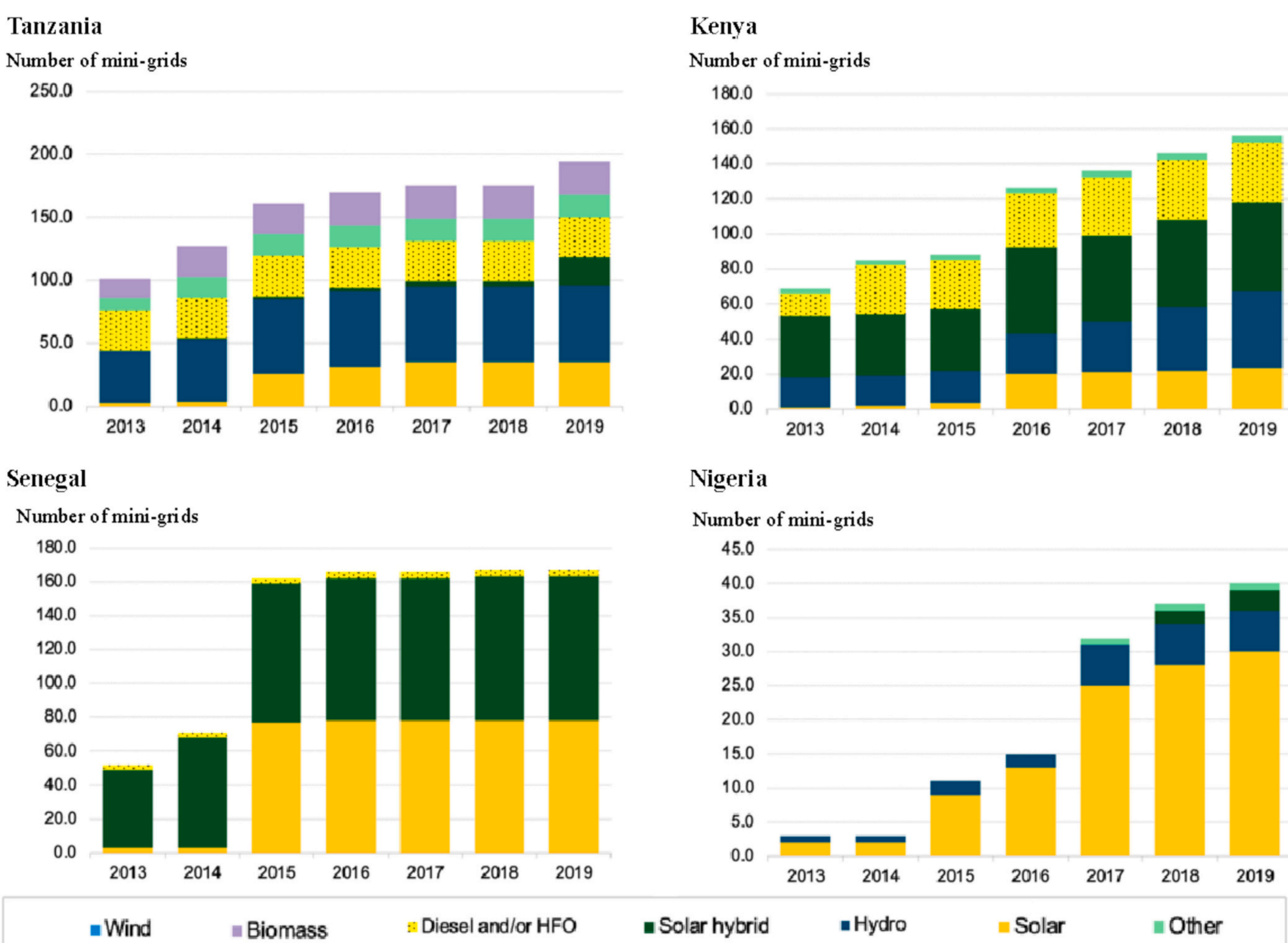

Fig. 1. Mini-gids by type of technology in Tanzania, Kenya, Senegal and Nigeria.
Source: Authors' own using information from Blomberg NEF database, 2022.

including the provision of public subsidies for either the project capex and/or the tariff, and the anchor business consumer-based model. While evidence from the literature points to hybrid (i.e., public-private) ownership, partial subsidies, the inclusion of anchor business customers, and the financial bundling of portfolios as the most promising strategies for financial sustainability and scalability, no bulletproof business model exists (Franz et al., 2014; Safdar, 2017). Additionally, the lack of quantitative evidence in the literature hinders the ability to compare and accurately correlate business models with financial outcomes.

The structure of this paper is as follows. Literature review methodology Section describes the methodology used for the literature review. Unpacking mini grid business models Section unpacks the different types of business models while Access to finance: actors, institutions, and processes Section explores the main actors, institutions and processes involved in access to finance for third generation mini grids in SSA. Exploring key risks and challenges Section examines the key investment risks and challenges of the sector to date. The paper concludes that the positive narrative towards private sector participation does not necessarily make electricity more accessible and affordable for users at the last mile and puts forward policy recommendations with this in mind.

Literature review methodology

This literature review primarily draws from academic articles and reports by the energy industry published between 2005 (the earliest year for which publications on mini grids were available) and 2022. Publications were selected based on their relevance to the development of the mini grid sector, particularly their analysis of the SSA context. Industry reports covering other developing countries and global perspectives were also analysed. A search process was carried out using the Scopus, ResearchGate, and Google Scholar databases. While there are a limited number of academic articles specific to mini grid business models, the review examined the literature focusing on the socioeconomic performance and sustainability of the sector. The scope of the review is briefly summarised in Table 1.

The literature originally reviewed consisted of 109 documents, of which 52 % were peer-reviewed academic papers, and 48 % grey literature and media. A number of additional documents were subsequently consulted as part of the paper's review process. The literature consulted was mainly in English, except for some country reports in French. In reflection of the sector's development, most publications focus on the last eight years, from 2015 to 2022, followed by the preceding six years, with relatively fewer publications covering the period between 2006 and 2007. The growing number of papers and reports in recent years reflects an increasing interest and relevance of the role of mini grids in energy access in developing countries, particularly in SSA. Tanzania, Kenya, and India are some of the most analysed countries in the literature, suggesting that one of the limitations is the lack of comparative case studies from elsewhere. This, in addition to the dominance of anglophone sources.

The research also drew from quantitative analysis from the Bloomberg NEF database, the results of which are presented throughout the paper. However, the absence of quantitative data to assess the influence of business models on mini grid profitability hindered our ability to compare their financial sustainability.

The literature analysis was conducted using Nvivo software, and the information was coded in three main areas: business models, access to finance, and risk and challenges. Within each section, a list of sub-codes aggregates the most significant themes mentioned by the literature, as described in Table 2.

Table 1
Scope of the review.

Scope element	Inclusion criteria
Electricity systems	Mini grids
Geographical scope	Low and middle-income countries (particularly from SSA)
Publication date	2005 onwards (lack of publications before this year)
Publication format	Journal articles, working papers, evaluations, institutional reports, and media
Methodological approach	Primary and empirical studies using quantitative or qualitative data
Publication language	English and French

Source: Authors' own.

Table 2
Literature review coding.

Main code	Business models	Risks and challenges	Access to finance
Sub-codes	- Ownership - Source of revenue - Customer focus - Implementation	- Regulation and market access - Demand and sizing - Macroeconomic risks - Affordability - Governance - Skills and technical - Social risks	- Type of funding - Sources of funding

Source: Authors' own.

Unpacking mini grid business models

There is no single definition of a business model in the literature. The term is used differently according to value creation, operations, and delivery structures. This section unpacks the various different mini grid business models that exist, with a particular focus on ownership and management; consumer-focussed; and cost recovery models.

Ownership and management models

Structures of mini grid ownership vary according to who holds and operates the project's assets, for instance the public utility, private sector, community, and hybrid arrangements. The ownership model often depends on the source of financing and the party responsible for managing the operations after installation. However, there is a lack of sufficient quantitative information in this topic that allows for comparison. For example, according to the Bloomberg NEF 2022 database, out of the 984 mini grids identified in four countries in SSA (Nigeria, Senegal, Tanzania, and Kenya), only 470 were defined by ownership type. Table 3 shows the number of mini grids in those four countries by ownership model, indicating that public ownership is predominant in Senegal and Kenya, as compared to Tanzania and Nigeria, where the private sector has a larger market share.

The nature of mini grid ownership also depends on context-specific variables including the regulatory framework, as well as geography, and socio-economic and political factors (Safdar, 2017). While our analysis found that none of the established ownership models have proven successful in SSA, according to industry reports, the hybrid public-private partnership (PPP) model (see Hybrid ownership Section) has the most potential for scale-up, so long as the appropriate balance between private and public ownership and control can be established (AfDB, 2016, ESMAP, 2022:152).

Public utility ownership

Under a public utility model, the national electricity utility owns and operates the mini grids, as is the case in Senegal and Kenya for instance (see Table 3), and is responsible for installing, managing, and maintaining the system. The initial financing is likely to be provided by the utility and subsidised by public funds from government or DFIs through support for national electrification programmes (AfDB, 2016; IED, 2013; Safdar, 2017). This model is seen as crucial to meeting the social objectives of electricity access and, in some countries, e.g. Namibia and

Table 3
Number of mini grids by ownership model.

Country	Total database	Public	Private	Public Private Partnership (PPP)	Community	Unknown
Nigeria	67	1	45	10	1	10
Senegal	431	107	1	6	7	310
Tanzania	278	36	112	5	42	83
Kenya	208	70	6	4	17	111
Total	984	214	164	25	67	514

Source: Authors' own using information from Bloomberg NEF Database 2022.

South Africa, the utility often matches the grid's national tariffs, which are cross-subsidised by other customers (AfDB, 2016; RECP, 2014; Safdar, 2017).

State-owned mini grids are relatively common in SSA, and national utility companies have been key players in early mini grid development, including TANESCO in Tanzania and KPLC in Kenya (Baker et al., 2022; ESMAP, 2019), though they have primarily depended on conventional technologies e.g. diesel, and hybrid systems (Pedersen, 2017). Despite the potential role that the public utility model could play in electricity provision, it is often perceived as more expensive and inefficient than privately-developed mini grids and there is inconsistent evidence on the model's success (Antonanzas-Torres et al., 2021; ARE, 2014). Indeed, as some argue, most utilities in SSA are not financially solvent, sell at a loss, often lack the necessary technical expertise and frequently prioritise social and political outcomes over financial sustainability (Trimble et al., 2016, USAID, 2017, ESMAP, 2022:152).

Private ownership

In this model, a private company develops, owns, and operates the mini grid, as is now the case in Tanzania and Nigeria for instance (see Table 3). The funding can come from different sources, including private equity, commercial loans, and subsidised finance such as grants, results-based finance, or public sector loan guarantees (AfDB, 2016; Franz et al., 2014; Safdar, 2017). The demands and expectations of equity investment are such that the mini grid must provide returns proportionate to the perceived investment risk, which is a challenge given the lack of cost-reflective tariffs in certain countries (Weston et al., 2018).

International energy institutions have called for more extensive private participation to help meet SSA's rural electrification targets, arguing that with appropriate and well-targeted investment, the private sector model is best placed to provide higher quality service and efficiency than other ownership models (ARE, 2014; IEA, 2022). Access to subsidies or grants may enable the expansion of this business model. Private sector interest in mini grids is enabled by favourable regulatory frameworks that allow it to charge cost-reflective tariffs, and operate in locations with the greatest commercial viability, including where anchor customers and productive users with higher demand are present (AfDB, 2016; ESMAP, 2022; Safdar, 2017). However, private participation has faced its own challenges, and few initiatives have achieved financial sustainability to date.

Hybrid ownership

Hybrid models combine public and private sector actors, with different parties building, owning, and operating the distribution and generation assets of the mini grid. These models are based on a division of responsibilities through various contractual arrangements including PPPs, renewable energy service companies (RESCOs), concessions, power purchase agreements (PPA), and others, as discussed in Table 4. The success of hybrid models requires a clear regulatory framework that establishes a balance between private and public participation and sets out the roles and responsibilities of both parties.

The most common hybrid models are PPPs with public ownership and private operation or split-asset models with public ownership of the distribution assets and developers owning the generation assets (ESMAP, 2022:152). According to Gershenson et al. (2015), under this structure private developers have a greater influence in defining the project's risks and benefiting from publicly-financed de-risking mechanisms. It has been argued that PPP structures can overcome government budgetary constraints, diversify project risk between actors, and optimise the expertise and efficiencies of the private sector.

Table 4
Contractual options for Hybrid models.

Public Private Partnership (PPP)	Contractual agreement between a public and a private party that combines financing, ownership, and management capacities.
Renewable Energy Service Company (RESCO)	RESCO companies work similarly to utilities at smaller scale, whereby the assets are purchased and owned by the government while RESCOs operate and maintain the mini grid.
Concession Model	A holder of a concession, usually a private developer, has beneficial terms for supplying electricity. Those terms can be translated in preferential market access for specific timeframes or specially designed tariffs for the area of operation.
Power Purchase Agreement (PPA)	A PPA is a contractual arrangement between public and private sector parties for electricity supply where the public entity will purchase the power generated by the private energy producer over a certain time frame and under an agreed tariff structure. A PPA is also mandatory for the public utility to sell power to a privately owned distribution network operator.

Source: Authors' compilation based on relevant literature cited in this section.

The participation of the private sector in mini grid development has been driven primarily by concessional instruments from DFIs and climate finance institutions, including low-interest and long-tenor project loans, public guarantees, and grant-based capacity building programmes. Its discursive rationale is that the private sector is far more efficient and less corrupt than that of a state-owned utility (cf Baker et al., 2022).

ESMAP (2022) argues that one of the success factors of hybrid models is the collaboration between different players, bringing together experience in access to finance, technical capacity, and operational efficiencies. Others have indicated that these models rely on the clarity of property rights regarding the assets, governance and technical arrangements, and interconnection policies concerning the utility's grid expansion (Safdar, 2017; Weston et al., 2018). Yet there is insufficient evidence to date e.g. quantitative analysis and case studies to demonstrate the effectiveness of this approach in enhancing project profitability.

Case study 1. Hybrid ownership of mini grids in Kenya.

Kenya has a long history of public funding and ownership of mini-grid systems in unserved rural areas, dating back to the 1970s (Ogeya & Lambe, 2025). This focus had delivered a legacy of 22 state-owned mini grids by the early 2000s, at which time investment in rural electrification was opened up to the private sector and a shift from diesel-powered to decentralised renewable energy systems was emphasised (ibid).

The Kenyan government has leaned towards a hybrid ownership model in more recent times, most notably through the World Bank-supported Kenya Off-Grid Solar Access Project (KOSAP). Under KOSAP, the state owns all the generation and distribution assets, essentially investing public funds in enabling access for some of its poorest citizens. While it is taking a while to get off the ground, the government's

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attention to matters of distribution and equity already seems clear: the project aims to generate only a third of the combined capacity of existing mini-grid installations in the country (14 MW as opposed to approximately 42 MW), yet it will serve 17,000 more households than the 45,000 served by pre-existing public and private schemes (Ogeya & Lambe, 2025).
KOSAP illustrates the promises and perils of the hybrid ownership model for mini grids: on the one hand, there are private actors who are distrustful of the inefficiencies of the state apparatus, and on the other hand, there are public agencies that are concerned about the potentially debilitating effects of unbridled privatisation on their most vulnerable citizens (Ogeya & Lambe, 2025). The long-term efficacy of the hybrid model will depend on the ability of public and private actors to mitigate these tensions in different contexts.

Community ownership

In this model, which is predominant in development aid projects, the mini grid is owned and operated by a local community that may have received the project's assets from a government programme, a non-profit, or a DFI. Communities may also receive external support in designing, financing, and installing the project, such as grants and in-kind contributions (AfDB, 2016; Peters et al., 2019; Safdar, 2017). This model, which is predominantly donor-funded, is more common in isolated rural areas that do not attract private-sector or utility interest because of the high cost of supply and the presence of consumers who may be too poor to afford cost-reflective tariffs (ARE, 2014; ECREEE, 2016).

Some authors have questioned the model's long-term sustainability due to the difficulties in building local capacity, and the risk of donor dependency (Duran & Sahinyazan, 2021; Franz et al., 2014; Yadoo, 2012). Others argue that while community models often require long-term subsidies and technical support (Gershenson et al., 2015). Ilskog and Kjellström (2008) the viability of this model could improve if it operates as a rural power cooperative in which financial discipline mirrors a private model.

Consumer focused models

While it is often assumed that mini grids will provide access to low-income, rural, and isolated communities, developers and financial actors generally consider the level of electricity demand within such communities too low to ensure the system's economic sustainability (Peters et al., 2019). Many have argued that the limited ability of low-income households to pay increases the need to foster productive energy use and integrate larger commercial and anchor customers to increase demand (AfDB, 2016, Pueyo et al., 2020, AMDA, 2020:40).

New approaches to incentivise productive use have therefore become a priority for designing and implementing many consumer-focused models. However, the extent to which such strategies will improve mini grid profitability is unclear. While some studies show positive impacts from productive use, e.g. Kirubi et al. (2009), others show no evidence of increased profitability (Pueyo & DeMartino, 2018).

Households and small businesses model

Off-grid solar systems often serve households and small businesses in low-income markets, sometimes providing electricity at a lower price than other energy sources, such as kerosene (Knuckles, 2016). However, given that mini grid tariffs are often more expensive than those from subsidised grid electricity, they can create an affordability barrier for off-grid populations. Indeed, there was little evidence in the literature to suggest that mini grids can achieve long term financial sustainability by focusing on household and small businesses customers alone (Peters et al., 2019; Pueyo & DeMartino, 2018). In rural SSA, the average consumption per mini grid customer tends to be very low, with limited ability to pay (AMDA, 2020:37) and electricity demand tends to fluctuate alongside seasonal household income, thereby failing to match the regular expected demand estimate for system profitability (Peters et al., 2019).

In response, various authors have called for increasing and promoting productive users and facilitating access to appliances, e.g. water pumps, freezers, and milling machines, and fostering community engagement to stimulate demand, achieve a sizeable and stable load and ultimately the revenue streams of the developer (Bahaj & James, 2019; Sharma & Palit, 2020; Uamusse et al., 2020). To do this, ESMAP (2022:8) argued that increasing the uptake of productive-use equipment would require approximately $3.6 billion in affordable consumer finance.

The Key-Maker model (KMM), which combines mini grid operations with an energy-intensive commercial activity, stands out among approaches to promote productive use (Peterschmidt, 2019a) and has been pioneered by the Tanzanian mini grid developer JUMEME (Pueyo et al., 2022). Under the KMM, the mini grid developer supplies electricity alongside the processing of another complementary electricity-intensive product, often using the natural resources and supply chains already available in the community. For instance, the mini grid company buys local agricultural products, processes them using electricity generated by the mini grid, and transports them to be sold in urban areas. This way, the developer sets up a stable demand for the mini grid while making profits further downstream (Peterschmidt, 2019a:8). However, a key challenge of the KMM relates to the capacities and knowledge needed to operate a business beyond the mini grid (Pueyo et al., 2022).

Anchor business consumer – A-B-C model

The A-B-C model was first developed in India in association with the telecom sector (GIZ, 2014). Under this model, a large industrial customer with a high and stable load, such as an agro-processing or mining company that requires access to reliable electricity, or a group of industrials with reliable cash flows, act as anchor clients. The electricity supply for these customers is prioritised, followed by small productive users and households (ESMAP, 2022; Franz et al., 2014; Ramachandran et al., 2016). This model aims for stable revenue that improves the sustainability of mini-grid operations, reducing the risk of connecting smaller consumers with lower payment capacity by lowering the unit cost of electricity (Beath et al., 2021). Two examples include Sincro Sitewatch in Tanzania and Kirchner Solar in Uganda (EAPN, 2018; EEP, 2015).

While the main success factor of the A-B-C model is the long-term relationship between the mini grid and the anchor customer, prioritising their demands can limit the mini grid capacity to extend connections and guarantee service reliability to smaller users. Therefore, it may not necessarily increase access to energy for low-income households (Bhati & Singh, 2018; EEP, 2015). Moreover, the lack of availability of large businesses in many rural areas may limit the scalability of this business model.

Case study 2. The promises and perils of the A-B-C model in Kenya.

Herbert and Phimister (2019) interrogate a range of tariff-setting scenarios for a wind-powered mini-grid plant that is anchored on the typically high demand from a tea factory in rural Kenya but also meets the much lower demand from surrounding households and small businesses. The overriding concern of their financial analysis was how to balance the benefits from the mini grid in such a way that cost savings are delivered to the tea factory (relative to its previous spending on electricity) – thereby increasing its incentive to bear a share of the capital expenditure for the mini grid – but only to a degree that allows tariffs to be set for smaller energy users that are proportionate to their ability to pay. The analysis essentially foregrounds the difficult question of how to simultaneously achieve efficient supply and equitable distribution across different customer segments – a goal that has historically been a key prerogative of national electrification efforts across SSA (see for example Nigeria's Electric Power Sector Reform Act, 2005).
The authors found that, without government intervention in the form of equitable regulation, tariffs for the mini grid are unlikely to be set at a rate that allows for equitable cross-subsidisation, or 'cost-sharing' between the tea factory and the host community. This highlights a double-bind with the A-B-C model: while, as Herbert and Phimister (2019) show, the model has the potential to spur local economic

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development beyond the few rural factories that have historically benefitted from energy-intensive production, generally low levels of productivity and consumption in rural contexts may make it difficult to realise this under business-as-usual scenarios. It is perhaps instructive that the most concrete examples of the A-B-C model in the literature tend to be in the Asian, rather than SSA, context (for example, Robert et al., 2017; Schnitzer et al., 2014). This indicates that substantive public-sector commitment is required (as the KOSAP case study above illustrates) if the A-B-C model is to have a significant impact on poor regions in SSA.

Cost recovery models

Business models can differ in their financial and organisational structure between for-profit, partially subsidised, and fully subsidised (Schnitzer et al., 2014). The sustainability and inclusivity of these models depends on finding a balance between profit and subsidy as we now discuss.

For-profit

Under the for-profit model mini grids must cover their investment and operational costs through tariff collection and therefore focus on the customers' ability to pay, particularly that of productive users (Schnitzer et al., 2014). For-profit models share the same commercial approach as the private ownership business model, in that both require cost-reflective tariff structures (Schnitzer et al., 2014). This model therefore prioritises medium to large electricity consumers and communities with greater demand and payment capacity and is unlikely to assist with energy access for low-income consumers. Indeed, the low payment capacity in many rural areas and the inability to apply cost-recovery tariffs would pose a challenge to the model's viability. Tariff subsidisation has therefore been emphasised as a solution (Knuckles, 2016; Muchunku et al., 2018).

Partially subsidised

There is a strong call in much of the literature for public subsidies to guarantee cost-reflective tariffs that match those of the utility. With this in mind the partially-subsidised model combines the need for financial sustainability with the purpose of providing access to multiple types of customers. The project developer receives grants or subsidies from government electrification programmes and DFIs for initial investment costs but relies on tariff collection to cover operations and maintenance. Projects in receipt of subsidy are often required to guarantee energy access to off-grid, low-income customers (Antonanzas-Torres et al., 2021; Schnitzer et al., 2014). Facilitating affordable tariffs requires the mini grid developer to innovate in the project's economic structure, for instance, allowing differential tariffs by type of customer, smart metering and pay-as-you-go (PAYGO) systems (Schnitzer et al., 2014). The most significant challenge for the viability of this model is its dependence on subsidised support and the operational risks of not offering a cost-effective and affordable supply.

Fully subsidised

Despite the strong case for subsidies as discussed above, the evidence is inconsistent on the level of assistance required and the best financial structures with which to channel it. Moreover, while financial support may allow for the setting of affordable tariffs, fully subsidised models may challenge developer autonomy and encourage donor dependency.

Under the fully subsidised model, all costs are covered through subsidies or grants from the government and DFIs, in-kind contributions from communities, and tariff collection. The model follows the interest of the funder, commonly targeting areas with low payment capacity or a remote or difficult-to-reach location, and often works with local communities to stimulate electricity demand (Schnitzer et al., 2014). The developer allows a tariff structure that fits the affordability needs of the consumer rather than prioritising cost-reflective tariffs. The fully subsidised model is similar to that of community ownership, as both are fully funded by a third party and focus on social impact over financial sustainability (Schnitzer et al., 2014).

Case study 3. Subsidising mini-grid development in Nigeria.

Husein et al. (2024) modelled the effects of the three 'most significant' government policies aimed at incentivising private sector participation in rural electrification in Nigeria, taking it as a given that such incentives are a precondition for attracting investment in such a high-risk sector. The policies are: concessionary loans (long-term loans at a fraction of the interest rates charged by local commercial banks); capital subsidies (donor- and DFI-supported grants given to offset the substantial capital expenditure required for new installations and connections); and financing equipment for productive uses on the demand side.

The study found that capital subsidies boosted mini-grid penetration in rural areas from a baseline of 27 % of the population to 41 %, four percentage points higher than the effect of concessionary loans (37 %). Implicit in the deployment of these supply-side incentives is the assumption that any reductions in the cost of generating and distributing electricity will be passed on to the final consumer, much like the subsidies that moderate tariffs for grid electricity customers.

Nonetheless, studies show that the problem of affordability remains for much of the rural population targeted by mini grids (Babayomi et al., 2023; Sesan, Uduka, et al., 2024), prompting an increasing focus on productive-use activities to boost rural productivity and, by extension, affordability (Booth et al., 2018). Here, too, the results are mixed, with several studies (for example, Sesan, Fajardo, et al., 2024; Wearne & Tiwari, 2021) pointing to the need for more holistic rural development strategies if the catalytic effects of productive-use equipment modelled by Husein et al. (2024) are to be realised.

Bundling models

Bundling an investment portfolio of mini grids, for instancy by location, operations, and/or financial structures, can help lower costs and risks for developers and investors (Franz et al., 2014; Safdar, 2017; Weston et al., 2018). Bundling initiatives are attractive for private players and financial institutions due to their potential to help scale up the market size, lower operational costs and ensure economies of scale in project management, procurement and installation (ESMAP, 2022:66, Bhattacharyya & Palit, 2016).

Operational bundling

This approach aggregates mini grids in neighbouring villages to provide an interlinked electricity market through distribution lines and smart control systems (Waswa, 2021). Mini grids are bundled under an operational management structure to economise on overheads, such as administration, maintenance, and transport costs (Franz et al., 2014; Safdar, 2017). The connection of a group of mini grids in the same region can lead to lower installation costs per system and increase efficiencies in operation and maintenance (Moner-Girona et al., 2018). As a result, DFIs are increasingly encouraging operators with proven track records to implement this model (ESMAP, 2022).

However, while clustering can help to lower the cost of capital for mini grid operators and reduce transaction costs for investors, distribution remains a capital-intensive activity in which few investors are interested, relying instead on utilities to make up the shortfall (Safdar, 2017, Weston et al., 2018). Moreover, there is little evidence about whether these approaches improve mini grid profitability or whether regulatory frameworks are leaning towards creating a single structure through integrating mini grids (Safdar, 2017; Sharma & Palit, 2020). Although this model establishes opportunities for economies of scale, the literature points to technological and financial challenges and the need for strong managerial and operational skills to succeed, limiting its scalability capacity in SSA.

Portfolio diversification and financial bundling

The aggregation of projects into an investment portfolio aims to reduce and diversity risk, create economies of scale, and lower transaction and capital costs per connection (ESMAP, 2019; Gershenson et al., 2015; Weston et al., 2018). Projects may be bundled by geography (urban and rural), delivery models (EPC and energy as a service) and by sector (commercial, agricultural and industrial) (Huber et al., 2021). Some authors suggest that portfolio diversification lowers the investment risks related to high transaction costs, the market risks of investing in a single geographical jurisdiction and the unfavourable risk-return profiles of many projects (Gershenson et al., 2015; Malhotra et al., 2017).

Case study 4. Bundling mini-grid financing and operations in Uganda.

The Ugandan government, supported by the GIZ- and EU-financed "Promotion of Mini Grids for Rural Electrification" programme, has developed an integrated procurement and financing model in which various stages of project development – site selection, tendering, licensing, contracting and financing – are bundled into a single state-mediated process (Pérez-López, 2020). Furthermore, the process enables the bundling of multiple mini-grid sites into single contracts, as opposed to the previous practice of contracting individual firms to develop one site at a time. This way, the programme simultaneously enables financial and operational bundling, potentially reducing the time required to set up mini-grid projects and lowering the cost to private developers while lending itself to replication (ibid.). Notably, this model, while ostensibly conducive to foreign investment and an increased pace of mini-grid deployment, does not resolve the problem of affordability for prospective rural customers – with projected tariffs more than twice as high as the national-grid tariff even with generous (60–70 %) capital subsidies (ibid.). Indeed, there is currently no subsidy scenario on the programme that puts mini-grid tariffs on a par with those set for grid customers: the former are consistently higher than the latter, leaving unresolved the question of energy access where poor populations are concerned. Further, there is no guarantee that the efficiencies and economies of scale achieved by larger-scale mini-grid projects in the Ugandan context will be passed on to the poorest households when private developers can more easily recoup their investments from consumers farther afield with a much higher ability to pay (Sareen et al., 2024; Weston et al., 2018).

Access to finance: actors, institutions, and processes

The lack of access to finance has been identified as one of the most significant obstacles to mini grid expansion in developing economies, particularly SSA (Peterschmidt, 2019b; Phillips et al., 2020; Wang et al., 2020). By 2021, about 60 % of mini grid financing in SSA came from governments and DFIs (AMDA, 2022:13), but ESMAP (2022) asserts that at least 50 % of any future funding will need to come from private investment to reach the 2030 electrification goal. While the involvement of DFIs has been critical in helping the private sector to overcome some of the perceived risks due to lack of scale, developer track record, regulatory uncertainties, and limited electricity demand (see Exploring key risks and challenges Section), commercial financiers are calling for additional subsidies and risk guarantees. According to AMDA, grants and concessional loans are not being provided at a rate that fully supports existing pipelines and the ability to scale-up (AMDA, 2022:14).

There is also a clash of perspectives between DFIs and project developers (IRENA, 2015). While the former indicate that there is no shortage of funding, developers state that they find it difficult and time-consuming to comply with all the procedures and assessments required before any public funds can be approved and that there is a problem with funds reaching the projects in a timely manner.

As levels of debt finance in the sector have increased in the last few years, equity investment has declined (ESMAP, 2022). While this might normally suggest that the mini grid sector is maturing, debt finance remains expensive and often carries an interest rate of 15 % or more for developers in SSA (Agenbroad et al., 2018). Significantly, the financial sustainability of developers still relies on subsidies at different stages of project development. The literature is consistent in suggesting that no unique source of finance can overcome all the barriers and risks, and that the scalability of mini grids requires different financing packages combining equity, debt, subsidy, and de-risking mechanisms according to the needs of different business models (Bahaj & James, 2019, Weston et al., 2018).

According to BNEF, increasing the availability of long-term equity and debt in mini grid project finance is required to move towards a mature decentralised electricity market in SSA. As mini grids are typically built on the developer's balance sheet, the investor is exposed to all other risks that the company faces. Isolating mini grid assets from the companies that own and operate them, and allocating the infrastructure and operational risks to the developer allows for the aggregation of projects into large, diversified portfolios that can attract long-term equity and debt (Huber et al., 2021).

Sources of finance: from public and private

Public funding from governments and DFIs plays a key role in supporting the sector by providing grants, subsidies, concessional loans, and loan guarantees. Public finance for up-front capital investment in mini grids in SSA has increased significantly in the last decade (ESMAP, 2022; Hosier et al., 2017). International DFIs and development partners had collectively committed more than $2.4 billion for mini grid development in SSA by 2022, excluding funding to governments for technical assistance and research (ESMAP, 2022). Of this funding, which has largely focused on energy access, the World Bank accounted for 25 % by 2021 (ESMAP, 2022). However, DFI funding for mini grids leans towards countries with active private-sector involvement and a robust legal and regulatory framework that supports the sector, for instance in Tanzania, Rwanda, and Nigeria (Odarno et al., 2017, Bukari et al., 2021). Projects in countries with higher market entry barriers and lower electricity demand therefore find it harder to secure DFI finance. The lack of coordination between bi-lateral and multi-lateral DFIs for mini grid programmes has also been raised as a problem (Dye, 2020).

Given the high upfront capital costs of setting up a mini grid project, the sector requires patient, long-term capital. However, the low volume of transactions and the fact that projects are often perceived as high-risk by investors has discouraged their involvement. Moreover, the tenure of private debt capital is usually too short for the nascent market, and the 'bridging capital' (i.e., capital with high-risk appetite, low return expectations, and long tenure) is missing (Bhattacharyya, 2018). Public sector financing structures are therefore essential to encourage private sector participation by decreasing perceptions of investment risk (REPP & AMDA, 2023).

Compared to public sector finance from governments, DFIs, and climate investment funds, there has been limited private investment for mini grids in SSA. Indeed, most private investment in the sector has been made possible through parallel support from de-risking mechanisms with DFIs, given that grants and subsidies from governments or DFIs can increase confidence in future cash flows for private investors (Bukari et al., 2021; Weston et al., 2018). For instance, in Tanzania, the World Bank's International Development Association (IDA) has provided risk guarantees to mini grid investors.

Private investors, which include commercial banks, private equity funds, venture capital funds, and impact investors, among others, have invested in the mini grid sector through equity, debt, and grant structures. In recent years, impact investors, including Acumen, Bamboo Capital Partners, Cross-boundary Energy, and InfraCo Africa, have increased their commercial support. Some of them have been willing to accept lower-than-market returns in light of the social impact of many projects and have offered loans at single-digit interest rates, lasting up to ten years.

Type of finance

Debt

Concessional debt finance from DFIs is essential for mitigating the perceived high risks and leveraging equity investment. There are two main types of debt finance: commercial loans and concessional loans. While commercial loans are often provided by local and regional banks, usually at double-digit interest rates, with shorter repayment terms, concessional loans are often provided by national energy agencies and DFIs at lower, sometimes single-digit, interest rates and for more extended periods (Baker, 2022).

However, the reluctance of commercial banks to provide affordable debt finance to mini grids has posed a significant obstacle to developers in many SSA countries. This reluctance often stems from a lack of knowledge and understanding of the technological systems by local commercial banks who do not have the sufficient technical expertise to conduct due diligence and project appraisals. This lack of knowledge and expertise in turn increases the perception of project risk, the interest rate and the cost of capital (Odarno et al., 2017; UNDP, 2018). Consequently, access to debt through local banks often requires additional support from DFIs that provide guarantees to the lender.

In some instances, governments and DFIs offer concessional loans to help developers address investor risk by ensuring that commercial lenders are repaid first. However, accessing concessional loans can involve relatively complex due diligence and high transaction costs in terms of implementation, management and oversight. Mature developers with larger and more ‘high-impact’ projects are much more capable of coping with such costs than small and local developers (Weston et al., 2018).

Indeed, it is easier for private investors with previous track records, existing operating assets and suitably large balance sheets to access debt finance from commercial lenders (Baker, 2022). In contrast, a small community-owned project will struggle to meet the lending requirements as it is likely to have no formal standing, no previous credit record, very limited own-funding, and hardly any security for loan guarantee purposes. Given that developers must always repay loans regardless of performance, such a risk is often too great for a smaller actor. Such factors limit the ability of small companies and organisations to integrate into the mainstream capital market and to ensure the financial sustainability of their projects (Bhattacharyya, 2018).

Equity

As mentioned above, most equity investment in mini grids has thus far come from impact investors (ESMAP, 2022; Safdar, 2017). Other sources include funds from project developers, corporate sponsors, and commercial investors. Raising equity for mini grids in most markets in SSA is challenging due to unproven business models and a lack of guarantees over investment return.

As indicated in Fig. 2, mini grid developers can raise equity and/or debt through multiple financing structures, including project finance and corporate finance. Project finance targets the financing needs of a single project and structures the financing around the cash flows generated by that project. Corporate finance raises equity and/or debt at the company level and uses the company’s overall assets to secure returns for investors and creditors rather than relying solely on the revenues generated by a specific project (Baker, 2022). While project finance is primarily available for larger projects, smaller projects are more likely to receive corporate finance though in both cases this is likely to be for developers with a well-established track record. Neither are easy to achieve (REPP & AMDA, 2023).

The key challenges to accessing and managing equity investment include uncertainty about future macroeconomic conditions which discourages investment; developers being unable to charge cost reflective tariffs; potential private investors lacking experience of mini grids, considering them too risky; and expectations from investors for immediate and short-term returns, despite the project’s long-term nature.

Subsidies

Subsidies, which are often provided by DFIs and administered by government, can be provided during different stages of a project: capex subsidies cover upfront capital costs, while demand-side subsidies match affordability in rural and densely populated communities (see Table 5). Capex subsidies may also support project construction and the connection of users as a substitute for debt and equity funding. While making mini grids a viable option for affordable electrification requires significant subsidies, there are numerous challenges to accessing them (Weston et al., 2018). Subsidies are limited in availability, subject to stiff competition and allocated in small amounts as compared to the total investment costs. The process to access them has high transaction costs, usually lacks transparency and is highly bureaucratic. Providers of subsidies often impose conditions that may limit the developer’s actions.

Table 5
Types of subsidies.

Subsidy	Description
Pre-investment subsidies	Pre-investment subsidies are provided to support market and resource assessments, geospatial planning, pre-feasibility and feasibility studies, and technical assistance (ESMAP, 2019). This type of subsidy is available primarily through DFIs.
Up-front capital subsidy	Covers the high initial investment costs of mini grids. The capex subsidy is disbursed before the mini grid installation, and calculated based on installation cost, the number of connections, and the internal project rate of return (IRR) (Franz et al., 2014). Up-front grants have been the most common subsidy for mini grids (ESMAP, 2019).
Demand-side subsidies	Demand-side subsidies target the tariff structure, such as lifeline tariffs, and provide subsidies to customers for purchasing energy-efficient appliances and productive equipment. These subsidies are available through government programmes and electrification plans. Subsidising the demand enables more extensive electricity use while improving the mini grids revenues (ECA & AMDA, 2020).

Source: Authors’ compilation based on relevant literature cited in this section.

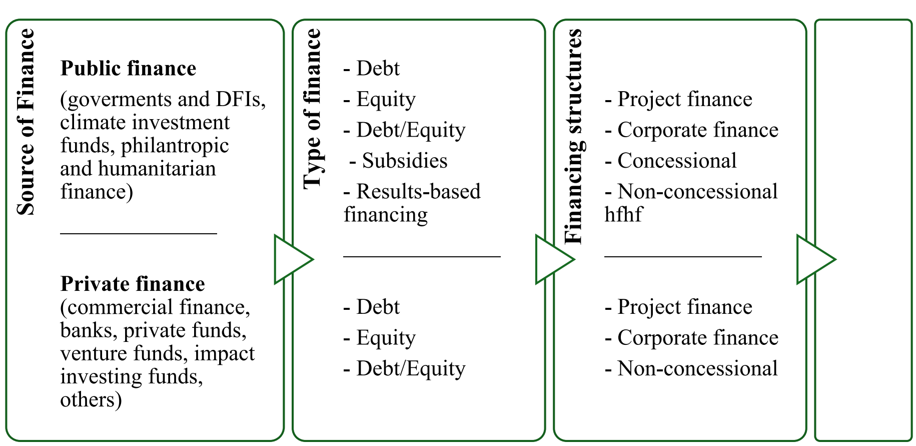

Fig. 2. Source, type and structures of finance.
Source: Authors’ own analysis based on relevant literature cited in this section.

Results-based financing (RBF)

Results-based financing (RBF), also known as performance-based grants, sees DFIs or government providing an ex-post subsidy to mini grid developers according to the number of successful connections met by the project. RBF is perceived to provide greater control and certainty over the project, preventing the provision of a subsidy before the project has proven its effectiveness. RBF provides a mechanism to combine commercial funding with subsidies, where the former provides the initial investment costs and has the guarantee of returns after installation (Bukari et al., 2021; ECA & AMDA, 2020).

RBF emerged in 2019 in six African countries, Nigeria, Algeria, Ethiopia, Mali, Burkina Faso, and Togo, led by DFIs (Antonanzas-Torres et al., 2021). For example, Nigeria's performance-based grant (PBG) programme has made $150 million available to mini grid developers, offering between $350 to $600 per new connection with a minimum total grant of $10,000 per mini grid (ESMAP, 2019). This programme was launched in 2018 as part of the Nigerian Electrification Project (NEP), supported by the World Bank and the AfDB which aims to increase the participation of hybrid solar mini grids in 250 designated sites, with a total budget of $48 million. By 2021 Nigeria ranked first in the continent for the quality of its minigrid framework, and among the best in terms of a framework for off-grid systems. Under this programme which takes a PPP approach, the REA signs agreements with qualifying mini grid companies who secure their own funding to develop the projects.

Exploring key risks and challenges

Investment risks in mini grids are defined according to factors that reduce the developer's probability of having sufficient cash flow to repay the debt or meet the expected return. The main areas of risk are summarised in Table 6.

External risk for mini grids

Regulation and market access

A lack of policy and regulation for mini grid development and for electricity governance more generally is perceived as the most significant challenge by developers and investors (AfDB, 2016, AMDA, 2022). In 2014 most countries in SSA lacked specific policies for mini grids in their national electrification plans (EEP, 2015). While this is starting to evolve, including in Nigeria, Kenya, and Tanzania (Sesan, Uduka, et al., 2024), in many localities the sector has often developed in the absence of adequate national regulation (Baker et al., 2022).

Obtaining project licensing and authorisation is often a lengthy and bureaucratic process which lacks clarity, particularly in countries where mini grid developers are at once governed and regulated by the same institutions, such as a regulator or the Ministry of Energy, that oversee national utilities. The requirement in many countries that each mini grid project go through the same licensing process as a grid-connected, utility-scale project, creates a heavy burden on developers and can serve as a barrier to access (AMDA, 2020).

Critical areas of regulatory risk include market entry procedures, rules for tariff-setting, and policies relating to the arrival of the main grid into the vicinity of the mini grid (see Table 6, SE4ALL & AfDB, 2019, ESMAP, 2022). In certain countries, national and/or local regulations may prevent or inhibit cost-reflective tariffs for mini grids, as is the case for instance in Senegal, which therefore reduces cost recovery options for developers (Weston et al., 2018). Investment uncertainty is further increased by the unpredictability of tariff policy, which may result from changes in government and political pressure from vested interests (Baker et al., 2022; Gershenson et al., 2015).

Perhaps the most significant concern for investors and developers is that the utility may extend the national grid to the community being served by the mini grid, particularly in countries where there is no regulation or compensation for such circumstances (Baker et al., 2022; ECA & AMDA, 2020; Muchunku et al., 2018). One example of where this has happened in Senegal where regulation has been inconsistently designed and applied with the nature of the regulation making it hard for many operators to claim compensation.

Table 6
Summary of risks, challenges and mitigation strategies.

Risks and challenges		Elements	Mitigation strategies
External Risks	Regulation and market access	Licensing processes. Tariff setting rules. Rules for main grid arrival and mini grid integration.	Reduce the sizing of mini grids. Bundling mini grids into portfolios Grid-interconnection ready technologies
	Demand uncertainty and poor forecasting	Lack of accurate demand data Errors on sizing the mini grid	Use technology to improve data reliability. Stimulate productive uses of electricity. De-risking finance mechanisms
	Country and macroeconomic risks	Inflation Currency mismatch between funding and revenues Exchange-rate fluctuations	Use long-term currency volatility assessment. Access and availability of credit in local currency
Internal Risks	Customer credit and non-payments risk	End-users limited and unpredictable income. Enforcement of payment collection mechanisms	Prepaid collection methods (e.g. PAYG) Smart metering systems Financing for productive equipment
	Governance risk	Developer's track record and expertise Transparency and monitoring	Clear accounting and reporting mechanisms. Integration of ESG standards
	Labour risk	Lack of a skilled local workforce Lack of adequate technical resources	Investing in local operations and management capacity Ensuring the supply of quality spare parts
	Community engagement challenges	Risk of non-acceptance due to public opinion, lack of transparency, and low local workforce involvement Low social perception of the service	Implementing clear communication channels Involvement of traditional authorities and local champions Timely available information on tariffs and service

Source: Authors' compilation based on relevant literature cited in this section.

The uncertainty as to whether developers will be able to recoup their investment in the case of grid arrival may pose as a deterrent (Bukari et al., 2021). One way to mitigate this is for developers to ensure that their systems are technically capable of connecting with the main grid and other mini grid projects, though this would still require mini grid operators being able to lease the distribution assets of the centralised utility. Consequently, the literature calls for policy guarantees that provide clear conditions about operating alongside the main grid and compensation schemes (Tenenbaum et al., 2014).

Demand uncertainty and poor forecasting

Developers use demand estimates to inform the sizing and design of the mini grid and in turn to secure financing. However, it can be difficult to accurately predict future electricity demand because this varies so widely within and between countries and many developers are unfamiliar with the nature of electricity provision, use and cost in any particular area (Bahaj & James, 2019, Hartvigsson et al., 2021).

Unreliable demand assessments can lead to forecasting errors, increase the risk of under or oversizing the mini grid, and directly affect the investment return (Peters et al., 2019). For instance, while large mini grids have higher operational costs, a smaller generation capacity may decrease the quality of service for the end-user (Hartvigsson et al., 2021).

There are various options to mitigate the risk of demand uncertainty. First, the use of geographic information system software and associated web-based and mobile technologies can perform more accurate assessments (ESMAP, 2019). Second, encouraging income-generating activities through the financing of productive-use appliances, or tariffs that encourage electricity consumption for productive use (ECA & AMDA, 2020). Finally, and as discussed in Type of finance Section, the provision of concessional loans from DFIs which guarantee that private investors are repaid first.

Political and macroeconomic risks

Country-specific risks, including political instability, social unrest and macroeconomic factors such as currency risks and inflation, extend beyond the context of any individual project (See Table 6, Baker, 2022) but are likely to increase the cost of capital for developers who will need to demonstrate their capacity to minimise these risks (ESMAP, 2019; Malhotra et al., 2017).

Country risk reviews, such as the Marsh World Risk Review (2021) and the World Bank Doing Business Ranking (2021) offer initial assessments for international investors but conducting thorough due diligence on a project remains crucial for making investment decisions (ESMAP, 2019). While political risk assessment examines a country's fiscal and monetary policies, legal and regulatory challenges, and social unrest risks, the Doing Business Ranking measures the ease of starting a business in a specific country (see Table 7). A comparison based on the Doing Business Ranking indicates that Kenya for example, provides a more favourable regulatory environment and lower country risk than Tanzania, given the latter's business environment and regulatory framework and what developers have referred to as the weak enforcement of regulations.

Returning to the risks outlined in Table 6, inflation significantly affects tariff-setting for mini grids, directly impacting the developer's operational costs, revenue, and the financial sustainability of the investment (Odarno et al., 2017). Developers are usually not allowed to change their tariffs once the tariff schedule has been approved and must set tariff adjustment levels to allow for inflation at the outset (Ilskog & Kjellström, 2008). Local currency depreciation will also impact financing and revenue costs, given that most mini grid financing in SSA is in a foreign currency such as dollars or euros, while revenues are received in local currency over the lifespan of the project of approximately 20 years (Franz et al., 2014; Gershenson et al., 2015). Investors and debt financiers will therefore consider the long-term exchange rate to assess currency volatility risk. Although international hedging tools are available, e.g. locking the exchange rate in for all or part of the duration of the investment, this option would increase the cost of capital for developers. Avoiding those risks requires credit availability in local currency, which is still limited in SSA (see Type of finance section).

Table 7
Selected countries from the World Bank's doing business ranking (2020).

Country	Global Rank (total 190)	Rank within SSA (total 48)
Kenya	56	3
Nigeria	131	17
Senegal	123	16
Tanzania	141	22

Source: Authors' own, adapted from Doing Business Ranking (World Bank, 2020).

Internal challenges for mini grids

Customer credit and non-payment risk

Penetration of third-generation mini grids has grown based on increasing consumer demand for electricity services, as well as innovations in telecommunications, which enabled the rise of smart metering and PAYGO models for small-scale systems (Baker et al., 2022). Although data that has been enabled from new technologies provides lenders and investors with more confidence regarding the ability of users to pay, mini grids are still exposed to credit risk and non-payment by end users (GOGLA, 2019). In addition, the high upfront cost of connection and payment for the electricity service poses an entry barrier for the most vulnerable customer. The willingness and/or ability to pay often becomes a challenge when mini grid tariffs are compared to tariffs from the main grid, or the community expects assistance that reduces the cost of electricity (Peters et al., 2019; Schmidt et al., 2013). Some low-income households in SSA may not be able to budget for high and regular energy costs, particularly as compared to traditional and more sporadically purchased energy sources such as kerosene (Inensus in AfDB, 2016, Bahaj & James, 2019).

In addition to the introduction of PAYGO systems, pre-paid electricity metering schemes have also been introduced in mini grid design, including in Kenya, Tanzania, Uganda, Nigeria, and Rwanda, with the aim of addressing non-payment risk; reducing the costs of payment collection; and providing greater transparency for the consumer on their use and payments (Bahaj & James, 2019; IEA, 2022; Jack & Smith, 2015). Third-generation mini grids are already integrating smart meters that provide prepaid options for end-users while incentivising them to use efficient household appliances and equipment for income-generating activities (Niyonteze et al., 2019, ESMAP, 2022:69).

For productive users with limited or seasonal cash flows, waiving the flat rate standing charge and facilitating access to credit for equipment would reduce their credit risk. Mini grid developers could partner with financing agencies or equipment sellers to support access to credit for productive equipment. Therefore, strategies to decrease credit risk must also reflect the needs of both households and productive users in terms of an affordable tariff structure and workable payment collection method.

Governance risk

The literature suggests that investors consider governance concerns from the experience of the mini grid developer in decision-making, and monitoring (Franz et al., 2014; Peters et al., 2019). Investors require that developers internalise the feasibility assessments, fulfil the technical standards, and set transparent accounting and reporting mechanisms. In addition, the developer's track record is essential to their to access finance given that, as companies develop more expertise, they become more attractive in investment terms for equity and debt investors. Finally, integrating environmental, social, and governance (ESG) standards facilitates the governance risk assessment and reduces potential conflicts of interest between financiers and developers (IEA, 2022).

Labour challenges

The need to develop appropriate human capital for the scale up of third generation mini grids is often challenged by the lack of a skilled local workforce, particularly given the geographical remoteness of many systems (see Table 7) (ESMAP, 2022:287). Developers are usually required to integrate capacity-building with community engagement in order to train local staff to carry out operations and maintenance, thereby reducing the need for external support and lowering the project's operational costs (Duran & Sahinyazan, 2021; Lillo et al., 2015). In some countries support is provided for capacity building of local technicians, for instance, in Tanzania by the Rural Energy Agency.

However, the lack of adequate technical resources, such as spare components in the local market as well as the often poor quality of the components that are available, adds to the labour risk and challenges, increasing the reliance on external consultants and suppliers and raising the project's operational cost (Azimoh et al., 2017; Sharma & Palit, 2020; Yadoo & Cruickshank, 2012).

Community engagement challenge

Inadequate or inappropriate community engagement can create socio-economic challenges which in turn affects the successful implementation of a project by undermining local support, reducing electricity demand from the end-users, and increasing the risk of local disputes and non-payment (Malhotra et al., 2017). Unfavourable public opinion, lack of transparency, insufficient local workforce involvement, and poor local capacity are some of the elements that can contribute to the risk of non-acceptance of the mini grid (Franz et al., 2014). Misleading information regarding tariffs and/or the reliability of the service will also create mistrust of the energy provider and the system among users, who in turn are more likely to miss payments (Lillo et al., 2015; Peters et al., 2019). Potential challenges may also arise from business models that prioritise commercial users and limit access to energy for low-income customers, thereby exacerbating existing inequalities in access to electricity.

All of these challenges highlight the importance of addressing the communities' needs, concerns and expectations in mini grid development, adopting a holistic approach to providing energy access to low-income consumers. As Duran and Sahinyazan (2021) explore, working with local authorities and including local champions to connect the community to the mini grid helps to reduce reputational risks. Likewise, providing accessible and continuous communication regarding the tariffs and the service strengthens trust.

Conclusion

In this review we have explored the various business models that currently exist, which vary by ownership, cost-recovery, customer focus and implementation strategy; the key actors, institutions and processes involved in accessing and providing finance for third generation mini grids; and some of the main investment risks. While evidence from the literature points to hybrid ownership, the role of subsidies, the inclusion of anchor customers, and financial bundling portfolios as promising business strategies, there is no one-size-fits-all model for a mini grid business model which is financially sustainable, scalable and replicable. Moreover, the lack of quantitative analysis on mini grid financial performance, makes it difficult to assess whether specific approaches to any business model will have more or less sustainable outcomes. As we have illustrated, business models are still evolving and adapting alongside various economic, social, and political variables.

Mini grid experiences across the region suggest that balancing affordable service provision with acceptable cost recovery remains difficult to achieve. While financial sustainability is often considered the most significant challenge for the sector's expansion, this is affected by other critical factors which drive the risk perception of investors, including regulatory uncertainties, tariff regimes, low electricity demand, and low payment capacity in rural communities. With this in mind, we now offer the following five conclusions and end with policy recommendations.

First, the categorisation of business models is very diverse. Operations may be led by the public utility, the private sector, the community, or a blended approach where both governments and private developers have shared obligations. All such approaches have been shown to work at times, though under different circumstances. However, contrary to the dominant narrative that prioritises private developers over state-owned monopoly utilities, a private sector approach does not necessarily make electricity more accessible and affordable for users at the last mile. One consideration in the expansion of energy access depends on identifying the right balance between private and public ownership and control.

Second, a mini grid focused on sustainable cost recovery would require that operation and maintenance costs be recovered from tariffs and/or targeted public subsidies that allow remote and rural populations to access electricity at the same subsidised price as their urban counterparts. There is therefore a balance to be struck between private competitiveness and public support. The literature proposes the A-B-C model as a viable way to provide a consistently high load to cover investment and operational costs because long-term contracts with anchor clients can guarantee a large portion of project revenue, improve the project's financial sustainability, support upfront fees, and help attract long-term financing. However, the lack of anchor customers in remote and rural areas challenges the viability of this model, which explains DFIs' interest in stimulating and supporting productive use. Moreover, findings on the impact of productive use on income generation from mini grids are still emerging. In addition, while the literature proposes operational and financial bundling of mini grids as a potential solution for the challenges of economic sustainability, the lack of examples limits conclusions on the scalability of this model.

A third conclusion relates to the challenge of access to finance. It is clear that no unique source of finance can overcome all the barriers and risks of the market and that the scalability of the mini grid sector requires different financial arrangements combining grants, equity, debt, subsidy, and de-risking instruments. The literature consistently suggests that most mini grid developers require grants for the initial stages, such as construction, installation, and electricity connections. Thus far, grants to fund capex for mini grids under rural electrification programmes have been the most committed financing for the sector in developing countries. In contrast, developers who have been able to raise debt or equity from either foundations or commercial finance, are required to show a certain level of return from their business operations and to minimise risk.

Fourth, the literature indicates that the success of a mini grid project is highly context-specific and dependent on multiple internal and external challenges. While the former includes project-specific aspects that the developer may be able to control or influence, the latter are likely to be beyond reach and often inherent to a specific market or country. As the literature reviewed indicates, the greatest risks and challenges in the SSA mini grid sector relate to regulation and market access, followed by the risk of grid arrival, and the lack of a sizeable and stable demand. Such conditions prioritise larger, mature, and often international developers, limiting opportunities for local actors. Thus, achieving the industry call to increase private-sector investment in mini grids requires reducing the internal and external challenges that raise perceptions of investment risk and in turn limit developers' access to affordable financing.

Finally, the grey literature in particular points to macroeconomic challenges, non-payment risk by mini grid customers and governance, social and technical challenges. But such findings are largely drawn from qualitative analysis, and there are few publicly available quantitative assessments of the impact of those risks on the profitability of mini grids. A deeper critical and comparative analysis of different business models' coping mechanisms could therefore help to understand the complex success factors that could define the most sustainable approach to mini grids.

Based on our findings from this study, we put forward the following policy recommendations with regards to the future regulation of mini grids: i) there should be greater clarity of regulation, compensation and enforcement in terms of the arrival of the main grid into the vicinity of a mini grid; ii) strategies to decrease credit risk must reflect the needs of both households and productive users in order to arrive at an affordable tariff structure and workable payment collection method; iii) communities' needs, concerns and expectations should be addressed in project development, including for instance working with local authorities and local champions to connect the community to the mini grid; iv) finally and relatedly there should be accessible and continuous communication regarding tariffs and the service provided to all mini grid users.

CRediT authorship contribution statement

Adriana Fajardo: Conceptualization, Analysis, Methodology, Data curation, Writing – original draft. **Lucy Baker:** Conceptualization, Analysis, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition, Project administration. **Temilade Sesan:** Conceptualization, Analysis, Writing – original draft; Writing – review & editing. **Subhes Bhattacharyya:** Writing – original draft, Funding acquisition, Project administration. **Daniel Kerr:** Writing – original draft, Writing – review & editing, Visualisation, Project administration. **Maneno Katyega:** Writing – original draft. **Andrew Barnett:** Conceptualization, Writing – original draft.

Declaration of competing interest

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