MGP
MINI-GRIDS PARTNERSHIP

STATE OF THE GLOBAL

MINI-GRIDS MARKET REPORT

2024

SUSTAINABLE ENERGY FOR ALL

UKaid from the British people

Transforming Energy Access

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ABBREVIATIONS

AC	alternating current
ADELE	Access to Distributed Electricity and Lighting in Ethiopia
AFD	French Development Agency
AfDB	African Development Bank
AFUR	African Forum of Utility Regulators
AMAP	Africa Mini-grid Acceleration Programme
AMDA	Africa Minigrid Developers Association
ARPU	average revenue per user
BGFA	Beyond the Grid Fund for Africa
BMZ	Federal Ministry for Economic Cooperation and Development
capex	capital expenditure
C&I	commercial and industrial
CB Access	CrossBoundary Access
CO_2-eq	carbon dioxide equivalent
CREDA	Chhattisgarh Renewable Energy Development Agency
DART	Demand Aggregation for Renewable Technology
DC	direct current
DOEN	DOEN Foundation
DREAM	Distributed Renewable Energy-Agriculture Modalities
D-REC	Distributed Renewable Energy Credit
EnDev	Energising Development
EPC	engineering, procurement, and construction
ESG	environmental, social and governance
ESMAP	Energy Sector Management Assistance Program
FCDO	Foreign, Commonwealth and Development Office
GEAPP	Global Alliance for People and Planet
GEP	Global Electrification Platform
GST	goods and services tax
IDF	Integrated Distribution Framework
IEA	International Energy Agency
KPI	key performance indicator
LCOE	levelised cost of electricity

Li-ion	lithium-ion
MGA	Mini-Grid Asset
MGF	Mini-Grid Funders
MIGA	Multilateral Investment Guarantee Agency
MSME	micro, small and medium-sized enterprise
MW	megawatt
MNRE	Ministry of New and Renewable Energy
MYTO	Multi-Year Tariff Order
Na-ion	sodium-ion
NEFCO	Nordic Environment Finance Corporation
NEP	national electrification plan
O&M	operation and maintenance
PPP	public–private partnership
P-REC	Peace Renewable Energy Credit
PRESS-D	Promoting Renewable Energy Services for Social Development
PUE	productive use of energy
PV	photovoltaic
RBF	results-based financing
REC	Renewable Energy Credit
REREC	Rural Electrification and Renewable Energy Corporation
RISE	Regulatory Indicators for Sustainable Energy
RREP	Rural Renewable Energy Project
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
TPRMG	Tata Power Renewable Microgrid
UEF	Universal Energy Facility
UNDP	UN Development Programme
UNOPS	United Nations Office for Project Services
WBREDA	West Bengal Renewable Energy Development Agency

EXECUTIVE SUMMARY

BACKGROUND AND OBJECTIVES

The global challenge of electrification, crucial for achieving Sustainable Development Goal (SDG) 7, has seen both progress and setbacks. Notably, the number of people without electricity decreased by 466 million between 2010 and 2021, attributed to advancements in renewable energy, increased investment and greater international cooperation. However, most gains occurred outside sub-Saharan Africa. Mini-grids emerged as a key driver of electrification in remote areas. Recent events, including the COVID-19 pandemic and geopolitical conflicts such as Russia's invasion of Ukraine, have disrupted progress. These challenges underscore the need to strengthen sustainable electrification efforts.

The State of the Global Mini-Grids Market Report 2024 serves as a comprehensive resource aiming to drive investment and inform decision-making in the sector. Utilising a bottom-up methodology, it provides up-to-date insights and forward-looking strategies for the sector's sustainable scale-up, synthesising inputs from stakeholder interviews and extensive desk-based research.

The quantitative analysis in this report is based on data from two primary databases: the Mini-Grid Funders (MGF) database and the Mini-Grid Asset (MGA) database. The MGF database encompasses over 160 projects from 14 funders, providing detailed information on project funding, connections planned and financing instruments used across 45 countries, primarily in Africa and Asia. The MGA database offers insights from approximately 1,100 mini-grid projects across 16 countries, on aspects including technology choices, customer segmentation and cost structures. Comparisons with other relevant databases were drawn to ensure a comprehensive and nuanced assessment of key trends in the mini-grids market.

MARKET TRENDS

General trends

Over the past decade there has been a consistent and notable upward trend in mini-grid installations globally. Installations are over six times higher compared with 2018. This growth, particularly notable in sub-Saharan Africa, underscores the increasing recognition of mini-grids as a feasible solution for electrification in remote areas.

Between 2018 and 2024 there was a significant decline in the share of diesel capacity in mini-grids, plummeting from 42% to 29%. This reduction stems from global efforts to reduce carbon emissions, rising operational costs associated with diesel, and declining battery storage costs. In contrast, the share of solar PV systems has seen a remarkable increase, rising from 14% to 59% during the same period. This surge is attributed to advancements in solar technology, affordability, scalability and supportive policies incentivising solar energy deployment.

Enabling environment trends

There is an increasing focus on strengthening government capacity and establishing clear policies for enabling private sector participation. Funders are including technical assistance in their mini-grid programmes and more countries have adopted comprehensive mini-grid regulatory frameworks compared to 2020, with Nigeria, Angola, Ethiopia, Kenya and Zambia making notable progress. However, a gap often remains between the formal written regulations and their implementation.

Integrating energy planning beyond national electrification plans is gaining traction. Despite the rise in the number of national electrification plans developed, detailed implementation guidance is lacking. To address this, efforts are currently being made to expand integrated energy access planning frameworks to put these plans into operation, with achievable financial strategies for each electrification modality. Efforts are also being made to integrate different electrification modes by combining on-grid, mini-grids and standalone systems, leveraging cross-subsidisation and public–private partnerships.

Regulatory processes are being tailored for different mini-grid scales to enhance flexibility and reduce costs. Small-scale systems under 100 kW are often exempt from licensing and tariff approvals, allowing operators to set tariffs in consultation with communities, as seen in Nigeria and India. This capacity-dependent approach balances low development costs in emerging markets with stronger protection in mature ones, although it is met with some scepticism from the sector, given the risk that the absence of any formal licence and tariff agreement issued by the government poses.

Mini-grid regulations are increasingly allowing for portfolio applications and extended licence durations to improve bankability. Portfolio applications minimise transaction costs and attract private financiers by allowing for larger deals, reducing risks and enabling competitive bidding processes. Additionally, ensuring that permit and licence durations align with financing agreements, typically 10 to 25 years, is essential for project viability.

Cost recovery tariffs, using a cost-based formula for calculating revenue requirements, have become common in mini-grid markets, including countries like Ethiopia, Kenya, Nigeria, Tanzania and Zambia. In light of recent macroeconomic challenges, the focus is shifting towards effective adjustment mechanisms that allow for inflation and currency fluctuations to ensure tariff framework bankability, while protecting mini-grid customers from excessive economic burdens.

More mini-grid regulations are being put in place to address the challenge of grid extension, but implementation of these regulations is often lagging behind, combined with a lack of sufficient clarity and detail regarding asset transfer valuation.

There has been a push towards standardising policy approaches for rapid scalability, but further progress is required. While frameworks must be adapted to country contexts, certain provisions, such as investment protection and tariff methodologies, can be based on blueprints. Despite progress, standardising due diligence processes remains a challenge.

Efforts to streamline and digitise application processes for mini-grid licences and permits are ongoing. With the urgency of accelerating universal electrification, digital technologies offer automated data processing, thereby expediting deployment. Development partners are supporting regulators and ministries in establishing one-stop shops for mini-grid applications.

Efforts to integrate mini-grids into the main grid are gaining momentum, aiming to enhance power system resilience and benefit consumers, utilities and mini-grid operators alike. Regulatory frameworks play a pivotal role in ensuring seamless integration, with recommendations emphasising voluntary setups and light-handed regulation.

There is a notable shift towards increased collaboration among stakeholders, spanning regulators, donors, private sector entities and local communities. Stakeholder dialogue is crucial, with a focus on early consultation with investors to develop bankable regulations. However, there is a need for greater emphasis on collaboration in application and due diligence processes among funders.

Business model innovations

The evolution of mini-grid business models reflects a shift from merely supplying electricity to fostering productive use of energy (PUE), often with an expanded scope, such as providing appliances and developing PUE value chains, ultimately supporting sustainable rural development and economic growth. In this context, financiers are increasingly recognising the importance of appliance financing in scaling up PUE.

Companies are leveraging alternative, high-value applications for surplus energy during the early stages of mini-grid operations to enhance revenues and drive down tariffs. One innovative model uses excess electricity from renewable mini-grids for bitcoin mining to generate a stable revenue stream, providing predictable demand and revenue.

Mesh grids are increasingly being considered as an effective solution to electrifying areas with low population densities. Unlike mini-grids, which require densely populated areas, mesh grids connect nearby houses to share power, allowing their consumption to be combined.

To optimise costs, mini-grid companies are increasingly forming partnerships and operating within vertically integrated value chains. This integration, encompassing stages such as technical design, construction, sales, and operation and maintenance (O&M), allows for economies of scale, higher profit margins and improved control over quality, leading to enhanced customer satisfaction.

Financing trends

Despite substantial increases in funding for the mini-grid sector over the past 15 years, a significant financing gap remains. Sub-Saharan Africa has been the primary recipient of funding from private investors, governments and development partners. Two key trends are evident: a significant rise in total committed funding, exceeding USD 2.5 billion in 2023, and a sixfold increase in private investment from less than USD 100 million in 2015 to nearly USD 600 million in 2022. Overall, the total committed funding for ongoing programmes amounts to over USD 3.1 billion across 377 programmes, with African countries receiving the bulk of this investment. Funding per connection averages USD 411, varying by region and programme. Longer programme durations, typically linked with technical assistance and favourable financing terms, further underscore funders' commitment to sustainable mini-grid deployment.

Over recent years, there has been a significant increase in total funding commitments, with the disbursement rate remaining around 60%. However, there is considerable variation in deployment rates among funders. Among programmes with available data, 57% of committed funds were disbursed by March 2024, underscoring the necessity for enhanced monitoring and strategies to accelerate fund disbursement.

Innovative mechanisms are being devised to de-risk mini-grid investments, addressing the high perceived risk and fluctuating demand. Blended finance—combining grants, equity and debt—has been pivotal in attracting both commercial and impact investors, enhancing the sustainability and bankability of mini-grid projects. Additionally, one-stop-shop financing platforms, offering comprehensive financial solutions that include pre-financing, outcome-based grants and technical assistance, are being developed to provide the adaptability required for mini-grid development.

Redesigning financing instruments to address inefficiencies in disbursement is becoming crucial for advancing mini-grid projects in hard-to-reach areas. While grants and results-based financing (RBF) schemes remain vital, they often come with restrictive requirements and limited timeframes, hindering project development. Recognising these challenges, efforts are underway to streamline processes and provide more flexible financing structures. Innovative solutions, such as forgivable loans, provide pre-development financing, bridging crucial funding gaps and expediting project initiation.

Financiers are increasingly exploring guarantees to mitigate currency risk in mini-grid investments. These guarantees align revenue streams with financing costs, reducing the impact of foreign exchange fluctuations. However, despite their importance, local currency financing remains limited, with only a few funders offering such options.

Leveraging climate finance options presents a promising avenue for bolstering revenue streams in the mini-grid sector. Innovative mechanisms like Distributed Renewable Energy Credits (D-RECs) and Peace Renewable Energy Credits (P-RECs) are emerging as effective tools for financing mini-grid projects.

The pursuit of scale continues to be an important strategy in ensuring the financial sustainability of mini-grid projects. Aggregating these projects, whether through portfolio bundling or aggregation platforms, offers developers the opportunity to capitalise on economies of scale, both in terms of hard and soft costs.

There has been limited progress towards the standardisation of reporting mechanisms and impact monitoring frameworks among the donor and investor community, and further support is needed for early-stage mini-grid companies, especially local companies, in order to meet financiers' strict due diligence requirements.

Technology trends

The declining costs of mini-grid components, including PV modules, inverters, batteries, battery inverters and smart meters, have significantly enhanced the financial viability of mini-grid projects. Notably, the price of solar PV panels has plummeted by approximately 90% over the past decade, driven by increased supply and technological advancements. Despite short-term disruptions caused by the global COVID-19 pandemic and geopolitical tensions such as Russia's invasion of Ukraine, the PV market has remained on its trajectory of declining prices.

There is an increasing prevalence of lithium-ion batteries as their cost continues to fall. As of 2021 the average cost of lithium-ion batteries stood at approximately USD 123 per kWh, notably lower than lead-acid counterparts, which ranged between USD 200 to USD 220 per kWh. Forecasts indicate a continued decline in lithium-ion battery costs, potentially reaching USD 75 per kWh by 2030. Lithium-ion batteries offer extended lifespans, heightened efficiency and reduced maintenance requirements compared to lead-acid variants, albeit site-specific factors may sway developer preferences towards lead-acid in certain instances, such as lower power demands.

Robust software solutions are revolutionising mini-grid development across all phases of the project lifecycle, by optimising planning, finance origination, equipment procurement and due diligence. Advancements in remote monitoring and control technologies have facilitated efficient management of even the most remote sites, yielding substantial cost savings estimated at least 15% in O&M expenses. Additionally, centralised technology solutions have emerged to streamline data processing and management, enabling developers to gain granular insights and track key performance indicators across their portfolio.

Economics trends

The levelised cost of electricity (LCOE) has been falling in line with broader cost reductions observed across the sector in recent years. Analyses reveal a remarkable 31% decrease in the LCOE from USD 0.55 per kWh in 2018 to USD 0.38 per kWh in 2021, driven primarily by decreased costs of mini-grid components, particularly PV generation and storage. However, contextualising LCOE figures is essential, considering factors such as electrification tiers and country-specific conditions, which impact both financial and economic LCOE calculations.

There has been a significant downward trajectory in capex costs over the past four years. Average capex per mini-grid connection has fallen by 43% from USD 1,250 in 2020 to USD 707 in 2024. Capex per kWp remained relatively stable between 2021 and 2024, hovering around USD 3,000 before dropping to approximately USD 2,200 in 2024. This downward trend in costs reflects the industry's advancements in technology and procurement efficiencies, and the scaling of operations.

MARKET OUTLOOK

Enabling environment outlook

- **Integrated energy planning:** The sector is likely to transition from separate electrification modalities to an integrated approach, exemplified by models like the Integrated Distribution Framework, focusing on multifaceted integration of electrification modes and sectors.
- **Regulatory approaches to cost recovery:** The sector is shifting towards flexible cost recovery mechanisms, such as automatic tariff adjustments, acknowledging the importance of scale for viability and allowing portfolio applications for licences and tariffs.
- **Standardisation in regulatory approaches and tools:** Further standardisation can be expected in regulatory aspects, such as tariff-setting methodologies, supported by established blueprints and collaboration among stakeholders through entities like AMDA.
- **Comprehensive asset valuation in case of grid arrival:** Methodologies for valuing mini-grid assets are evolving, with emerging regulations on compensation entitlement in grid arrival scenarios, aiming to encourage private sector involvement.
- **Interconnected mini-grids:** There will be an increased focus on improving energy access through interconnected mini-grids to address poor service quality.

Business model outlook

- **Innovative business models for last-mile electrification:** Developers are exploring innovative approaches like mesh grids to reach sparsely populated areas, offering cost savings on distribution and expedited deployment without land acquisition requirements. However, this may lead to cherry-picking of commercially viable sites, posing challenges for subsidy policies.
- **Proactive approach to PUE:** PUE will remain crucial, prompting a shift towards proactive models such as the business acceleration and supplier-offtaker approaches, exemplified by initiatives that involve the provision of education, training and business development for micro, small and medium-sized enterprise (MSMEs), aiming to enhance mini-grid profitability while empowering communities.

Technology outlook

- **Aggregation for mini-grid financial viability:** Aggregator platforms and funds are set to become increasingly crucial in enabling smaller companies to benefit from economies of scale, securing discounted equipment and financing, thus enhancing financial viability.
- **Cross-sector collaboration for sector scale-up:** Partnerships within the donor community and across sectors should aim to break down silos, pool resources and encourage innovation, while also emphasising the role of climate finance in scaling up the mini-grid sector.

Economics outlook

- **Further LCOE reduction:** Modelling by the Energy Sector Management Assistance Program (ESMAP) predicts ongoing reductions in the LCOE for best-in-class mini-grids, driven by anticipated cost decreases in components like solar panels and Li-ion batteries by 2030, propelled by industry scale and advancements in associated sectors such as solar farms and electric vehicles.

RECOMMENDATIONS AND CONCLUSIONS

Areas of action for the public sector

- Clear and up-to-date distribution network expansion plans to mitigate the risk of grid encroachment.
- Consideration of interconnected mini-grids as a potential least-cost solution.
- Regulatory treatment of mini-grids as infrastructure to align with their nature as long-term investments.

- Clear and efficient tariff indexation mechanisms to partially mitigate key risks such as currency depreciation and inflation.
- Early involvement of investors in regulatory framework development to create bankable frameworks and encourage private investment.
- Strengthened collaboration between regulators at a regional level.

Areas of action for funders

- **Enhanced collaboration and data sharing** among financiers to save resources for donors, investors and mini-grid developers.
- **Targeted approaches** to mini-grid development based on a deep understanding of the local context and the inclusion of local players.
- **Simplified grant access and standardised application processes** to improve efficiency and reduce financing costs for developers.
- **Extended donor programme durations** to align with the longer timeframe needed for mini-grid sector development and allow developers to recover investment costs.
- **More focus on financing for growth stages**, which are often neglected, to reduce funding acquisition times for expansions.
- **Long-lasting relationships between financiers and developers**, facilitated by regular meetings, to enhance trust and understanding, leading to continued financial support.
- **Targeted technical assistance** for governments to foster an enabling environment and for early-stage mini-grid companies to facilitate accessing grants and improve corporate capabilities.

Areas of action for the private sector

- **Aggregation of larger, less risky sites with smaller, higher risk sites** to achieve economies of scale, secure better commercial terms and mitigate currency risk.
- **More robust business case with clear profitability paths and transparent impact metrics** to attract investors and highlighting the developer's commitment to the SDGs.
- **Prioritisation of PUE** not just for economic empowerment, but also community development, such as by electrifying public institutions.

Shared responsibilities

- **Reduced sector fragmentation by sharing data on mini-grid economics** to allow stakeholders to identify trends and address challenges more efficiently and effectively, thus fostering transparency, accountability and a conducive environment for innovation and investment.

- **Enhanced efficiency in funds' disbursement** through improved processes and procedures among funders, and favourable policy and regulatory conditions—including clear public–private arrangements on tariffs—by the public sector.
- **Collaborative creation of a comprehensive enabling framework** for mini-grid development, which involves supportive regulations, tailored financing instruments and access to long-term capital.
- **Adoption of a long-term perspective grounded in commercial viability** to develop sustainable mini-grid projects, which involves having a viable commercial model and access to blended finance, as well as recognising that returns are realised over an extended period and that profitability needs to be balanced with broader, non-financial, electrification goals and the SDGs.

CHAPTER ONE

BACKGROUND AND OBJECTIVES

Background

The global electrification challenge, pivotal to achieving Sustainable Development Goal (SDG) 7, has experienced a mix of significant advancements and setbacks. Notably, between 2010 and 2021 the population lacking access to electricity was reduced by 466 million, decreasing from 1.14 billion to 675 million.[1] This progress can be attributed to a combination of factors, including advancements in renewable energy technologies, increased investment in electrification projects, and international cooperation. However, it is important to note that the majority of these reductions occurred in regions outside sub-Saharan Africa. During this period, solar energy emerged as a key driver of electrification in remote and rural areas, due to its scalability and the declining cost of the technology. Mini-grids and standalone solar systems have become the electrification approaches for delivering electricity to communities where extending the traditional grid is not economically feasible. Additionally, policymakers worldwide have prioritised universal access to electricity, resulting in targeted initiatives to bridge the energy access gap.

However, recent global events have posed new challenges and exacerbated existing ones in the path towards universal electrification. The COVID-19 pandemic resulted in major disruptions,

[1] SEforALL. 2023. Deep Dive Analysis: Tracking SDG7: The Energy Progress Report 2023.

affecting supply chains, increasing the cost of materials, and diverting government attention and resources towards immediate health and economic crises. These disruptions have slowed down or stalled electrification projects, particularly in developing countries where resources are more constrained. The pandemic has also impacted the financial conditions of many households and businesses, thus reducing their ability to pay for electricity. This has, in turn, negatively affected the revenues of energy companies, jeopardising their financial viability. The Russian invasion of Ukraine in early 2022 further complicated the global electrification landscape. This conflict led to increased logistical challenges and raised the cost of capital. The disruption to energy markets, particularly in Europe, has cascaded globally, affecting both the availability and the cost of energy resources. Additionally, the conflict contributed to a reorientation of global priorities, with many countries focusing on energy security, potentially diverting attention and resources away from energy access efforts in developing countries. The electrification landscape in Africa has further been affected by increased civil unrest, with businesses facing supply chain disruption, rising insurance costs and threats to employee security.[2] This, together with high inflation and a subsequent environment of sustained high interest rates, has made previously viable projects unviable.

The consequences of these setbacks are multi-faceted. While they threaten to slow the pace of electrification and may even reverse gains in some areas, they also offer a chance to develop innovative approaches to financing, sourcing and deploying mini-grid technologies. According to data from the International Energy Agency (IEA), the number of people around the world who live without electricity rose in 2022,[3] signifying the first global increase since the IEA began tracking the numbers 20 years ago. The rise is mostly in sub-Saharan Africa, where the number of people without access is nearly back to its 2013 peak. In the long run, these challenges underscore the importance of continued innovation in electrification methods, particularly those that are sustainable and less dependent on global supply chains. There is also a growing recognition of the need for more flexible financing mechanisms to support electrification, especially in the face of global economic uncertainties. However, while the pandemic presented unprecedented challenges, it also became a catalyst for innovative policy responses aimed at minimising impacts on electricity access, quality and affordability.[4]

According to a new module in the Regulatory Indicators for Sustainable Energy (RISE) 2022 survey focusing on electricity access policies during the pandemic, many countries incorporated specific measures into their COVID-19 recovery packages to support the electricity sector, as shown in Figure 1.1 below.[5] Approximately 41 percent of the countries surveyed implemented mechanisms to support end users, while 39 percent provided financial assistance to service providers. Furthermore, 44 percent of countries took measures to support the electrification of public institutions. These efforts were critical in maintaining the momentum towards achieving universal electricity access. Notably, the World Bank's 2022 Global Indicators Briefs highlighted that power utilities continued to establish new electricity connections throughout the pandemic,

[2] Maplecroft. 2023. Civil unrest in Africa hits 6-year high.

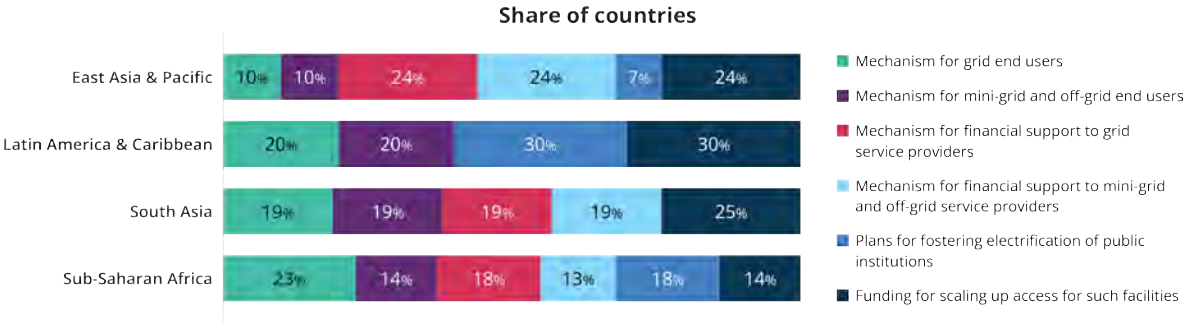
[3] IEA. 2023. Access to electricity improves slightly in 2023, but still far from the pace needed to meet SDG7.

[4] Arizona State University interview.

[5] ESMAP. 2022. Regulatory Indicators for Sustainable Energy.

demonstrating resilience and adaptability.[6] Mini-grid companies, recognised as “essential services” in many countries, played a pivotal role in ensuring continuity of service, even during lockdowns.

FIGURE 1.1 Policy support for mini-grids during COVID-19



Source: ESMAP. 2022. Regulatory Indicators for Sustainable Energy (RISE).

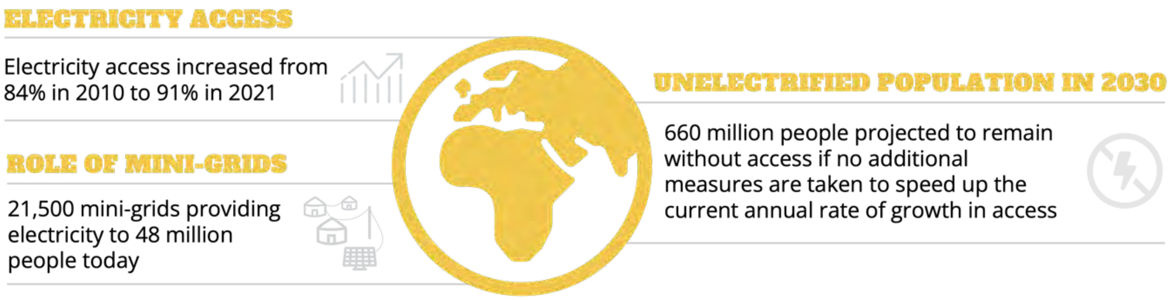
Mini-grids play a crucial role in the electrification efforts. Mini-grids have emerged as a pivotal solution in bridging the global electricity access gap, particularly in areas where extending the main grid is not feasible or cost-effective. This holds true even in countries where electrification efforts have nearly achieved 100 percent electricity access. Mini-grids are essential for reaching the final frontier in remote and hard-to-reach places, such as islands, and for addressing poor quality of supply in regions with weak grids. These decentralised systems offer a versatile approach to electrification. In regions where the main grid is unreliable, mini-grids offer a more reliable alternative. They are also often the least-cost electrification option in rural and remote areas, where over 80 percent of the world’s unelectrified population resides.[7] The potential of mini-grids is further highlighted by their ability to adapt rapidly to market innovations, both technological and in business models, and their alignment with the demands of the grid of the future. Additionally, mini-grids can be deployed in a staged approach, scaling generation capacity and availability in line with demand growth, thus supporting income-generating activities effectively. This adaptability is crucial for connecting the approximately 660 million people who need electricity access by 2030 to achieve SDG 7.[8]

[6] ESMAP. 2022. Regulatory Indicators for Sustainable Energy.

[7] ESMAP. 2023. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[8] ESMAP. 2023. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

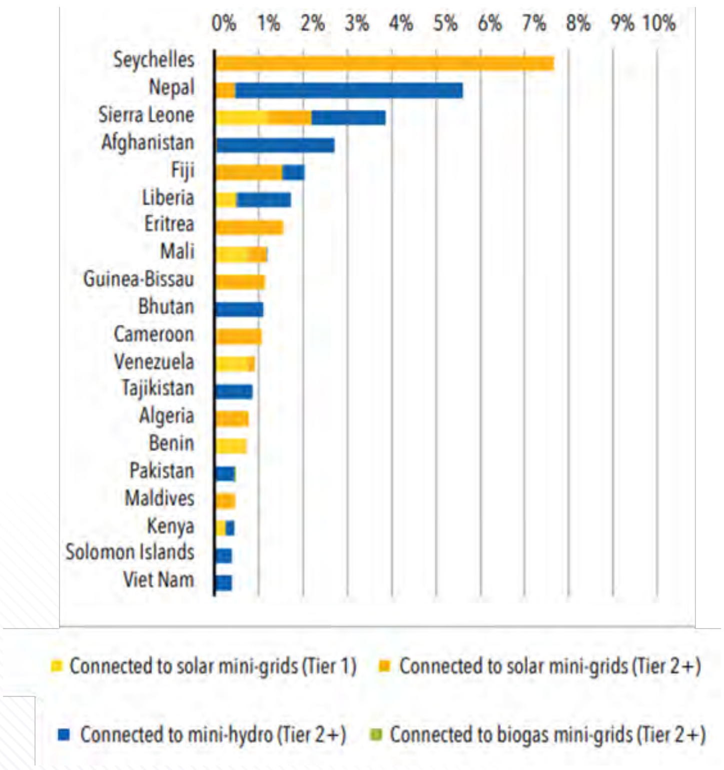
FIGURE 1.2 The current role of mini-grids



Sources: IEA et al. 2023. Tracking SDG7. The energy progress report 2023; ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

Mini-grid access continues to expand, driven by the support of policymakers, private investors and consumers. Mini-grids have emerged as an electrification solution for rural areas, together with grid extension and standalone systems, for providing reliable electricity to remote communities or those affected by frequent power disruptions. Of the top 20 countries with extensive access to mini-grid electricity, nearly half are located in sub-Saharan Africa. Seychelles and Nepal are providing mini-grid electricity to over 5 percent of their populations.

FIGURE 1.3 Share of population connected to mini-grid supply



Source: ESMAP. 2023. Tracking SDG7.

Objectives

This State of the Market report aims to raise awareness of mini-grids, mobilise investment in the mini-grid sector and serve as a benchmark to allow decision makers to measure progress in the sector. The report provides the latest updates on the global mini-grid market and highlights key trends in the industry that, together, can stand as the definitive source of information for stakeholders. This State of the Market report on mini-grids is a significant addition to the current array of studies, distinguished by its unique bottom-up methodology.

The report not only presents the current mini-grid market's status, but also proposes a forward-looking strategy for its sustainable expansion. It synthesises findings from extensive interviews with around 25 stakeholders and a review of over 100 studies and assessments. It delivers a holistic and well-informed outlook on the mini-grid sector, and also acts as a guide for the sector's strategic development and sustainable growth. By combining data, expert opinions and a visionary approach, this report aims to be an essential tool for decision makers, financiers and field experts committed to achieving the goal of universal access to affordable electricity, ensuring no one is left behind.

CHAPTER TWO

MINI-GRID MARKET TRENDS

Together with stakeholder interviews, the following databases were analysed in order to understand key trends in the mini-grid market:

- The Mini-Grid Funders (MGF) database
- The Mini-Grid Asset (MGA) database.

The **MGF database** covers over 160 projects from 14 funders in the MGF group, across over 45 countries, mainly in Africa and Asia.[9] These projects account for USD 2.4 billion of committed funding, of which USD 260 million has so far been deployed. The data reported include variables such as programme duration, type of financing instruments used, total connections planned, and total funding committed and disbursed.

Whenever possible, data provided by the World Bank on "investment deals" for 217 projects, with total committed funds of USD 700 million, have been included in the analysis, ensuring no duplication between databases. An overview of these data by region is presented in Table 2.1. The detailed methodology for data collection can be found in Annex A4.

[9] The MGF Group was initially formed in 2017 and currently includes approximately 30 funders and financiers from the sector who collaborate and exchange insights. Leadership of the MGF Group is provided by the World Bank, the African Development Bank (AfDB), and the UK's FCDO, with the Carbon Trust serving as the secretariat. The data collection for this database took place between December 2023 and April 2024.

TABLE 2.1 Overview of financing flows databases

REGION	NUMBER OF PROJECTS	TOTAL FUNDING COMMITTED (USD MILLION)
MGF database data		
Global	10	197
Africa	142	2,119
Asia	8	94
Total	**160**	**2,410**
Data provided by the World Bank		
Africa	151	437
Global	50	185
Latin America & the Caribbean	4	15
Asia (South-Central)	12	71
Total	**217**	**708**
Grand total	**377**	**3,118**

Source: ECA analysis based on the MGF database and data provided by the World Bank.

The MGA database includes up-to-date data from approximately 1,100 mini-grid projects currently operating across 16 countries. The MGA database was compared with other databases, such as the one developed for the 2020 State of the Global Mini-Grids Market report[10] and the 2022 Benchmarking Africa's Minigrids[11] study by the Africa Minigrid Developers Association (AMDA), to draw insights on trends.

TABLE 2.2 Overview of MGA database

COUNTRY	NUMBER OF MINI-GRIDS	TOTAL INSTALLED CAPACITY (MW)	AVERAGE SIZE (KW)
MADAGASCAR	357	20	55
INDIA	280	n/a	n/a
NIGERIA	117	14	143
BENIN	108	14	132
ZAMBIA	72	5	73
SIERRA LEONE	71	7	92
KENYA	36	4	111

[10] SEforALL. 2020. State of the Global Mini-Grids Market Report.

[11] AMDA. 2022. Benchmarking Africa's Minigrids Report.

COUNTRY	NUMBER OF MINI-GRIDS	TOTAL INSTALLED CAPACITY (MW)	AVERAGE SIZE (KW)
OTHER COUNTRIES	56	11	202
Total	**1,097**	**75**	

Notes: kW stands for kilowatt; MW stands for megawatt.
Source: ECA analysis based on the MGA database.

General Market Trends

The data present a compelling narrative of growth in the mini-grid sector. Over the past decade there has been a consistent and notable upward trend in mini-grid installations globally. This increase clearly indicates the growing recognition of mini-grids as a viable solution for electrification, especially in remote and underserved areas. Projections based on the MGA database suggest that mini-grid installations in 2024 will be around six times higher than in 2018. In sub-Saharan Africa alone, the number of installed connections almost doubled between 2019 and 2021, from 40,700 in December 2019 to over 78,000 in December 2021, despite the challenges posed by the COVID-19 pandemic. While some of this increase reflects the implementation of projects that were halted during the initial stages of the pandemic and the support packages offered during this time, it also showcases the sector's growth momentum.[12] Advancements in technology and decreasing costs of renewable energy sources, as discussed in section 0, have contributed to this substantial growth. Additionally, the development of supportive policy and regulatory frameworks in some counties, including Nigeria and Sierra Leone, have played a crucial role in facilitating this expansion.

This consistent growth of the mini-grid sector is not just a testament to the sector's past successes, but also reflects that viable, investible and politically acceptable models are being achieved at least in some countries.

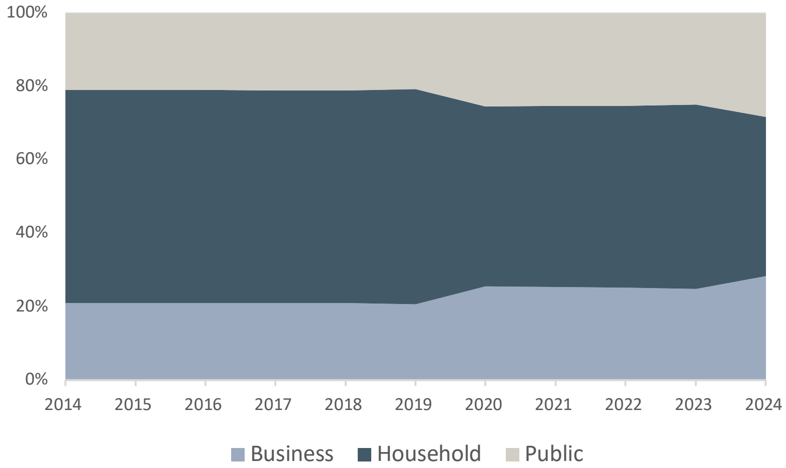
[12] These are data captured from AMDA members and represent only sub-Saharan Africa.

FIGURE 2.1 Mini-grids installed and connections added, 2018–2024, and growth with respect to the base year (2018)

Note: This only includes projects where the year of commission has been reported.
Source: ECA analysis based on the MGA database.

Over the past decade, the mini-grid sector has exhibited a stable pattern of customer composition, primarily comprising households, with business customers consistently representing about 15 percent of total connections. However, a notable shift is anticipated in projects planned for 2024, where the proportion of business customers is expected to rise to 27 percent. This shift aims to enhance system utilisation and improve the financial viability of these projects by incorporating more income-generating activities. Public institutions account for only 2 percent of total connections; combined with businesses they make up approximately 17 percent of total connections, but together are responsible for over 50 percent of total electricity consumption (Figure 2.2). Public institutions typically have higher energy usage than households, though they often face challenges in meeting their electricity bills, posing a risk of non-payment that can adversely affect developers' cash flows. Ensuring the continuous electrification of public institutions is crucial not only for developers' reputation, but also for fostering community growth and well-being.

FIGURE 2.2 Share of total mini-grid power consumption by consumer type, 2014–2024

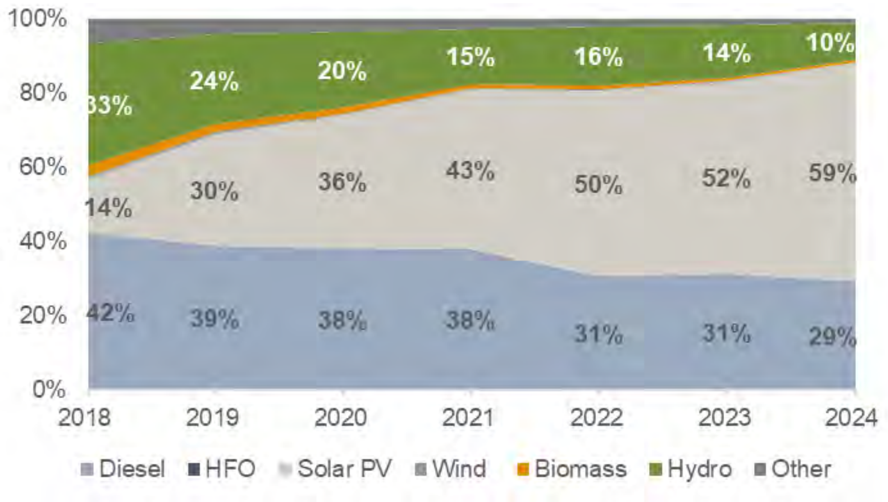


Note: Comprises data from 340 mini-grids with a total installed capacity of 44 MW.
Source: ECA analysis based on the MGA database.

Between 2014 and 2024 the cumulative share of diesel in the total installed capacity of mini-grids has decreased dramatically, falling from 42 percent in 2018 to 29 percent in 2024. While in absolute terms the diesel capacity added each year between 2019 and 2024 has been increasing, this growth has been far surpassed by the increase in solar PV capacity in mini-grids. As a result, diesel's share of mini-grid capacity has decreased. This decline can be attributed to several interlinked factors. Firstly, the rising global awareness of carbon emissions and commitment to reducing them have led to a gradual move away from fossil fuels, including diesel, in favour of more sustainable energy sources. Additionally, the operational costs associated with diesel, including fuel and maintenance, have increasingly made it a less economically viable option, especially in the face of fluctuating oil prices and countries moving away from fuel subsidies. Finally, the reduction in battery storage costs has also played a significant role in the decrease in diesel usage, as greater battery storage capacity translates into reduced reliance on diesel fuel.

Conversely and unsurprisingly, the cumulative share of solar PV systems in mini-grids has seen a remarkable increase, growing from 14 percent in 2018 to 59 percent in 2024 (Figure 2.3). This surge can be largely attributed to rapid advancements in solar technology, which have significantly reduced the cost of solar PV panels, making solar energy more accessible and affordable. Furthermore, solar PV's scalability makes it an ideal solution for off-grid electrification. The environmental benefits of solar energy, coupled with its decreasing cost, have made it an increasingly attractive option for mini-grid developers. Additionally, as storage solutions like batteries become more affordable and efficient, they mitigate one of the primary challenges of solar energy—its intermittency. This generation mix allows for a more reliable and consistent energy supply, enhancing the viability of solar-powered mini-grids. Policies have also played a crucial role in incentivising the deployment of solar-powered solutions while disincentivising the use of diesel. Governments and regulatory bodies have introduced subsidies, tax incentives and favourable tariffs to encourage investment in solar energy. At the same time, they have implemented stricter emissions standards and higher taxes on diesel, making it a less attractive option.

FIGURE 2.3 Cumulative share of installed capacity by fuel type, 2018–2024

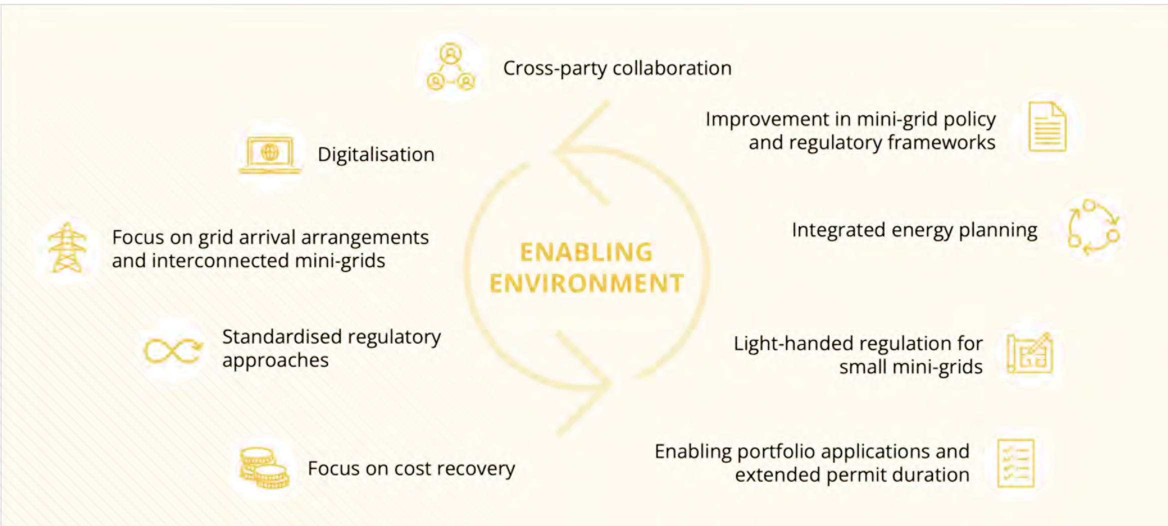


Note: HFO stands for heavy fuel oil.
Source: ECA analysis based on the MGA database.

Enabling Environment Trends

Policy and regulatory risks are major factors slowing down investment flows into the sector. The existence of an enabling policy and regulatory framework, which has a clear role for mini-grids in achieving the country's electrification goals, is necessary to provide investors with confidence, as are enforceable provisions regarding key aspects such as tariff setting and grid arrival. The reduced perception of risk encourages these investors to commit funding and can, ultimately, lower the cost of their capital, which can in turn result in lower tariffs for mini-grid end users. The key enabling environment features are summarised in Figure 2.4 below and analysed in the sections below.

FIGURE 2.4 Summary of enabling environment features



Increasing focus on strengthening government capacity and establishing clear policies for enabling private sector participation

The success of mini-grid programmes is intrinsically tied to political decisions. The role of the private sector and the factors that determine the viability of mini-grid projects for private investment and operation, such as tariffs and grid interconnection arrangements, are largely shaped by the political environment. The politics of mini-grids, which emerges from a complex set of relationships among the relevant stakeholders within a country, can either catalyse or stall the development of mini-grid programmes. When a government demonstrates strong commitment, it paves the way for successful implementation of mini-grid initiatives. For instance, a special unit was established in Haiti by the Ministry of Public Works, the Energy Cell, for the implementation of a national mini-grids programme, showcasing the government's commitment to mini-grid electrification.[13] Recognising the necessity of strong governmental support and clear policies, AfDB's Africa Mini-grid Acceleration Programme (AMAP) aims to facilitate government buy-in to encourage private sector-led mini-grid development. UNDP's Africa Mini-grids Programme also focuses on strengthening political will through national dialogue on mini-grid delivery models with relevant stakeholders, in order to build consensus and address pertinent topics hindering mini-grid scale-up. However, not all political decisions are positive. For example, in July 2020, four months before Tanzania's presidential election, its Energy and Water Utilities Regulatory Agency, Under instructions from the minister of energy, a concise directive was issued that significantly altered the tariff-setting method previously approved by the agency in its 2019 regulations.[14]

In addition, lack of capacity within governments and public authorities has often slowed the pace of mini-grid development, a factor that has profound implications for the growth of the mini-grid market, given that a significant share of mini-grid projects are structured as public–private partnerships (PPPs). This involvement stems from the fact that grant financing often flows to the public sector, which then takes on key responsibilities within PPP contracts. Various public stakeholders, including ministries of energy and finance, rural electrification agencies, PPP units and utilities, are integral to the negotiation, procurement and due diligence phases of mini-grid projects, but they may also be directly involved in the implementation and operation of mini-grids. For instance, in Cameroon, the Rural Electrification Agency operates more than 200 mini-grids, while in Ethiopia, the Ethiopian Electric Utility is developing over 100 mini-grids under the Access to Distributed Electricity and Lighting in Ethiopia (ADELE) project and already operates more than 30 mini-grids. Capacity and experience gaps within these public entities have sometimes been mitigated through embedding experts directly within government bodies to provide support and streamline processes as part of donor-supported mini-grid programmes. However, there is a pressing need for capacity-building to become an integral part of technical assistance programmes targeted at the public sector. This becomes even more crucial in cases of interconnection, where the role of utilities becomes central in managing the

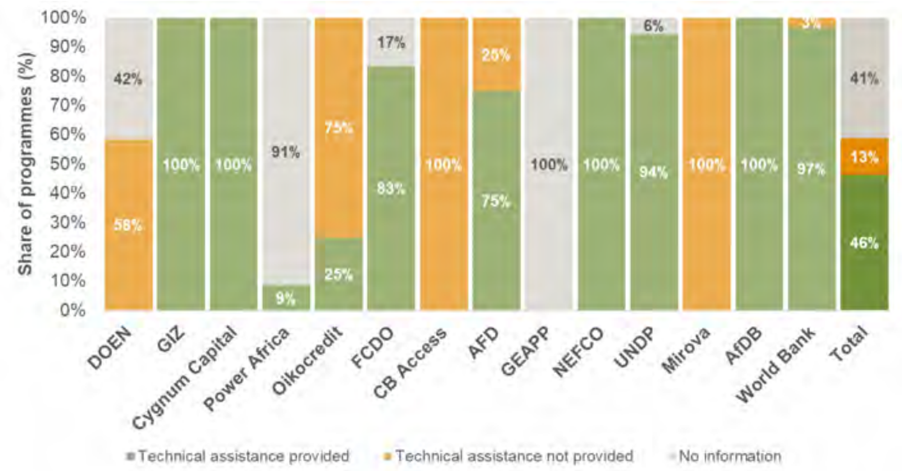
[13] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[14] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

technical and operational aspects of integrating mini-grids with the main grid, as well as for the sustainable operation and maintenance (O&M) of mini-grids.

Acknowledging the need for such support, the majority of the funders included in the MGF database have incorporated technical assistance into most of their programmes. Figure 2.5 shows that eight out of the 14 funders in the database provide technical assistance for more than 50 percent of their programmes, which is reflected in the total share of programmes with technical assistance by far exceeding the share of programmes without such assistance.

FIGURE 2.5 Share of mini-grid programmes offering technical assistance, by funder



Notes: AFD stands for French Development Agency; CB Access stands for CrossBoundary Access; DOEN stands for DOEN Foundation; GEAPP stands for Global Alliance for People and Planet; NEFCO stands for Nordic Environment Finance Corporation.

Source: ECA analysis based on the MGF database provided by the Carbon Trust.

Efforts to improve frameworks to support mini-grids have been increasing among the countries with the largest access-deficit populations, with Nigeria, Angola, Ethiopia, Kenya and Zambia making notable progress and reaching the green zone in ESMAP's Regulatory Indicators for Sustainable Energy (RISE) 2022.[15] For instance, in December 2020 Ethiopia's Petroleum and Energy Authority approved a new Mini-Grid Directive, which constitutes a key step in establishing a streamlined regulatory review process to foster an enabling environment for private sector investment in mini-grids; indeed, since the introduction of the Mini-Grid Directive, Ethiopia has seen an increase in applications for licences.[16] However, further progress is required to bridge the mismatch between the introduction of such regulatory tools and the lack of genuine political alignment between stakeholders. In other words, there is often a gap between the formal written regulations, on which the RISE scores are based, and their

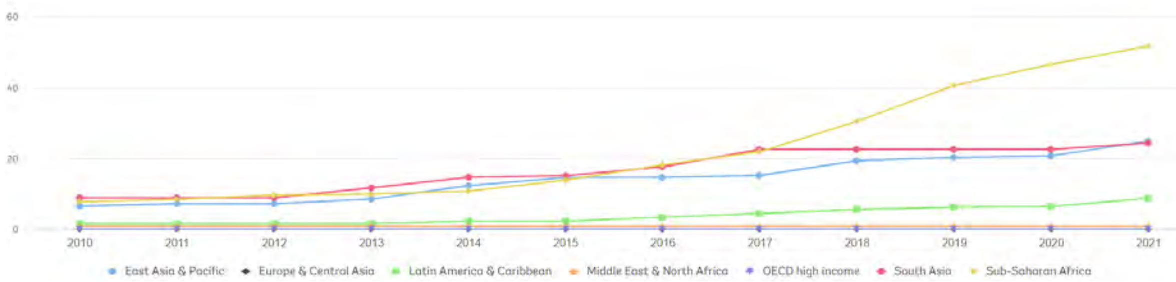
[15] ESMAP's RISE scores, on a 0–100 scale, can be used to compare 140 economies that now account for 98 percent of the world's population. They use a traffic light system, whereby green is for the highest third of scores (67–100), indicating a relatively mature policy and regulatory environment.

[16] National Association of Regulatory Utility Commissioners. 2021. Ethiopian Regulator Approves Groundbreaking Mini-Grid Directive, Improves Licensing Process, Paving the Way for Increased Electrification.

implementation.[17] Another case in point is Tanzania, which had received a high score for its mini-grid regulatory and policy framework in the 2020 RISE. However, as explained above, the implementation of this framework was affected by the directive issued by the regulator in July 2020, under orders from the minister for energy.

Overall, there has been a significant decline in the number of countries where the policy and regulatory mini-grid framework remains at an early stage. Figure 2.6 below shows the evolution of RISE scores for mini-grid frameworks over time, highlighting sub-Saharan Africa's significant improvement since 2017. Figure 2.7 shows the RISE scores per country, with sub-Saharan African countries having the top scores.

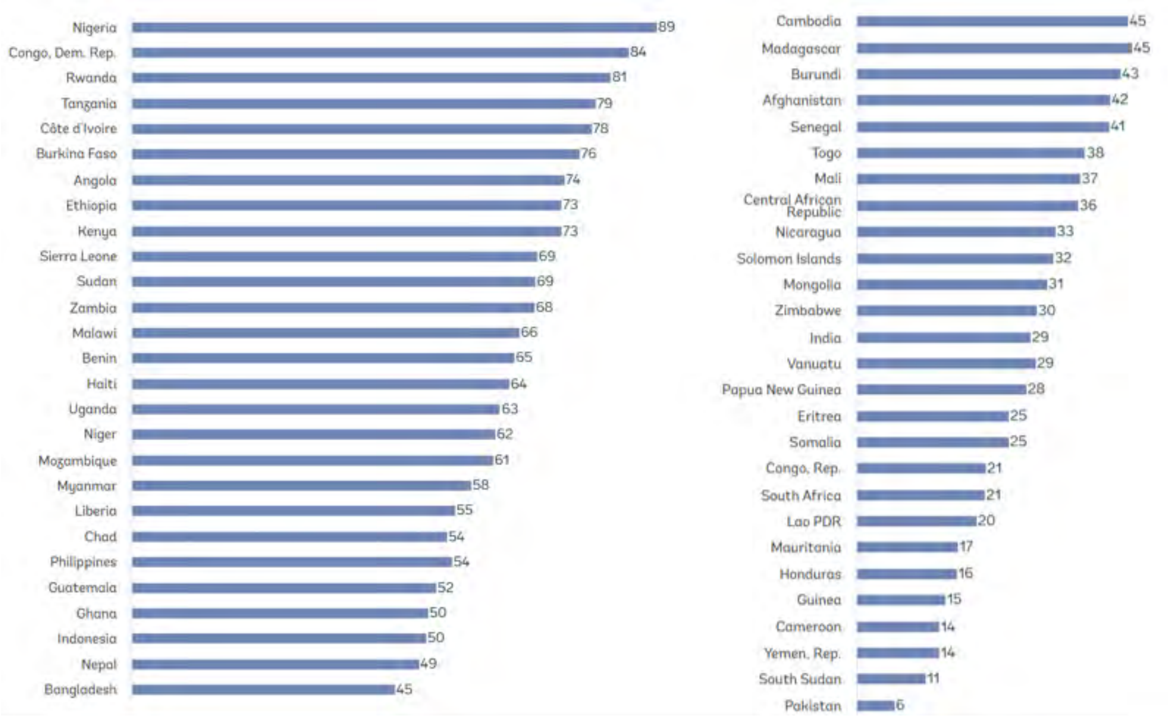
FIGURE 2.6 Evolution of RISE scores for mini-grid frameworks by region, 2010–2021



Source: ESMAP. 2024. RISE.

[17] Foster, Vivien and Anshul Rana. 2020. Rethinking Power Sector Reform in Developing Countries.

FIGURE 2.7 RISE scores for mini-grid frameworks by country, 2021



Source: ESMAP. 2024. RISE.

Going beyond integrating mini-grids in national electrification plans

The role of mini-grids in achieving universal access by 2030 has been established and is reflected in their integration into national electrification plans (NEPs), as well as policy documents that define targets for each electrification mode (grid extension, mini-grids and standalone systems) along with interconnection arrangements. However, to provide certainty to investors and scale up mini-grid deployment, policymakers **need to ensure not only that mini-grids are integrated into NEPs, but also that the NEPs themselves integrate realistic and up-to-date distribution company network expansion plans**. This is particularly crucial where a country has multiple distribution companies, as an interested developer might have limited clarity regarding their expansion plans. Integrating these plans into the NEP could reduce the transaction costs associated with requesting them from the regulator or the distribution companies and provide certainty to the developers regarding potential areas for mini-grid development.

In addition, while the number of NEPs being developed in the sector has increased significantly, guidance on the steps required to implement them is lacking. Multiple countries have developed NEPs that typically provide some high-level guidance on short-term to long-term electrification goals, without going into the detail of how these goals will be achieved. Thus, there is an urgent need to go beyond the first step of geospatial energy access modelling. In this context, SEforALL is supporting the development of expanded integrated energy access planning frameworks. These Integrated Energy Planning Frameworks intend to operationalise the data-driven NEPs by developing achievable financial plans for each electrification modality, supporting the creation of appropriate institutional and regulatory frameworks and building capacity at the national and sub-national levels.[18] This expanded framework should also provide additional data and intelligence for the mini-grid sector at the site level, adding more nuance to the sites traditionally identified as the least-cost option for electrification via mini-grids.

There are efforts to integrate the different electrification modes within the same area. Policymakers and regulators are putting forward the concept of an Integrated Distribution Framework (presented in Box 2.1), which considers the potential for concessionaires being responsible for distribution in an area and ensuring universal access, by leveraging all three modes of electrification. For instance, Engie Energy Access has put forward a multi-technology approach,[19] whereby energy is provided to the community based on energy consumption density and cost: solar home systems are typically suitable for low-density areas with lower levels of economic development, while mini-grids are appropriate for communities with higher willingness and ability to pay. This approach requires rethinking every step of mini-grid development, including:

- Planning: conducting a business model viability assessment for site selection that includes diverse technology types.
- Tendering: including multiple technology types in tenders to provide energy based on the community's energy needs and financial capabilities.
- Funding: identifying a consortium of funders that support integrated projects.

BOX 2.1 Integrated Distribution Framework for energy planning

Currently, the three modes of electrification (grid extension, mini-grids and standalone systems) typically coexist in silos in a given territory/region, with each mode providing access to customers most attractive for their business models. Not only does this make universal coverage unlikely, but it also results in a variety of tariff regimes within the same area, without allowing the use of cross-subsidisation.

The proponents of the Integrated Distribution Framework (IDF) advocate that an "entity" (comprising one or more actors) should be held responsible for distribution in a given area (under a contract like a concession) and ensure universal coverage. The entity could include the existing distribution company, potentially in partnership with the private sector, or a combination of companies involved in various electrification modes.

Thus, the IDF views "integration" as a multi-faceted concept that includes:

- Integration of the three modes of electrification at the distribution level
- Integration of all types of end customers, leveraging complementary demand patterns and tariff cross-subsidisation programmes
- Integration of the public and private sectors in the distribution sector with clearly defined roles
- Integration of the power systems of neighbouring countries into regional pools.

Sources: Global Commission to End Energy Poverty. n.d. Integrated Distribution Framework; Integrating Isolated Mini-Grids With an IDF-Compliant Regulated Distribution Sector.

[18] Based on information provided to the Consultant by SEforALL.

[19] Engie Energy Access. 2024. Towards Universal Access to Energy: Enabling a Multi-Technology Approach in a Mini-Grid Environment.

Tailoring regulatory processes to different mini-grid scales

Regulatory processes are being tailored to different mini-grid scales. For instance, small-scale systems (smaller than 100 kW) often do not require a licence and are being exempted from tariff approvals, allowing operators to decide tariff levels and structures in consultation with their communities. In Nigeria, for instance, tariff levels can be decided between the mini-grid operator and the community (represented by customers consuming at least 60 percent of the electricity supplied by the mini-grid).[20] This approach has also been legally mandated for all non-interconnected rural mini grids in India since 2003.[21]

However, the regulator typically maintains the right to intervene following specific triggers: in Nigeria, the community can request an intervention and review of the tariffs by the regulator, to ensure equity and fairness. In Tanzania, a regulatory safety valve ensures that the regulator can intervene if a petition is signed by 15 percent of the households in the area served by the producer in very small power projects.[22] For larger systems, some form of official tariff approval is established to mitigate the risk of future tariff disputes that could put capital investment at risk.

This capacity-dependent regulatory approach addresses the risk inherent in each stage of the mini-grids' trajectory, by allowing greater flexibility to keep development costs low in nascent markets and strengthening protection in mature ones.[23] However, there are cases where investors and developers have noted that **the absence of any formal licence and tariff agreement issued by the government is a risk**. The sector continues the efforts to find an optimal balance between light-handed regulation and project bankability. Developers might prefer to obtain a permit instead of a deregulated approach to smaller mini-grids, as the permitting approach offers enhanced protection. In addition, it is worth considering that such exemptions may create an incentive for developers to size their projects at less than 100 kW even if a larger system were to have lower unit costs.

Enabling portfolio applications and extending the duration of permits

Sector stakeholders recognise the importance of establishing portfolios with a large number of projects to achieve economies of scale and attract investment. Portfolio applications are key for scaling up the sector, given that speed of deployment is crucial for achieving universal access by 2030. Data from the Africa Minigrid Developers Association (AMDA) show that for a single mini-grid, the average total time to attain all licences and approvals is 58 weeks,[24] which makes the timely deployment of the mini-grids required to power the unelectrified populations in the global South unattainable by 2030.

[20] Nigerian Electricity Regulatory Commission. 2023. Mini-Grid Regulations.

[21] World Bank. 2024. Mini-Grid Solutions for Underserved Customers.

[22] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[23] ESMAP. 2019. Ensuring That Regulations Evolve as Mini-Grids Mature.

[24] AMDA. 2022. Benchmarking Africa's Mini-grids Report.

Minimising transaction costs for obtaining licences is a key benefit of portfolio applications. Given that the majority of rural mini-grids range from just 10 kW to 100 kW, many private financiers are not willing to dedicate the time and resources required for due diligence, unless they have the option of larger deals that allow them to amortise such costs over larger volumes of capital.[25] Not only is the portfolio approach beneficial for attracting project finance investors, but it also helps distribute risk.

Acknowledging the importance of mini-grid portfolios, Nigeria's updated mini-grid regulations (2023) include the definitions of a portfolio of interconnected and isolated mini-grids, with a range of provisions that aim to promote a portfolio approach, such as allowing for a single tariff application to be submitted for a mini-grid portfolio, and the submission of a combined report (required by the regulator) for a portfolio.[26]

Concession schemes, under a top-down approach, have similar benefits. Regulators often opt for competitive bidding processes whereby developers can bid for multiple service areas, thus enabling them to aggregate mini-grid projects, reduce costs through economies of scale in planning, financing, supply of equipment and O&M,[27], and avoid overlaps with other providers in that region and related inefficiencies.

Given the increasing importance of project finance for mini-grid development, the duration of permits and licences should aim to reflect the tenor of financing agreements. The selection of a time limit on a licence is a balancing exercise between a duration short enough to incentivise developers to make progress, but long enough to allow for preparatory activities.[28] While licence duration varies by country, stakeholders highlight the need for a duration of at least 10 years, a typical tenor for financing agreements under a project finance approach,[29] or even 15 to 25 years, which is long enough to amortise all assets under the specified tariff regime.[30] For instance, in Sierra Leone the full mini-grid licence has a validity period of up to 20 years.[31]

Allowing for cost recovery tariffs

Cost recovery tariffs have emerged as a common approach in both nascent and developed mini-grid markets. Regulators tend to adopt a building block approach to mini-grid tariff setting by using a cost-based formula for calculating the revenue requirement. Countries following an individualised cost-based tariff methodology include Ethiopia, Kenya, Nigeria, Tanzania and Zambia.[32] Standardised tools, such as the Multi-Year Tariff Order (MYTO) tool used in Nigeria

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[25] SEforALL. 2020. Three Key Challenges to Scale Up the Mini-Grid Sector.

[26] Nigeria Electricity Regulatory Commission. 2023. Mini-grid regulations, 2023.

[27] USAID. 2017. Practical Guide to the Regulatory Treatment of Mini-Grids.

[28] USAID. 2017. Practical Guide to the Regulatory Treatment of Mini-Grids.

[29] REPP, REAN and AMDA. 2022. Future-proofing the expanding market: Recommendations for improving the bankability of the mini-grid regulatory framework in Nigeria.

[30] IRENA. 2016. Policies and Regulations for Private Sector Renewable Energy Mini-grids.

[31] EWRC. 2019. Mini-Grid Regulations 2019.

[32] USAID. 2020. Exploring Africa's mini-grid tariff methodologies.

and Sierra Leone or the Standard Tariff Application Model for mini-grids[33] in Kenya (see Figure 2.8), help simplify the tariff approval and review process by showcasing the bottom-up calculations of the cost of service, as well as the adjustments required to reflect changes in key inputs. In addition, AMDA and the African Forum of Utility Regulators (AFUR) are working on a *Mainstream Minigrid Tariff Settlement tool* project in Africa. The tool is intended to provide clarity on mini-grid tariff methodologies and calculation tools used on the continent by regulators and shorten the steps and procedures developers go through to have a mini-grid tariff approved.

The main components of this calculation are the regulatory asset base, the allowed rate of return on the developers' capital investment, depreciation and (typically) the treatment of capital subsidies, as shown in Figure 2.8.

[33] EPRA. 2024. Tariff Application Model for Minigrids.

FIGURE 2.1 Snapshot of the tariff building blocks in Kenya's Standard Tariff Application Model

Tariff Building Blocks:
A. Depreciation & Ammort-Straightline A. Depreciation & Ammort-Units of Outputs
B. O&M Expenditure *Income (recurrent) subsidy*
C1. Regulated Asset Base (RAB) Investment C2. Cumulative RAB Investment *Capital Subsidy* *Customer Payments for Connection* *Accumulated Depreciation*
D. Working Capital (WC)
Sum of RAB + WC (Cost reflective) Sum of RAB + WC (excluding Subsidy)
E. WACC
F. Debt Return/Interest
G. Equity Return
H1. Total Return on Capital (Cost reflective) H2. Total Return on Capital (Minus Subsidy)
I1. Tax Allowance (Cost reflective) I2. Tax Allowance (Minus subsidy)
J. Unsubsidised Revenue Requirement
K. Subsidised Revenue Requirement
L. Required Subsidy Revenue Req

Source: EPRA. 2024. Tariff Application Model for Minigrids.

Within this building block approach, the focus is increasingly turning to adjustment mechanisms, in light of the recent macroeconomic challenges during COVID-19. To ensure the bankability of the tariff setting framework, clear processes have to be in place to adjust tariffs for inflation and currency fluctuations in an effective and timely manner. Tariff indexation mechanisms play a pivotal role in mitigating currency risks, as explored in Section 0. Nonetheless, it is imperative to ensure that the economic burden stemming from macroeconomic forces does not disproportionately fall upon mini-grid customers. The sector is progressively adopting a more flexible perspective on cost recovery, prioritising risk mitigation over the conventional method of determining tariffs based on cost of service calculations, a topic elaborated upon in Section 4.1.

Allowing for flexibility in grid arrival arrangements and ensuring adequate compensation

More mini-grid regulations are being put in place to address the challenge of grid extension. Grid arrival is a key risk faced by developers, as mini-grid assets could become stranded, or expropriated with minimal compensation. Mini-grid regulations that include grid arrival arrangements typically offer a range of flexible solutions that can be negotiated between the operator and the utility or distribution company expanding into the mini-grid's service territory. For instance, Nigeria’s new mini-grid regulations enable the operator to choose from the following options in case of grid arrival:

- Convert into an interconnected mini-grid operator
- Transfer its distribution assets and receive compensation based on the book value of depreciated network assets (based on the historical acquisition cost, including the construction and development cost), plus the equivalent of the pre-tax profit for two years before handover
- Once the distribution assets are transferred, either deploy its generation assets as an embedded generator to the distribution company or become an emergency supplier during outages.

In some of the countries that have established interconnection arrangements, the mini-grid regulatory framework also defines a standardised approach for asset transfer valuation and efficient processes for ensuring timely payments. In Sierra Leone (also see Annex A1), the mini-grid regulations require the compensation to be equivalent to the residual value of privately financed assets after depreciation, the residual value of activated and amortised privately financed project development cost, and the audited revenue generated from the mini-grid for the 12 months before grid arrival. Defining depreciation is crucial in this context; based on the current market characteristics, it is suggested that the depreciation should be defined as ten years for generation assets and 25 years for distribution assets.[34]

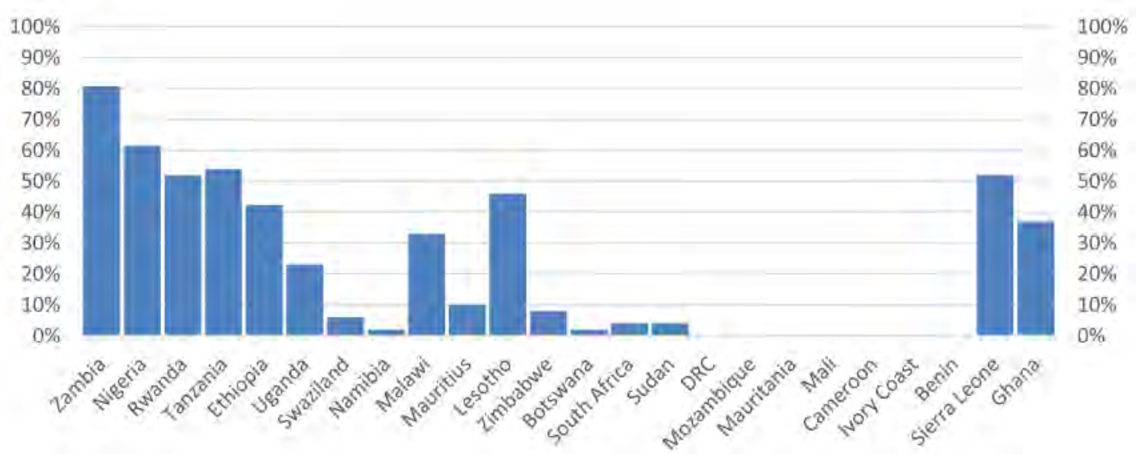
However, implementation of these regulations is often lagging behind, combined with a lack of sufficient clarity and detail. In India, for instance, the mini-grid regulations of the states of Madhya Pradesh, Odisha and Uttar Pradesh enable the interconnection of mini-grids with the main grid, but interconnections have not yet taken place.[35] Figure 2.9 presents the overall effectiveness of mini-grid regulations against main grid encroachment in 24 African countries, addressing five key aspects: (i) technical requirements, (ii) legal protection (permits and licences), (iii) business models, (iv) financial compensation mechanisms and (v) customer interests. The effectiveness of the regulations is expressed as a rate that reflects whether the mini-grid regulations provide information on each aspect, as well as whether there is clear wording that reduces scope for differing legal interpretation. Thus, a higher rate implies that

[34] REPP, REAN and AMDA. 2022. Future-proofing the expanding market: Recommendations for improving the bankability of the mini-grid regulatory framework in Nigeria.

[35] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

the grid encroachment regulations provide adequate guidelines in the event of grid arrival in areas already served by mini-grid investors, while a rate of zero reflects the lack of legal regulatory frameworks for protecting mini-grids against grid encroachment. The figure highlights that the Zambian mini-grid regulations are the most effective in safeguarding mini-grid investors' interests against potential main grid encroachment, while most African countries' existing regulations fail to provide adequate protection for the mini-grid licensee.

FIGURE 2.9 Overall effectiveness of mini-grid regulations against main grid encroachment



Source: Mambwe, Christopher et al. 2022. Benchmarking and Comparing Effectiveness of Mini-Grid Encroachment Regulations of 24 African Countries: A Guide for Governments and Energy Regulators to Develop Effective Grid Encroachment Regulations.

Push towards standardisation of regulatory approaches

Increased harmonisation and standardisation of regulatory approaches to mini-grids are crucial for achieving scale quickly. While the development of a mini-grid regulatory framework needs to be tailored to the country context so that the specific risk factors and challenges are taken into account, some regulatory aspects can be based on blueprints, which can be further adjusted to market and project conditions.[36] This is the case for regulatory provisions that protect investments, such as tariff-setting methodologies based on the principle of cost recovery, as well as grid arrival arrangements.

Buy-in is key to standardised mini-grid regulation. Establishing consensus across the sector on core regulatory aspects is essential for facilitating the adoption of standardised approaches and tools. In this context, AFUR recently engaged with development partners, regulators, ministries of energy and AMDA members to develop a standardised mini-grid tariff tool that is robust and accepted by a broad range of stakeholders.[37] The development of the tool considered the existing tariff-setting methodologies in Nigeria, Sierra Leone, Kenya and Tanzania, aiming to build on the strengths of these tools and address any shortfalls identified.

[36] SEforALL. 2023. Mini-Grids Partnership Newsletter, December 2023; and Consultant's interview with MIGA.

[37] Bunnya, Samuel S. 2023. Mainstreaming mini-grid regulation across Africa. ESI-Africa.

The consultation process with both regulators and mini-grid developers who have successfully gone through the application process in the aforementioned countries served to highlight challenges both from the public and private sector perspective.

Efforts to standardise due diligence processes for mini-grid projects have not yet gained sufficient momentum. Currently, due diligence expenses can amount to 7-10 percent of the total project cost, which poses a significant barrier for many companies. By standardising a substantial portion of the technical and legal due diligence across different countries, there is potential to decrease these costs. An example of such an initiative is AfDB's AMAP, which aims to streamline processes and enhance efficiency through four pillars: (i) opening new markets (designing bankable, national mini-grid acceleration programmes to attract public and private investment); (ii) catalytic support (developing new financial de-risking instruments and providing technical assistance to unlock private investment); (iii) strengthening the ecosystem (expanding knowledge sharing and technical skills across industry actors); and (iv) programme management (ensuring smooth project implementation and high quality outputs).[38]

Digitalising regulatory processes through a one-stop shop for mini-grids

The sector is seeing continued efforts to streamline and digitalise application processes for licences and permits. The granting of licences and permits, as well as the evaluation of proposals as part of tender-based procurement processes, requires handling many documents in a short period of time.[39] Given the need for rapid mini-grid deployment to accelerate universal electrification, the use of digital technologies with automatic data processing can be crucial. Development partners continue to focus some of their technical assistance efforts towards facilitating regulators and ministries of energy in creating one-stop shops for mini-grid applications and regulatory requirements.[40] Odyssey, for instance, is providing a digital one-stop shop, or unified platform, that streamlines application processes and mini-grid deployment.

Facilitating "undergrid" mini-grids

Mini-grid regulatory frameworks are increasingly acknowledging the integration of mini-grids with the main grid as a way to enhance the resilience of the power system, creating win-win-win situations for utilities, mini-grid operators and consumers alike. "Undergrid" mini-grids are mostly solar hybrid-powered mini-grids built and operated by private companies in areas already connected to the main electricity grid but facing poor quality service. Currently, millions of people live with unreliable and low-quality power or receive no power at all.[41] The frequent power outages disrupt economic activity (with many commercial and industrial (C&I) customers

[38] AfDB. 2020. Multinational - Africa Mini-Grid Market Acceleration Programme (AMAP) - SEFA Appraisal Report.

[39] UNIDO. 2020. Clean Energy Mini-Grid Policy Development Guide.

[40] Consultant's interview with GEAPP.

[41] Graber, Sachiko et al. 2019. Electrifying The Underserved: Collaborative Business Models for Developing Mini-grids Under the Grid.

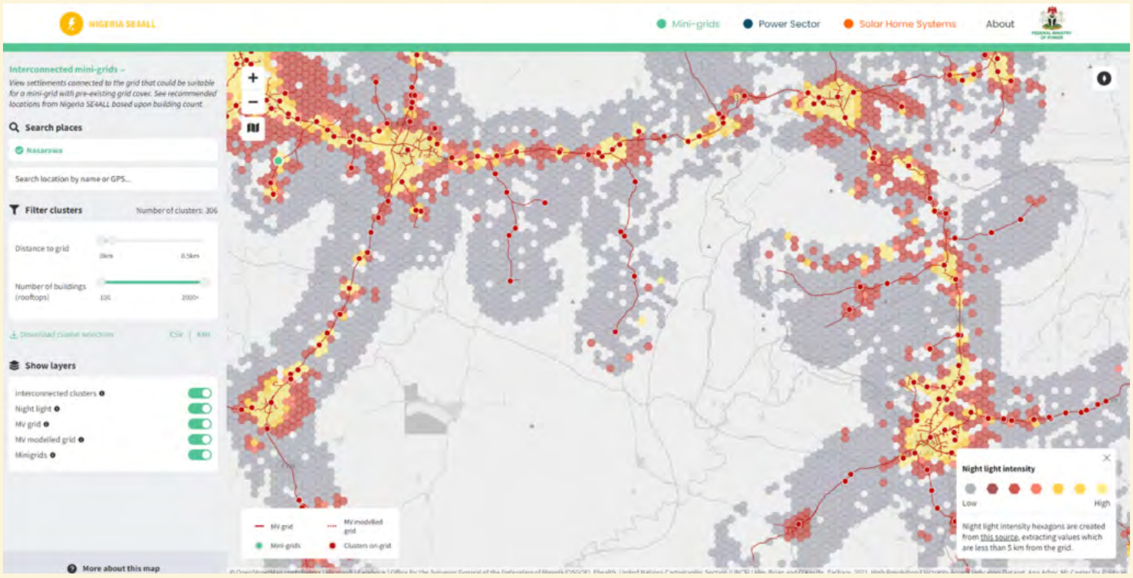
resorting to traditional fuels, such as diesel), and vital services such as healthcare. Interconnected mini-grids could offer a solution in this context, by improving service quality in underserved areas, unlike isolated mini-grids that operate in unserved areas.[42] However, institutional misalignments between grid (state-owned) and mini-grids (privately owned) often pose a major barrier for interconnected mini-grids.

BOX 2.21 Interconnected Mini-grid Acceleration Scheme in Nigeria

Nigeria's Rural Electrification Agency has launched the Interconnected Mini-grid Acceleration Scheme (IMAS) with the aim of accelerating the deployment of interconnected mini-grids in the country. The scheme is supported by the European Union and the German government through the Nigerian Energy Support Programme.

As part of the scheme, an "interconnected mini-grid explorer" has been developed to estimate the potential for these mini-grids. It focuses on settlements that currently have a grid connection, but only receive between four and eight hours of power per day. Night light intensity (shown in the figure below as coloured hexagons, calculated from the intensity of light emitted from the area during dark hours) is a key variable for interconnected mini-grids, as it represents the likelihood of an area having high- or low-quality grid supply.

FIGURE 2.2 Snapshot of the interconnected mini-grid explorer for Nigeria



Source: Nigeria SE4ALL. 2022. Exploring the Potential for Interconnected Mini-Grids with the Nigeria SE4ALL Web Map.

The role of the regulatory framework is crucial, in particular when it comes to mini-grid technical standards, which need to ensure the potential integration into the main grid, and contractual arrangements between the utilities and the mini-grid companies. Box 2.3 summarises key recommendations for regulating interconnected mini-grids.

[42] UNDP. 2021. Derisking Interconnected Solar Mini-Grid Investments in Nigeria.

BOX 2.32 "Mini grid solutions for underserved customers": Recommendations

The World Bank's latest publication on undergrid mini-grids provides the following recommendations for governments and regulators:

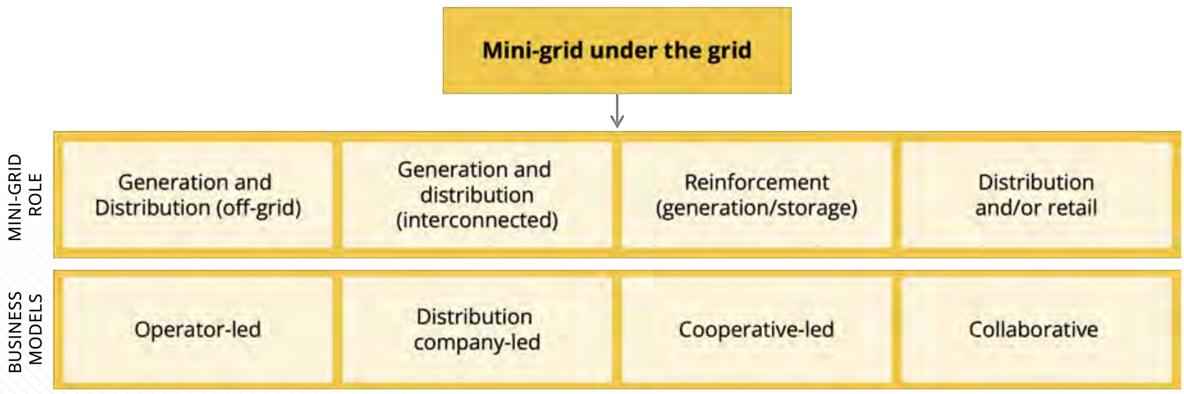
Interconnected mini-grids should be set up on a voluntary basis as a result of financial incentives. Interconnected mini-grids that are mandated by policy and regulation without producing a win-win-win outcome for the distribution company, the mini-grid developer and the mini-grid customers are unlikely to be commercially sustainable.

A light-handed approach to regulating the commercial arrangements of interconnected mini grids should be preferred. Undertaking a lengthy regulatory review of each element of the interconnection agreement might not be necessary given that both the developer and the distribution company are protecting their commercial interests. The regulatory review should, instead, focus on the broader design of the agreement so that the retail tariff is lower than that of non-interconnected mini-grids offering comparable service.

Source: Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

Several potential business models are emerging for undergrid mini-grids, depending on the entity that has the key responsibility for mini-grid development and operation. For instance, under a **mini-grid operator-led** model, the private operator is responsible for the development and operation of the interconnected mini-grid in consultation with the distribution company and/or community, while under a **distribution company-led** model the main responsibilities lie with the distribution company, which subcontracts some functions to a private mini-grid operator. Other proposed business models include the **cooperative-led** model, with a community cooperative taking the lead in mini-grid development and operation, and the **collaborative** model, under which the responsibilities are shared among the interconnected mini-grid operator, community cooperative and distribution company, as shown in Figure 2.11.[43]

FIGURE 2.3 Potential contractual arrangements for undergrid mini-grids



Source: Global Commission to End Energy Poverty. n.d. Towards actionable electrification frameworks: Mini-grids under the grid.

[43] Global Commission to End Energy Poverty. n.d. Towards actionable electrification frameworks: Mini-grids under the grid.

Undergrid mini-grids are already used in the Indian state of Uttar Pradesh, where a private mini-grid operator (OMC Power) has built mini-grids in villages that are already served by the distribution utility, as a result of the lack of reliable service, especially during peak evening hours.[44] They are also increasingly being used in Nigeria, as highlighted in Box 2.4.

BOX 2.43 PowerGen's undergrid mini-grids in Nigeria

While Nigeria's Toto community is connected to the main grid and has an old local distribution system, the infrastructure is not functional due to chronic lack of maintenance and widespread electricity theft. Thus, despite nominally having electricity access, the community struggles with unpredictable blackouts, power rationing or lack of any power at all. In this context, PowerGen and Abuja Electricity Distribution Company negotiated a mini-grid and grid power-sharing agreement, based on which **PowerGen built a mini-grid for Toto that supplies reliable power during the day and buys electricity from the Abuja distribution company at night.** The arrangement has been described as "win-win-win", as the community will have access to reliable power, the utility will have a new influx of revenue, and PowerGen will benefit financially from the operation and maintenance of the solar PV generation and newly installed distribution systems. The agreement acknowledges the differing strengths of the two parties, with the distribution company being more suited to urban environments and PowerGen being experienced in managing customers at the grid edge. By installing smart meters to streamline revenue collection and remote monitoring technology infrastructure, PowerGen aims to cut down on theft and vandalism.

Source: Francklyn, Lili. 2022. Nigerian minigrids improve power reliability and utility revenues for communities "under" the grid. HOMER Microgrid News.

Greater focus on cross-party collaboration and involvement

There has recently been a shift towards increased collaboration among the entire spectrum of stakeholders involved in the mini-grid sector, including increased coordination between regulators and between donors, as well as increased involvement of the private sector and the local communities.

The sector is promoting greater collaboration between regulators at a regional level, in an effort to reduce the resources and time required to develop a comprehensive mini-grid framework from scratch, but also to facilitate mini-grid developers who are interested in working in different countries. Regional harmony in regulatory requirements can help the private sector execute projects more efficiently by reducing the costs of market development. Following the recent launch of the African School of Regulation, the sector, including governments and the donor community, has rallied behind the institution as a platform that offers extensive knowledge-sharing and capacity-building opportunities, tailored to the regulatory challenges in Africa. In addition, AFUR and GET.transform have established a partnership to provide resources, peer exchange and regulatory best practices for scaling up mini-grid investments through a toolbox of model mini-grid regulations, aiming to create consensus and reduce the fragmentation of the mini-grid sector.[45]

[44] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[45] GET.transform. 2022. A Toolbox of African Model Mini-Grid Regulations.

Increased donor coordination has become a key priority in order to ensure consistency in the regulatory approaches pursued in the beneficiary countries. Donors are increasingly working closely together to avoid mixed messages when interacting with governments and local stakeholders, as well as to leverage complementarities between their programmes. Development partners that become involved in a given country often choose to follow the lead of the donor that has had the longest in-country engagement, including their approach with respect to business models and mini-grid regulation; this is the case in Madagascar, for instance, where GIZ has been active for a long time and coordination among donors (World Bank, AfDB, GIZ, IFC) is achieved through bi-monthly calls.[46] Other examples include Nigeria, where GIZ's Energy Support Programme paved the way for the World Bank's Nigeria Electrification Project, and Ethiopia, where the World Bank and AfDB have come in at the same time as the Rockefeller Foundation and sought to design complementary programmes, namely the ADELE programme and the Distributed Renewable Energy-Agriculture Modalities (DREAM) project, respectively.[47] A greater push for collaboration on application and due diligence processes is currently lacking from this wider effort towards donor coordination.

There has been renewed attention on strengthening a collective voice for the mini-grid industry that can represent their interests in the context of stakeholder collaboration. There is a growing recognition of the need to establish an effective dialogue between the private and the public sectors so that there is a common understanding of each party's priorities and key challenges. Consultation with investors early in the process of regulatory framework development is crucial for establishing bankable mini-grid regulations that effectively address investment risks and can mobilise new capital. In Africa, for instance, the sector is increasingly focusing on AMDA's potential to effectively represent the private sector in meaningful discussions with the public sector on policy and regulation that will enable mini-grid scale up.

Finally, a crucial and sometimes overlooked stakeholder that is key to the project's success is the local community. There are many examples of projects that have not included the local population throughout their duration, which have ultimately failed. A recent encouraging trend has been the greater inclusivity of end users (also highlighted in 2.54). For example, the mini-grid developer Weziza highlighted the need to engage with the local community prior to their project in order to convince them that it was indeed going to deliver electricity, given the mistrust created through projects that were launched but did not ultimately go ahead.[48] In the Pacific region, this issue has progressed to the point where projects are not approved without following a set of "social protocols", ensuring that recipients are included in the project.[49] RMI's programme "Sharing the Power", which was rolled out in Nigeria in February 2023, makes the local community a central part of the business model by promoting the co-ownership of the electricity source, or "inclusive energy governance": host communities can own a stake in the mini-grid through financial, land and in-kind contributions, while the proceeds from the mini-grid operation are distributed according to an agreed-upon formula between the

[46] Consultant's interview with Sustainable Energy Fund for Africa (SEFA).

[47] INENSUS. 2023. The Mini-Grid Business podcast. "Where to go next – Which countries are at the top of the funders' list? Part 1".

[48] Oikocredit International. 2023. How Oikocredit partner Weziza is improving access to electricity in Benin .

[49] Consultant's interview with ASU.

community and the developer. Crucially, community representatives have voting rights in matters such as tariffs, service levels and upgrades, which directly impact the community.[50]

BOX 2.54 Integration of local community in mini-grid projects

In order to raise awareness and achieve the active engagement of the community in its mini-grid project, JUMEME, a mini-grid developer in Tanzania, set up a **Village Power Committee**, which was responsible for organising discussions and sharing the latest developments on the project with the population. JUMEME also organised promotional events and door-to-door communication campaigns that were aimed at highlighting the benefits of electricity, improving the customers' understanding of the tariff structure and informing them of financing options.

Source: IIED. 2017. Making mini-grids work: Productive uses of electricity in Tanzania.

Business Model Innovations

The need for scalable business models

While the transformative impact of mini-grids is undeniable and crucial, it is equally important to recognise that the profitability of the existing business models remains a key metric for potential investors. The majority of current investors in mini-grid projects typically look for a balance between societal impact and financial returns. The appeal of mini-grids lies not only in their clear and significant impact on improving energy access and sustainability, particularly in underserved regions, but also in their potential to yield profitable returns. Consequently, investors meticulously examine the business plans of mini-grid projects, seeking a clear and feasible path to profitability. This dual focus on impact and profitability underscores the necessity for developing scalable and financially sustainable business models within the mini-grid sector. Okra Solar's financial metrics reflect this dual focus; average revenue per user (ARPU) and its anticipated growth are used as an indicator of project success, while utilisation is an indicator for the potential to scale up and revenue opportunities.[51]

Mini-grid companies are increasingly prioritising a minimum number of connections as a key factor in the final investment decision for electrification projects. In the evolving landscape of the mini-grid sector, the number of potential connections has become a critical consideration for companies when deciding to build a mini-grid. This shift reflects an increasing focus on achieving economies of scale, which are essential for the viability and profitability of these projects. For instance, companies like PowerGen have set a benchmark, often not considering the electrification of communities with fewer than 1,000 potential connections.[52] This threshold is seen as the "sweet spot" where electricity can be provided at a reasonable cost while maintaining profitability.

[50] RMI. 2024. Sharing the Power: Nigerian Community Takes Charge of Their Energy Development.

[51] Okra Solar

[52] Consultant's interview with Powergen.

The rationale behind this strategy is multi-faceted. In larger communities, with a substantial number of connections, there is a higher likelihood of existing economic activity. This existing activity reduces the need for extensive resources to be allocated towards training and incentivising economic development, as is often required in smaller communities. Additionally, the demand for electricity tends to increase exponentially with the size of the town, making larger towns more attractive for electrification from a demand perspective. However, this does not mean that smaller communities are left without options. Companies like Husk Power are open to supplying electricity to smaller communities, albeit with the support of subsidies. These companies recognise that with concerted efforts to boost economic activity—such as introducing solar pumps for irrigation—it is possible to run a mini-grid profitably even in smaller settings. This approach often involves an initial push to stimulate economic activity, which can then sustain the demand for electricity.

Political decisions shape the range of business models that private mini-grid developers can choose from, but typically acknowledge the need for scale. Five main strategies are currently being followed by governments in Africa and Asia, analysed in Box 2.6. The approach under which private developers select sites based on projected profitability (approach 1) is currently the most common, given that it can speed up mini-grid development once the regulatory framework is in place. Competitive procurement for portfolios of sites (approach 3) is also often preferred because of the lower costs arising from grouping sites, while concessions (approach 4) are not as common, given that it requires extensive documentation and buy-in from many domestic and international stakeholders.[53]

BOX 2.65 Government approaches to mini-grid development

1. **Private developers select the sites.** Under this approach, developers choose mini-grid locations based on their projected profitability, often leveraging geospatial databases developed by governments and donors. Licences or permits and tariff approval can be granted on a site-by-site basis or for a mini-grid portfolio. Capex grants to make the projects commercially viable are typically awarded by the rural electrification agency or other government entity on a first-come, first-served basis (as long as specified minimum technical and financial requirements are met), with the final portion being performance-based. This approach is followed by the World Bank-funded Nigeria Electrification Project, under which 110 mini-grids have become operational as of October 2023.
2. **Private developers select the sites, combined with deregulation.** Under this approach, the developer can sell electricity without a licence or permit and may also be able to set retail tariffs without regulatory approval. An example of this approach is provided by India (see Annex A2).
3. **Government selects groups of individual sites and conducts competitive procurement.** Under this approach, multiple mini-grid sites are grouped into lots to lower soft development costs and interested developers typically bid on either proposed tariffs or minimum required subsidies. For instance, in Sierra Leone's Renewable Rural Energy Program (see Annex A1), the Ministry of Energy selected 54 villages for mini-grid development, which were split into four lots. The winning developers were selected on the basis of multiple criteria and obtained 20-year licences to manage and operate the mini-grids.
4. **Government conducts competitive procurement for concessions in areas it selects.** A concession is a formal contract between the government and a private operator (concessionaire),

[53] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

based on which the concessionaire assumes O&M obligations and, often, investment responsibilities for the asset over an agreed period. This approach embeds the relevant regulations (such as tariffs, quality of service, exclusivity and grid arrival arrangements) within the agreement, thus providing a stable and predictable regulatory regime for the developer. The Democratic Republic of the Congo is planning to follow this approach, combined with grants to the developers to improve affordability.

5. Government conducts competitive procurement for private developers to build and operate new mini-grids for later takeover by a utility. This approach aims to ensure that the utility retains its monopoly on all retail sales of electricity throughout the country. The construction and initial operation of mini-grids is outsourced to private companies typically due to the utility's limited experience in mini-grid development.

Source: Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

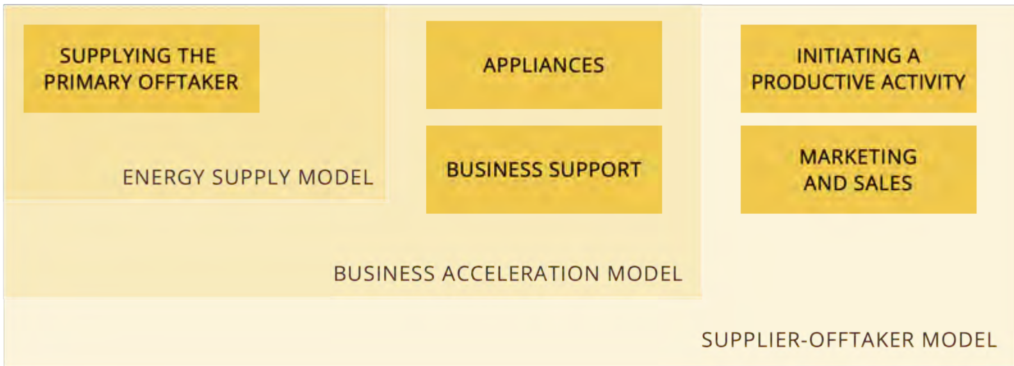
Productive use of energy remains an integral part of mini-grid development, often with an expanded scope

Productive use of energy (PUE) has been established as a fundamental aspect of mini-grid development, improving the financial viability of mini-grids and catalysing economic growth within communities. PUE refers to energy applications that enhance economic activity, enabling communities to increase revenues or replace less efficient power sources like diesel generators. The importance of PUE extends beyond just providing energy; it involves actively facilitating the economic empowerment of communities. The significance of PUE to mini-grid sustainability is highlighted by mini-grid developers in India (discussed in section A2), where PUE is an integral component of their business. PUE can address the key challenge of low electricity demand in rural areas, thus making it easier to recover the investment costs of generation, distribution and metering infrastructure. This is also reflected in a lower levelised cost of electricity (LCOE) (also see section 0) compared to the LCOE in a scenario without PUE. Additionally, PUE can provide a solution to the problem of residential load shape and load factor, given that residential demand is concentrated in the evening when solar PV generation is not directly useable and must be cycled through batteries before use.[54]

As the sector matures, developers are increasingly acknowledging the fact that fostering PUE growth in a sustainable way requires a broader enabling environment. This includes identifying gaps in the business and technical skills required to make use of PUE appliances, building awareness of and capacity for productive activities, and improving access to capital for acquiring PUE equipment, access to the physical energy applications themselves, and access to markets to sell the products. Thus, the scope of PUE is expanding from the mini-grid operator supplying electricity to anchor loads (*energy supply model*) towards providing consumer financing to facilitate the acquisition of PUE equipment (*business acceleration model*) or introducing PUE value chains and becoming the primary offtaker itself (*supplier-offtaker model*). These business models are presented in Figure 2.12 and analysed in the sections below.

[54] van Hove et al. 2022. Evaluating the impact of productive uses of electricity on mini-grid bankability.

FIGURE 2.4 PUE business models



Source: ECA based on EPP Africa and Nordic Development Fund. 2019. Powering Productivity: Lessons in Green Growth from the EEP Africa Portfolio.

Energy supply model

Mini-grid business models have traditionally focused on having an anchor client, namely a single large electricity consumer such as a telecom tower, which consumes the majority of electricity supplied by the mini-grid. The anchor client is the first step in the so-called ABC strategy[55] (Anchor—Business—Consumers) for mini-grid financial sustainability. The strategy entails first negotiating an agreement with an anchor client, which has a predictable load profile, and then identifying or helping develop local businesses that can provide stable demand and promote economic growth in the communities. The last step is residential customers, given that this segment cannot guarantee economic viability, but is crucial for achieving the goal of access expansion. Research based on demand and cost data from India has shown that connecting health centres as anchor loads improves both the financial and environmental sustainability of mini-grids, by lowering the unit cost and the greenhouse gas emissions intensity of electricity.[56] Examples of the ABC strategy being used in practice include Engie Energy Access (outlined in Box 2.7), OMC Power in India,[57] and many developers in Bangladesh who first connect key business customers to ensure an initial baseload of consumption and generate trust in the project, before expanding to household customers.[58]

[55] GIZ. 2014. The ABC-Model: Anchor customers as core clients for mini-grids in emerging economies; and EEP Africa. 2018. Opportunities and challenges in the mini-grid sector in Africa.

[56] Beath et al. 2021. The cost and emissions advantages of incorporating anchor loads into solar mini-grids in India.

[57] International Solar Alliance. n.d. Case Study. Operational use of "Anchor Load Business Community Model".

[58] Climate and Development Knowledge Network. 2019. Solar Mini-Grids: Investment Case – Bangladesh.

BOX 2.76 ABC strategy in practice

The ABC strategy is based on the concept of focusing on a primary customer with reliable demand and subsequently connecting other customers with less predictable usage patterns. Engie Energy Access utilises the ABC strategy to achieve the economic viability of its mini-grid sites:

- Site surveys are used to collect information on future energy needs to appropriately size the systems. Additional site analysis facilitates planning to provide development support for income-generating activities.
- Once the different activities are identified, Engie Energy Access develops a list of **core clients**, including those who own large capital machines such as hammermills and oil expellers.
- Finally, the **residential customers** are connected within two years, according to the following targets:
    - 60 percent before the start-up of the site
    - 80 percent at the end of the first year
    - The rest in the year after.

Source: Engie Energy Access. Impact Review 2023.

A different application of this model is emerging, namely sustainable cooling, which is crucial for reducing the large post-harvest losses of perishable food products, often occurring at rates of 40 percent of what is grown in agricultural value chains in developing markets.[59] As explained in Box 2.8, cold rooms can function as anchor loads to improve mini-grid financial viability. Inspira Farms[60] operating in Africa and Ecozen[61] operating in India are examples of providers of cold rooms and other cold chain technologies that can increase consumption of mini-grid electricity.

BOX 2.87 Sustainable cooling as a way of increasing demand for mini-grid electricity

Cold storage is the best way to reduce post-harvest loss of perishable food products, especially in the "first mile"; the closer to the farm that the temperature of produce is lowered, the bigger the impact on its shelf-life. Reducing produce loss rates through expanding cold storage capacity increases household income among the farmers who live in the communities served by remote mini-grids. This, in turn, increases their ability to purchase appliances and their demand for electricity.

Technical design is an important consideration for balancing solar energy fluctuations in communication with the mini-grid; the use of ice and battery storage in refrigeration devices is crucial for reducing consumption overnight or on days with low solar radiation.

SEforALL is currently developing the **Agricultural Cold-Chain Access Planning (AgCAP) Tool**, a first-of-its-kind open-source planning tool for (geospatially) assessing agricultural cold storage needs and the implications of cooling demands for electrification planning. The tool is poised to support as well as improve the viability of mini-grid electrification projects through the planning of cold rooms serving as anchor loads.

Source: Opinion piece provided by SEforALL.

[59] Opinion piece provided by SEforALL.

[60] InspiraFarms

[61] Ecozen

Mini-grid companies are increasingly considering a shift from anchor loads towards a diversified, sustainable customer base. The traditional approach of relying on a single anchor customer was initially favoured for its perceived ability to provide a stable and predictable source of demand and revenue, in addition to providing a "creditworthy counterparty" to sign a contract that could be shown to a lender. However, this approach is increasingly seen as less viable. One of the critical challenges with anchor customers, especially telecom towers, is the substantial negotiating power that these anchor loads wield, often leading to thin profit margins for mini-grid operators. The industry is now moving towards a model that focuses on a broader spectrum of customers. This shift is not just about diversifying risk, but also about identifying and cultivating a sustainable load that can replace the anchor customer. Companies like Powergen and Husk Power are at the forefront of this trend, strategically focusing on identifying the 20 percent segment of their grid that drives 80 percent of the consumption and revenue.[62] This approach is about pinpointing who constitutes this critical 20 percent and tailoring services to meet their needs. This transition to a sustainable customer base model reflects a deeper understanding of market dynamics and a more nuanced approach to achieving profitability and long-term viability.

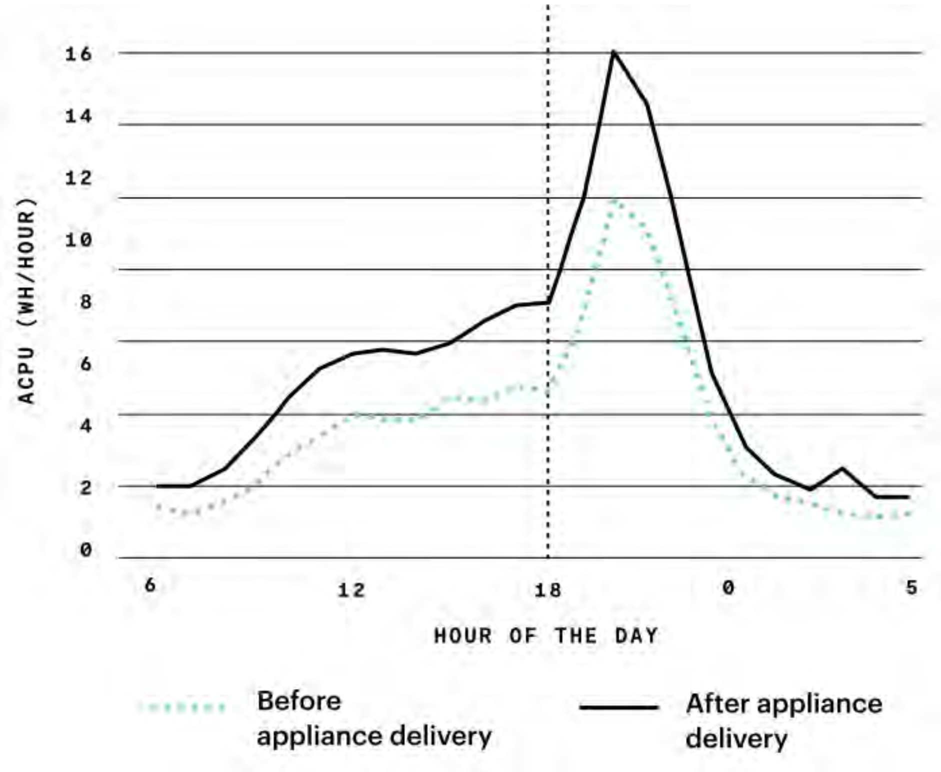
Business acceleration model

In an effort to increase demand and establish a stable base of revenue, developers are increasingly providing appliances to customers, aiming to equip rural mini-grid customers who are often ready to consume more electricity with the means to put this energy to use. Without appliances, customers cannot leverage the full benefits of electrification, while their energy use is too low to enable developers to sustainably operate their mini-grids. The CrossBoundary Mini-Grid Innovation Lab's pilot programme in East Africa and Nigeria showed that in the first five months after appliance delivery, purchasers of those appliances consumed twice as much electricity (Figure 2.13).[63]

[62] INENSUS. 2023. The Mini-Grid Business podcast. "Anchor loads, productive use and rural industrialisation".

[63] Rockefeller Foundation. 2020. Electrifying Economies: Appliance Financing. CrossBoundary Mini-Grid Innovation Labs East Africa, Zambia, and Nigeria.

FIGURE 2.5 Average consumption per user by time of day, pre and post appliance delivery, East Africa



Source: Rockefeller Foundation. 2020. Electrifying Economies: Appliance Financing. CrossBoundary Mini-Grid Innovation Labs East Africa, Zambia, and Nigeria.

The high upfront costs of PUE equipment remain a challenge, and appliance financing is used to address this, such as lease-to-own or fee-for-service schemes. A lease-to-own scheme requires the customer to pay a monthly fee that covers both the electricity and the payment towards the appliance for a specific payback period (often 12 months), after which they own the appliance and the monthly fee is reduced to just the electricity costs.[64] This leasing arrangement enables the customer to earn income from the productive activity, thus increasing their ability to pay the fee. Companies like Engie Equatorial (see Box 2.9) and PowerGen have dedicated a significant portion of their business to supplying energy efficiency devices, recognising the value of PUE in their operational model. In addition, Okra Solar has developed a digital application for appliance leasing that lowers overhead costs, encourages load growth and drives up revenue. The application collects data on energy usage and mobile payments and creates a credit profiling which can be used to improve access to finance.[65]

[64] EPP Africa and Nordic Development Fund. 2019. Powering Productivity: Lessons in Green Growth from the EEP Africa Portfolio.

[65] Okra Solar

BOX 2.98 Business acceleration model: Engie Equatorial

In 2022 Engie Equatorial (a collaboration between Engie Energy Access and Equatorial Power) inaugurated a hybrid solar 600 kWp mini-grid on Lolwe Island, Uganda. This project has an **integrated productive hub** that transforms raw materials into value-adding products, including water pumping, distribution and purification services, fish-drying facilities and ice-making devices to conserve the daily catch of fish.

In addition, the business model includes an **e-mobility** solution for fishing boats and motorcycles, coupled with **business incubation and asset-financing** services to support the growth of local businesses.

Source: ENGIE Energy Access. 2022. ENGIE Equatorial inaugurates game-changing Lolwe Mini-Grid in Uganda.

The limited business management capacity of local businesses, which threatens their economic viability, remains a key challenge under this model. Developers, such as JUMEME (see Box 2.10), often need to engage in resource-intensive hand-holding and training to the local businesses to make this model viable.

BOX 2.109 JUMEME: Targeted development support

In Tanzania, JUMEME employed the business acceleration model to support its mini-grids in 20 island villages on Lake Victoria, an economically vibrant area, and in particular tilapia fish trading. Apart from increasing electricity consumption from the mini-grid, this venture benefited the local economy by creating jobs and entrepreneurial opportunities in a multitude of sectors, including tilapia semi-processing, transport and freezing, and fish feed production, thus creating an **energy-aquaculture nexus**.

JUMEME has also enabled the automation and expansion of existing businesses by setting up a shop to sell appliances on credit (typically for six months) based on the needs of the local businesses. Given the limited access to finance and prohibitive upfront cost of PUE equipment, **JUMEME fostered links between its customers and local banks, savings and credit cooperative organisation and microfinance institutions**, while also providing the option to pay for only 10 percent of the equipment upfront.[66] However, challenges persist and often lead to defaults. In this context, businesses have suggested that a grace period would enable them to build their cash flow based on the new equipment.[67]

Crucially, JUMEME recognises **that its model requires targeted business development support to become sustainable**. Therefore, it conducts training programmes, advisory services and mentoring to improve the skillset of local businesses regarding management methods, bookkeeping and administrative tasks. JUMEME also focuses on maintaining a close relationship with the newly connected entrepreneurs to provide any engineering support required to connect or adapt machinery, which can prevent technical issues.

Sources: PREO. 2020. JUMEME; and ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

Given the significant resources required for developers to be able to successfully implement the business acceleration model, private financiers, who are starting to pay attention to PUE in

[66] IIED. 2017. Making mini-grids work Productive uses of electricity in Tanzania.

[67] EPP Africa and Nordic Development Fund. 2019. Powering Productivity: Lessons in Green Growth from the EEP Africa Portfolio.

connection with mini-grids, can play a crucial role in addressing this challenge. For instance, CrossBoundary and Oikocredit (as discussed in Box 2.11) have facilitated mini-grid developers Havenhill and Weziza respectively to implement appliance financing at scale.

BOX 2.1110 Oikocredit: Building an ecosystem around PUE

Impact investor Oikocredit places heavy emphasis on the establishment of an enabling ecosystem for PUE as part of the projects for which it provides finance. It does this by working with appliance financiers and tapping into agricultural cooperative networks to maximise the outreach of PUE support. To avoid working in silos, a dedicated department within Oikocredit looks at the intersection of PUE and mini-grids.

For instance, Oikocredit financing has enabled Weziza, a mini-grid operator in Benin, to implement a **leasing programme that allows households to use freezers or electric mills for a flat fee**. Compared to the previously used diesel-powered mills, the electric mills require little maintenance, saving up to 35 percent on maintenance costs, while the equipment has also created opportunities for additional income, such as through running small mill operations. The mills were deployed after carrying out **field studies and training** among the local population.

Source: Consultant's interview with Oikocredit and Oikocredit. 2023. How Oikocredit partner Weziza is improving access to electricity in Benin.

This model underscores the potential for mini-grid companies to generate more revenue by supplying additional services, rather than solely focusing on electricity provision. In essence, by offering a range of services and solutions that cater to the comprehensive needs of rural communities, mini-grid companies are not only enhancing their business models, but also playing a pivotal role in driving sustainable development and economic growth in rural areas.

Supplier-offtaker model

The scope of mini-grid companies has been expanding remarkably, transcending the traditional role of energy providers to become architects of rural industrial ecosystems. The last step in the evolution of the PUE-focused business models has been the increasing importance of mini-grid companies in promoting rural development that is no longer limited to merely supporting existing economic activities. The supplier-offtaker model reflects this shift, whereby the mini-grid operator establishes a commercial or industrial activity that is based on a local commodity (such as producing ice for fishermen), which serves as the primary offtaker for the mini-grid, thus filling the demand gap.[68] For instance, alongside setting up a mini-grid in Uganda, Volt-Terra also developed a farming model that uses a block-farming approach, in close collaboration with local farmers. Volt-Terra purchases farmers' produce, provides training and utilises an on-site heat pump dryer fuelled by the mini-grid's electricity for processing. In turn, the farmers' increased revenue from chili and vanilla production enables them to afford larger amounts of mini-grid electricity.[69]

[68] EPP Africa and Nordic Development Fund. 2019. Powering Productivity: Lessons in Green Growth from the EEP Africa Portfolio.

[69] PREO. 2024. Project News: From farm to market.

Donor support and standardisation are key under this model given the substantial resources that developers need to devote to detailed value chain analysis. Identifying ways to expand existing PUE activities using the local resources is resource-intensive, which highlights the importance of donor programmes that involve PUE market scoping. In Ethiopia, for example, the World Bank-funded ADELE programme has centred its mini-grid rollout activities around identifying and stimulating income-generating uses of electricity,[70] while the DREAM project in Ethiopia involves the Rockefeller Foundation providing technical assistance to the Ministry of Water and Energy to help determine PUE-focused mini-grid business models through feasibility studies and follow-on pilot projects.[71]

In addition, developers are increasingly looking into productive uses that communities all have in common. While PUE value chains vary significantly across different regions, developers are increasingly identifying a variety of solutions that can be standardised and scaled across multiple sites. For instance, productive uses that are relevant in any context, such as water purification equipment or e-mobility, can be developed into standardised solutions that can be efficiently deployed across different portfolios of sites. By facilitating access to clean water through energy-efficient purification systems, mini-grid companies are addressing a fundamental need while spurring local business opportunities. Similarly, the integration of e-mobility solutions, such as electric bicycles and vehicles, is not only enhancing transport in rural areas, but also opening up new avenues for economic activity and employment. For instance, OX Delivers,[72] a UK-based e-mobility start-up, has created a purpose-built electric truck under a transport-as-a-service model. More specifically, customers book space on the truck through an app or a phone call and pay roughly the same amount it would cost to make a delivery by bicycle.[73]

The expansion of mini-grid development into these diverse business lines is not just about profitability; it is about scalability and the holistic development of rural areas. Thus, **the intended impact of PUE has been expanded to encompass social development, beyond economic empowerment**, with some PUE initiatives considering local social issues and disparities, as highlighted in the case of East African Power in Box 2.12.

BOX 2.1211 Community empowerment through PUE

East African Power (EAP) is promoting community empowerment through its 150 kW mini-grid in Rwanda, which will supply affordable energy to a **micro-industrial park** and an **Empowering Villages Centre** that includes a multipurpose community building, a library/ learning centre and an agricultural centre of excellence. The expected outcome of the project is the provision of energy **to local micro-businesses, as well as the development of social and educational initiatives through the community centre.**

Source: EEP Africa. 2019. East African Power - Hydropower plant providing clean energy in Rwanda.

[70] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[71] SNV. n.d. Distributed Renewable Energy-Agriculture Modalities (DREAM).

[72] OX Delivers

[73] Peters, Adele. 2024. These electric trucks can be shipped flat and assembled on-site. fastcompany.com.

Innovative approaches to promoting PUE have also acknowledged that men and women occupy different spheres in the productive economy[74] and benefit from electricity access in different ways. For instance, the World Bank's Africa Gender and Energy Programme worked with the government of Mali to ensure that rural electrification initiatives consider the different needs of women, promoting equitable outcomes. Surveys that were conducted as part of the programme showed that women were less likely to leverage electricity for income-generating activities compared to men, for reasons including limited access to credit and training, as well as the lack of consideration of women's specific energy needs in the design of energy access programmes. The programme highlighted the challenges of supporting gender-responsive enterprise development as part of electrification efforts.[75]

Addressing the challenge of low initial demand in a flexible manner

Companies are finding alternative, high-value applications for surplus energy in the initial years of mini-grid operations to maximise revenues. Especially in the initial years of mini-grid operation, the available capacity is much higher than the usage. In this context, the unused electricity from the mini-grid can be purchased by a buyer of last resort, thus generating additional revenue for the developer and driving down tariffs for other users. An example of this business model has been pioneered by Gridless, a company based in Kenya that utilises excess electricity from renewable mini-grids for bitcoin mining, through co-locating small bitcoin data centres alongside these mini-grids.[76] This approach is crucial in the early stages of mini-grid development, when the demand from households might be insufficient to make the economics of mini-grid projects viable.

[74] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[75] ESMAP. 2023. Accelerating the Productive Use of Electricity.

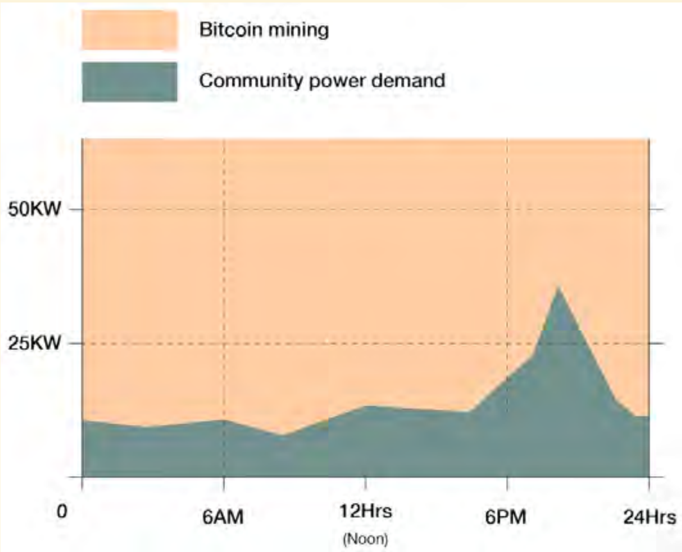
[76] Gridless

BOX 2.1312 Using excess electricity for cryptocurrency mining: Gridless

Gridless focuses on utilising renewable energy from mini-grids for bitcoin mining, particularly in East Africa. Through partnerships with renewable energy companies, Gridless finances and manages the operation of data centres in rural areas where traditional industrial or commercial customers are not available. The partnership with Gridless provides mini-grid operators with a stable revenue stream, enhancing their financial viability, especially in the early years. While the communities' energy demand is unstable, with peaks at 6–8 a.m. and 6–9 p.m. and very little energy used during the other hours of the day, bitcoin mining can help create a consistent demand, as shown in Figure 2.14. Real-time demand levelling guarantees that the bitcoin mining's energy needs are turned on and off within seconds.

By creating a predictable demand and revenue, the Gridless business model functions in a similar way as an anchor load. However, unlike the anchor customers under the energy supply model, who are difficult to serve due to their negotiating power and rigid service requirements, the Gridless model offers flexibility as to how much and when electricity is consumed. Automated real-time demand levelling enables consumption to be ramped up and down at seconds' notice relative to the mini-grid's supply. Thus, the bitcoin data centres also function as a grid-balancer of last resort, providing demand-response ancillary services to keep the mini-grid always stable.[77] As the demand from the community grows, Gridless can decrease its mining activity or remove it entirely.[78]

FIGURE 2.6 Gridless model



Other than bitcoin mining, the mini-grids' electricity is used for various community purposes, such as cold storage for local farmers, charging stations for electric motorcycles, and public WiFi points. Thus, the model not only supports the sustainability of mini-grid projects but also contributes to broader rural development.

Source: Green Africa Mining Alliance. 2023. Energy and Bitcoin in Africa.

[77] Green Africa Mining Alliance. 2023. Energy and Bitcoin in Africa.

[78] African Crypto. 2022. Gridless Enables Cheap Renewable Energy in Rural Kenya via Bitcoin Mining.

Mesh grids as a cost-efficient way to connect dispersed communities

Mesh grids are increasingly being considered as an effective solution to electrifying areas with low population densities. Unlike mini-grids, which require densely populated areas, mesh grids connect nearby houses together to share power, allowing them to pool their consumption. Because of the short distance between the houses, the distribution network is low voltage, resulting in cheaper installation compared to a mini-grid. Distribution costs are approximately 75 percent lower than mini-grid distribution costs.[79] In addition, deployment is faster as there is no requirement for land acquisition; instead, a direct agreement with the household suffices. With this solution, there is no need to design a complete mini-grid from the start with distribution lines running to all households and businesses; instead, the links in the grid grow organically.[80] Mesh grids have been successfully deployed in Haiti by developer Alina Enèji, in partnership with Okra Solar and with support from GEAPP, with over 900 connections achieved and a target of 5,000 by August 2024.[81]

BOX 2.1413 Okra Solar mesh grids

Okra Solar has been deploying mesh grids in Southeast Asia, where by 2021 it had created mesh grids for over 400 households. It has recently expanded into Nigeria. The mesh grid is coordinated by the Okra Pod, a device that allows individual household solar power systems to share energy via low-voltage transmission cables. The pod is the building block of every mesh grid, ensuring that energy is optimally redistributed between neighbouring households. More specifically, power control algorithms as part of the Okra pod take excess power from each system and redistribute it to nearby loads, thus maximising network efficiency and battery health. The pods are **bundled together with standardised mesh grid kits** of solar panels, inverters and batteries, forming a **modular and scalable solution that can be increased in network capacity as demand growth**. Okra Solar's cost per connection for the mesh grid is USD 550.

The company recently released a mini-grid to mesh-grid charger, which enables developers to set up the mini-grid where there is a large anchor load and leverage low-cost mesh grids for the residential network. Excess power generated from the mini-grid is fed into the mesh.[82]

Sources: GET.invest. n.d. A power-sharing breakthrough for off-grid communities and Okra Solar.

Vertically integrated value chains to leverage synergies

In order to optimise costs and leverage synergies, mini-grid companies are forming partnerships and operating within a vertically integrated value chain. Integration of various stages of the value chain, such as technical design and construction, and sales and service, as well as O&M, allows for economies of scale and increased profit margins. In addition, mini-grid companies can have greater control over the quality of components and services at each stage of the value chain, which often leads to enhanced customer satisfaction and trust. Crucially, integration also enables innovation by facilitating seamless collaboration and communication

[79] Okra Solar

[80] GET.Invest. n.d. A power-sharing breakthrough for off-grid communities - GET.invest.

[81] GEAPP. n.d. Rural Electrification: Are Mesh Grids a Game Changer?.

[82] SEforALL. 2021. Okra Solar: Start rapidly, start small and grow over time.

between different departments. Engie Energy Access is an example of a company operating within a vertically integrated value chain in order to quickly adapt to market trends and technological advancements, thus maintaining a competitive edge. By covering the entire mini-grid value chain, from tendering and financing to sales and O&M, Engie Energy Access has stronger leverage on suppliers and can reduce costs.[83]

The cooperative model as a potential solution for areas "unattractive" to private investors

The cooperative model is often met with scepticism by government officials and lending institutions, even though co-ops have successfully electrified rural populations in the United States, the Philippines, Bangladesh and Latin America. Bolivia's Cooperativa Rural de Electrificación, for instance, is the largest electricity co-op in the world, serving more than 800,000 members.[84] Bangladesh offers a prime example of co-ops facilitating rural electrification, with 80 co-ops or PBS (*Palli Bidyut Samity*) serving more than 100 million people across the country.[85] Pakistan has also followed the community-based model for mini-grid development, whereby the mini-grids are operated and managed by community members. More specifically, the O&M responsibility lies with committees comprised of members drawn from local communities. Technicians are selected from the local community and paid through the tariff collected from consumers.[86] The model is difficult to implement given that it requires a lot of time and resources dedicated to technical assistance,[87] as well as a number of characteristics in the community, such as social cohesion, the existence of trusted leaders and economic activity. However, a growing number of countries are leveraging the community-based model, including Liberia, Uganda and Zambia,[88] proving its potential for serving rural customers.

Financing Trends

Public funding is limited and cannot meet the financing needs required for the mini-grid sector to reach its full potential as part of the universal electrification agenda. Therefore, governments and international financial institutions have been focusing their efforts on attracting private capital by creating an enabling environment and reducing the risks associated with mini-grid investments to increase their bankability. This involves implementing supportive policies, offering financial incentives and providing guarantees to mitigate investment risks. These measures aim to leverage additional resources and expertise, accelerating the deployment and

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[83] Engie Energy Access. 2023. Performance and Impact Review.

[84] NRECA International. 2023. CRE's Story: The Power of Perseverance.

[85] NRECA International. 2018. Bangladesh: Secret for Success.

[86] SAARC. 2021. Minigrids and Access to Electricity in SAARC.

[87] Consultant's interview with NRECA.

[88] NRECA International. 2023. Electric Co-ops Catching on in Africa.

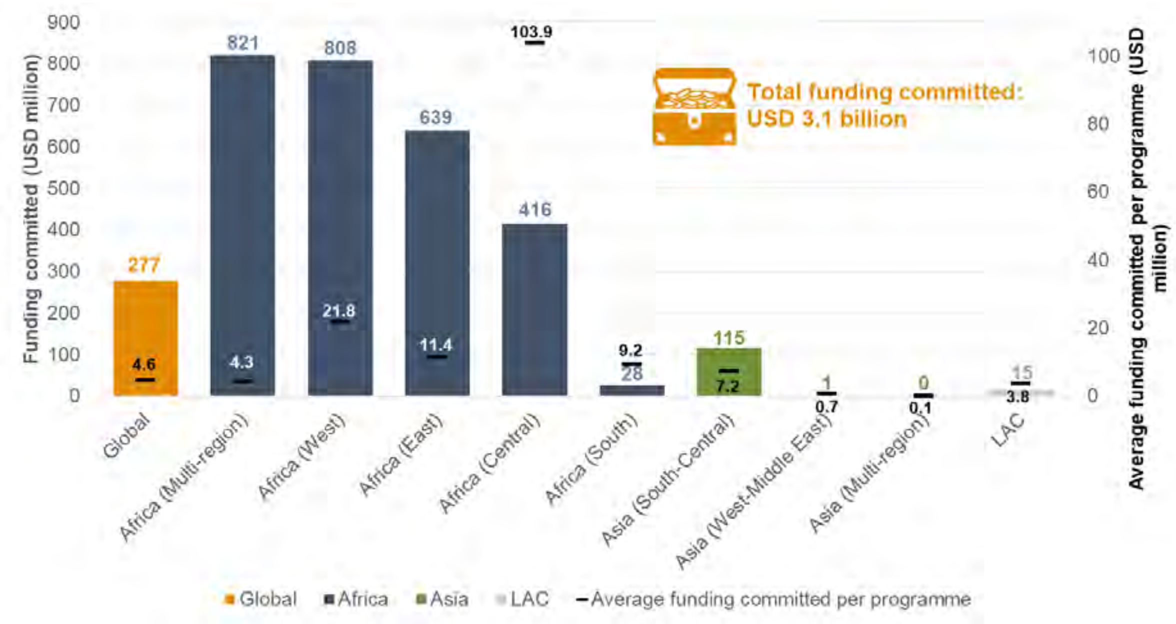
scaling of mini-grids in remote and underserved areas, and thus contributing significantly to the goal of universal electrification.

Funding for the mini-grid sector remains substantial, but the financing gap is still large

In the past 15 years there has been a substantial increase in funding for the sector, with sub-Saharan Africa remaining the main recipient of funding from private investors, governments and development partners. Two trends can be identified in mini-grid sector funding. First is the significant increase in total committed funding, with the main development partners rapidly increasing the available financing for programmes from millions of US dollars in the 2000s[89] to over USD 2.5 billion in 2023. The second trend is the increasing participation of private investors. According to data from ESMAP,[90] funding from private investors has increased sixfold in seven years from less than USD 100 million in 2015 to almost USD 600 million in 2022.

The total committed funding for ongoing programmes from the data available amounts to over USD 3.1 billion, as seen in Figure 2.15 and Figure 2.16, across 377 programmes. Over USD 2.7 billion of the committed funding is being directed to African countries, with USD 820 million being committed to multiregional programmes across the continent and USD 277 million funding cross-continental programmes.

FIGURE 2.7 Total funding committed to ongoing programmes by region

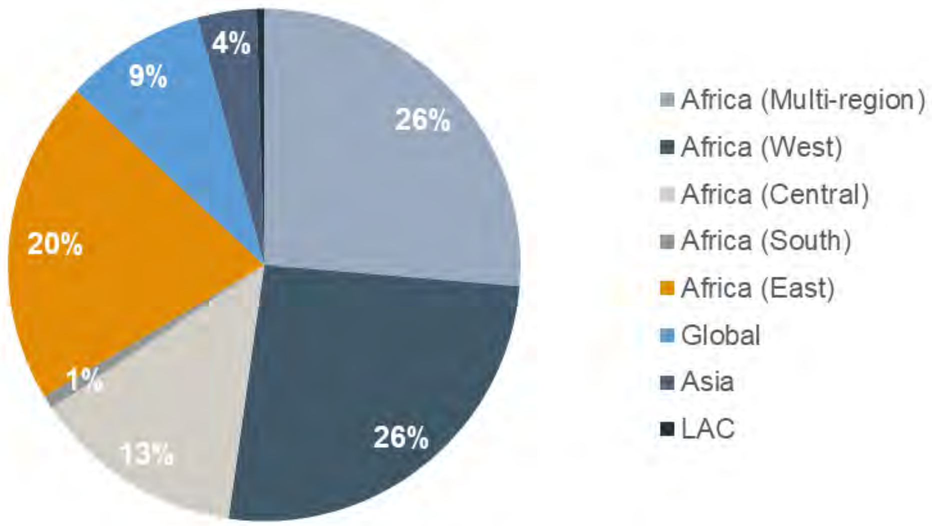


Source: ECA analysis based on MGF database and additional data provided by the World Bank.

89 ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

90 ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

FIGURE 2.8 Total funding committed for ongoing programmes by region



Source: ECA analysis based on MGF database and additional data provided by the World Bank.

The mini-grids sector is showing signs of growth

The mini-grids market has started to attract the attention of commercially minded investors. As noted above, there is currently limited public capital available to meet the financing needs of the sector. The scarcity of bankable projects restricts private investment in the sector. However, more recently, private financiers such as Stoa[91] and Triodos Investment Management[92] have been actively seeking investment opportunities in the mini-grids market, which reflects a growing interest from a range of investors, including venture capitalists, private equity firms and development finance institutions. This shift indicates a broader recognition of the role mini-grids can play in global energy access and sustainability goals, presenting new opportunities for growth and impact in the energy sector. In this context, impact investors in the mini-grid sector are also increasingly recognising the necessity of being prepared to take on more risk.

Over the past decade, there has been a shift from venture capital to infrastructure project financing. The increasing global focus on sustainable development, especially in energy access, has elevated the role of mini-grids as a viable solution for electrifying remote and rural communities. This recognition has made mini-grids attractive to a broader range of investors, particularly those looking for long-term, stable returns associated with infrastructure projects. While funding in the sector remains a significant obstacle, new sources of capital and financing approaches have emerged recognising mini-grids as critical infrastructure assets rather than mere commercial ventures. The transition from venture capital to infrastructure project financing allows for longer investment horizons with extended repayment periods and

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[91] STOA. 2023. STOA, DFC and Proparco join FMO and other existing investors in a USD 43 million equity investment in minigrid leader Husk Power Systems, to improve energy access in rural Sub-Saharan Africa and India.

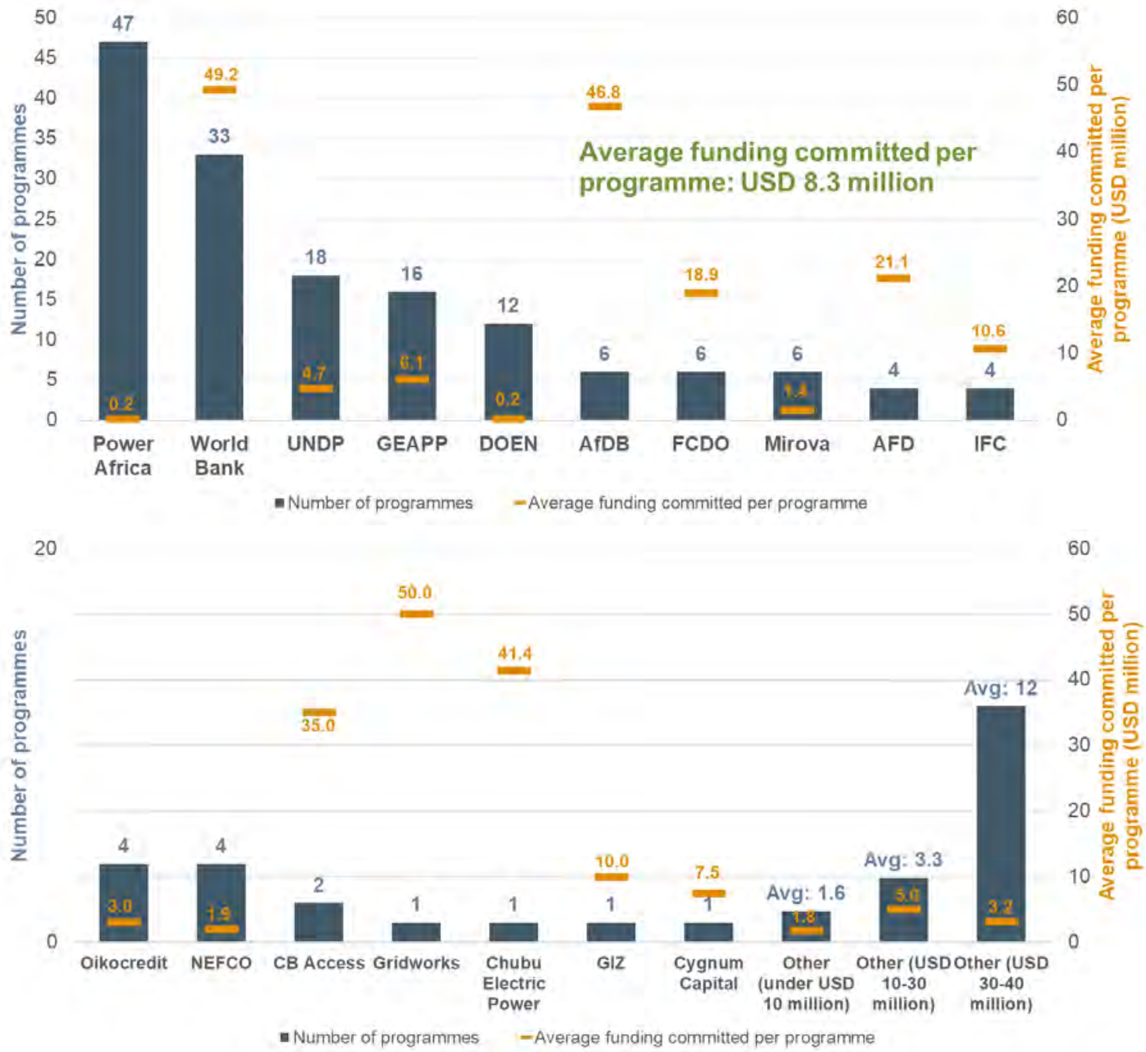
[92] PV Magazine. 2023. Minigrids edging closer to profitability.

lower return expectations that align with the project lifecycles of mini-grids. These projects are designed for long-term societal benefit, aligning with the nature of mini-grids that aim to provide sustainable and reliable electricity access, particularly in rural and underserved areas. Venture capital, however, with its appetite for higher risks and returns, remains a source of funding for areas such as technology platforms, research and development, and innovative business models within the sector.

Funders have been ambitiously committing more capital to support scale-up

Funders have acknowledged the importance of mini-grids in practice by committing large amounts of funding to numerous mini-grid programmes. Figure 2.17 shows that Power Africa, the World Bank, UNDP and GEAPP claim the highest number of mini-grid programmes. An average of USD 8.3 million is committed per programme, based on the data received.

FIGURE 2.9 Number of programmes per funder and average funding committed per programme

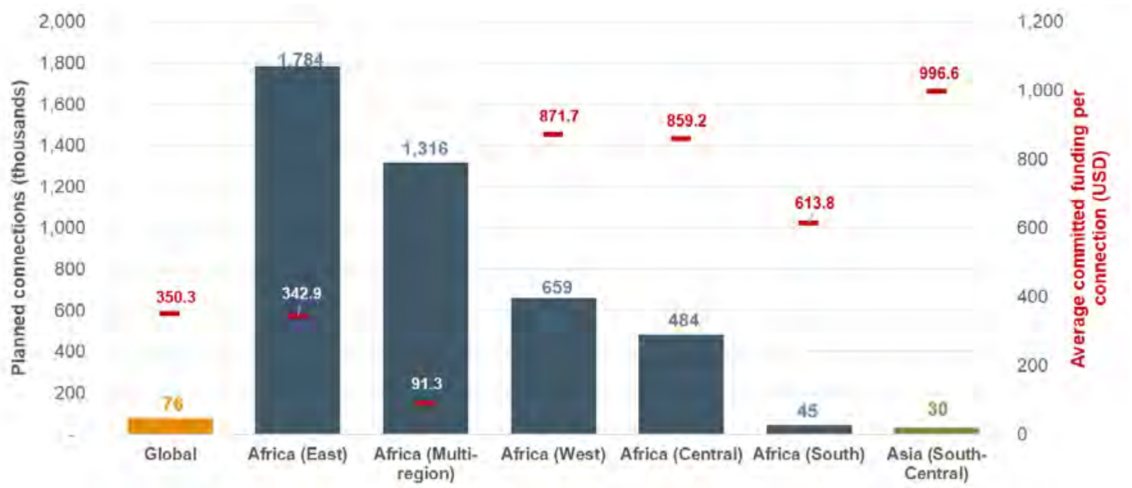


Note: The category “Other” encompasses funders that were included in a database provided by the World Bank, disaggregated by their total committed funding.

Sources: ECA analysis based on Mini-Grid Funders database provided by the Carbon Trust and data provided by the World Bank.

The funders' ambition in terms of funding committed to mini-grid programmes also translates into a large number of total mini-grid connections planned. Based on the projects for which data on connections were provided, the total connections planned are 4.4 million, with the World Bank accounting for 64 percent of them, followed by the AfDB with 28 percent. Projects targeting East Africa have the most planned connections, with roughly 1.7 million planned in total, as shown in Figure 2.18. Projects targeting countries across different regions in Africa (denoted as multiregion in the graph below) follow, with 1.3 million planned connections. Based on the same projects for which data were obtained, the average level of committed funding per connection is USD 411, with the highest level of funding per connection being committed by projects targeting South-Central Asia (USD 996), followed by projects targeting West and Central Africa (USD 872 and USD 860 respectively).

FIGURE 2.10 Average committed funding per planned connection and total number of planned connections for selected programmes

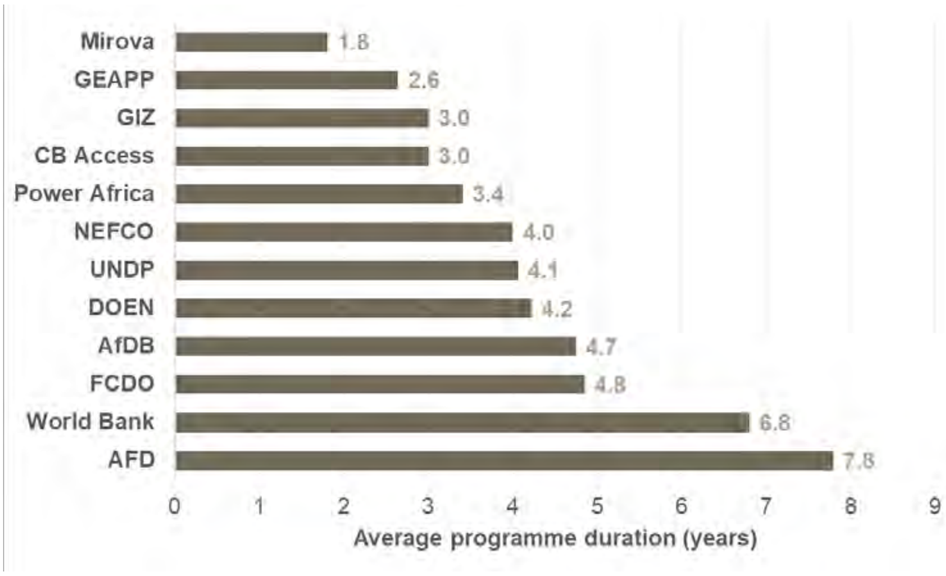


Note: The Global and Multiregion categories do not represent averages, but instead programmes targeting mini-grids worldwide or across regions within a continent, respectively.

Sources: ECA analysis based on MGF database provided by the Carbon Trust and data provided by the World Bank.

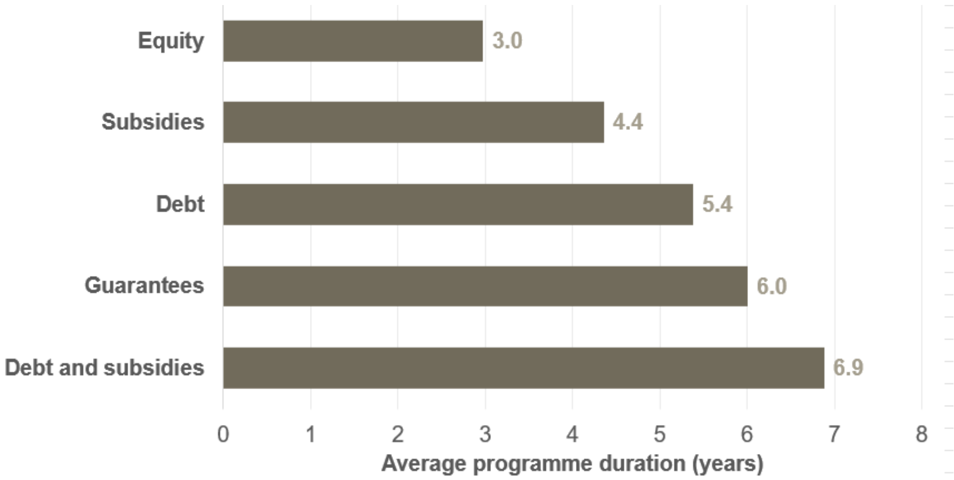
The duration of mini-grid programmes varies widely across funders and funding type. It ranges from approximately two years for Mirova to approximately eight years for AFD. The funders that have launched programmes with the largest duration, namely AFD, the World Bank, the Foreign, Commonwealth and Development Office (FCDO) and AfDB, shown in Figure 2.19, also provide technical assistance for the majority of their programmes (analysed later in the section). Programmes that include technical assistance have an average duration of 5.4 years, compared to less than four years for programmes where technical assistance is not provided. Also, equity-funded programmes, which may involve higher risk but quicker implementation, tend to have shorter durations, compared with more complex or risk-averse financial structures (Figure 2.20).

FIGURE 2.11 Average programme duration per funder



Source: ECA analysis based on MGF database provided by the Carbon Trust.

FIGURE 2.12 Average programme duration by primary funding instrument



Source: ECA analysis based on MGF database.

Innovative mechanisms are being devised to de-risk mini-grid investments

One of the primary challenges in the mini-grid market is the high perceived level of risk, particularly in relation to demand. Unlike conventional utilities or independent power producers, which often rely on long-term power purchase agreements for stable cash flow, mini-grids face higher risk of fluctuating demand. This risk is exacerbated by the necessity for mini-grid operators to stimulate demand to ensure full utilisation of their infrastructure, a critical factor for the bankability and sustainability of these projects. Additionally, financing challenges are intensified by currency fluctuations, as most funding is available in hard currencies such as US dollars or euros, whilst revenues for mini-grids are collected in local currencies.

The use of blended finance at both the project level and the fund level has been crucial in bridging the gap between the need for sustainable energy solutions and the financial viability of these projects. This model combines different forms of financing, such as grants or technical assistance from development agencies, equity investment from impact investors, and guarantees and debt to mitigate risk and improve the financial returns of mini-grid projects. This approach not only brings in commercial investors seeking market-rate returns, but also attracts impact investors who are focused on the social and environmental outcomes of their investments. While the availability of debt financing for mini-grid projects remains relatively low, especially in Africa, blended finance facilitates the mobilisation of more debt financing. Combining these sources of capital ensures that projects are not only impactful, but also commercially viable, addressing sustainability issues often seen in projects funded solely by donors. Blended finance models can be particularly innovative, combining grants, construction debt and results-based financing (RBF). In Bangladesh, for instance, Infrastructure Development Company Limited (IDCOL) provides finance under a fixed structure, which comprises 50 percent grant, 30 percent concessional loan and 20 percent equity.[93] This model has proven to be successful in mobilising public and private finance for mini-grid market development.

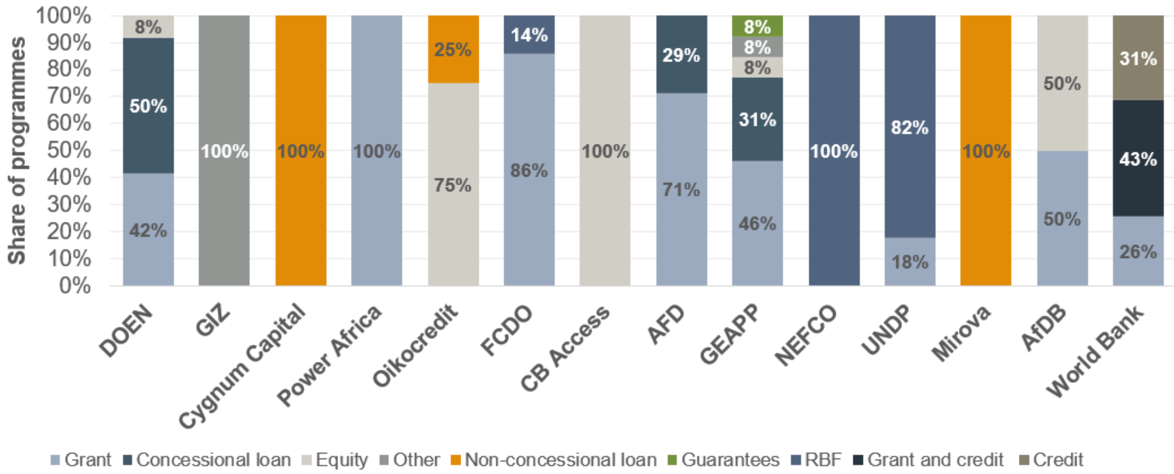
Blended finance models are also responding to the sector's increasing call for one-stop shops for financing. In light of the urgent need for speed in the sector, mini-grid developers and financiers alike are acknowledging the key role that financing platforms covering a variety of instruments can play. For instance, CEI Africa, a finance facility incorporated by KfW on behalf of Germany's Federal Ministry for Economic Cooperation and Development (BMZ), provides a one-stop-shop approach to financing by offering a combination of debt, equity and grants to support electricity access.[94] Partial pre-financing of the grants is tied to equipment orders to assist companies at the pre-construction stage, followed by RBF grants for new connections, outcome-based grants for implementation of PUE on operating mini-grids, and junior and senior debt, as well as small tranches of equity offered in collaboration with crowd lenders, coupled with technical assistance.

Despite the importance of leveraging a menu of financing instruments through one-stop shops that can easily adapt to the needs of mini-grid development in different contexts, around 40 percent of funders among the MGF Group utilise only a single instrument in their mini-grid programmes, as shown in Figure 2.21 below.

[93] IDCOL

[94] Information provided by GreenMax Capital Advisors.

FIGURE 2.13 Funding instruments used per funder (share of programmes)



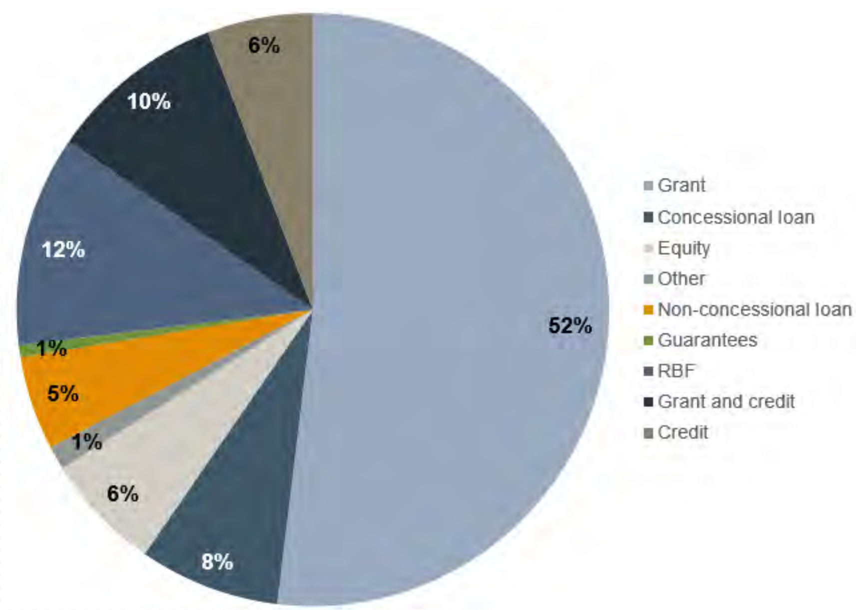
Note: The breakdown illustrates the final allocation of funding provided by the MGF Group, regardless of the specific channels through which the funds were disbursed.

Source: ECA analysis based on MGF database provided by the Carbon Trust.

Redesigning financing instruments to address inefficiencies in disbursement

Public funding programmes, such as grants and RBF schemes, play a pivotal role in bridging the viability gap in hard-to-reach areas where the development of mini-grids may not immediately present a profitable venture. Grants and RBF remain the principal modalities of funding for mini-grids, as shown in Figure 2.22, representing the primary funding instrument for 52 percent and 12 percent of programmes led by the MGF Group respectively. A combination of grant and credit is used in 10 percent of programmes, while the rest of the instruments are less frequently used, with guarantees being the least used funding instrument.

FIGURE 2.14 Share of mini-grid programmes per primary funding instrument



Source: ECA analysis based on MGF database provided by the Carbon Trust.

However, grant programmes often come with their own set of challenges — their requirements can be restrictive, with developers finding themselves in a constant cycle of fundraising to meet the equity levels required to participate. They typically also have a limited timeframe, which adds another layer of complexity, as mini-grid projects take longer to develop due to the need for extensive preparatory work before construction, including negotiations with the regulator. The stringent conditions imposed by these programmes can inadvertently create obstacles for developers, complicating the path to electrification in areas that most need it. This scenario underscores the urgent need for more flexible and supportive financing structures that can accommodate the unique challenges of mini-grid development, especially in remote and underserved regions.

Some grant providers have recognised the need to streamline their processes to disburse resources more efficiently to project developers. This nascent trend is pivotal in enabling developers to access the necessary initial funding, which in turn positions them to seek additional financing for project expansion and sustainability. A prime example of this streamlined approach is the Nigerian mini-grid programme, implemented by Nigeria's Rural Electrification Agency with support from the World Bank. The RBF model simplifies the grant application and disbursement process, thereby reducing administrative burdens and accelerating the deployment of funds to developers. This streamlining not only quickens the pace of project development, but also builds a foundation of financial stability, allowing developers to focus on scaling up their projects and exploring further funding avenues. Streamlining RBF processes also requires addressing the "stop-and-go" issue that developers face due to strict timelines of the RBF windows. The Universal Energy Facility (UEF), presented in Box 2.15, was created to solve this issue by consolidating different RBF sources into one large cross-funder instrument to ensure continuity of funding.[95] Greater alignment between the due diligence of different programmes would also be beneficial. Harmonised standards could further ease the administrative load on developers and ensure smoother, more consistent funding flows.

BOX 2.1514 Universal Energy Facility

The Universal Energy Facility (UEF) is a multi-donor RBF facility established to significantly speed up and scale up energy access across sub-Saharan Africa by providing incentive payments to eligible organisations deploying energy solutions, including mini-grids, and providing verified end-user electricity connections based on pre-determined standards.

The UEF was established by SEforALL in collaboration with several donors and partners, including the Shell Foundation, Rockefeller Foundation, IKEA Foundation, Power Africa, Good Energies, UK FCDO, Carbon Trust, BMZ, GIZ and AMDA, in response to growing demands from the sector for RBF. More than 13 private mini-grid developers support the facility.

The UEF disburses grant payments to approved mini-grid projects according to a results-based incentive of USD 592 per electricity connection, regardless of the country in which the mini-grid is operating.

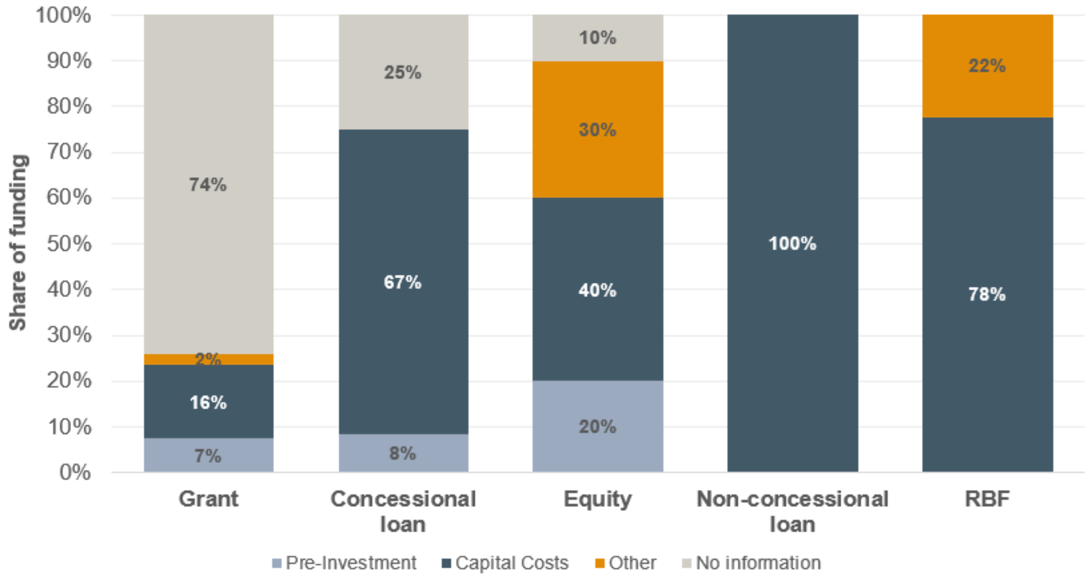
The grant disbursement is made once the UEF programme manager verifies deployments and connections. The verification process is done both remotely and physically, through verification visits by the independent verification agents. In addition, grantees are required to comply with the UEF quality and service standard requirements.

Source: SEforAll. n.d. Universal Energy Facility.

[95] Based on the consultant's interview with GEAPP.

There is a recognised need for more flexible RBF structures to accommodate the varying needs and stages of mini-grid projects, as highlighted in Box 2.16. RBF typically comes into play quite late in the implementation stage; Figure 2.23 shows that the majority of RBF funding (as well as the majority of concessional and non-concessional loans) target the capital cost stage of mini-grid development.

FIGURE 2.15 Share of funding per mini-grid development stage and primary funding instrument



Source: ECA analysis based on MGF database provided by the Carbon Trust.

BOX 2.1615 Incorporating flexibility in RBF programmes

The dynamics of the mini-grid market are site-specific, which creates the need for RBF contracts to be adapted, especially regarding incentive structures, delivery timelines and system capacity. In this context, project developers highlight the importance of RBF having "built-in flexibility" as a key factor for its success.

The importance of adaptive management is also underscored by Energising Development (EnDev), the global energy access programme, for implementing an RBF project that aims to achieve market development. Continuously monitoring the market, including the products available, the key players and the enabling environment, as well as regular interaction with the relevant stakeholders, are prerequisites for an RBF that adapts its strategy according to the latest market developments.

Most of EnDev's RBF projects adapt their initial approaches over time based on the implementation experience gained, in particular the incentive structure and verification procedures, or to address major changes in the enabling environment.

Sources: Opinion piece provided by SEforALL; and GIZ. 2021. Transforming energy access markets with results-based financing.

Developers need substantial pre-development financing, which leaves a significant financing gap in the initial stages of the projects. In this context, RBF needs to be restructured so that it can be disbursed prior to project development. An innovative solution is a forgivable loan, an approach that has been pioneered by CEI Africa (see Box 2.17). In addition, the Beyond the Grid

Fund for Africa (BGFA), a multi-year funding facility operating in sub-Saharan African countries, works through a combination of innovative RBF mechanisms for energy companies, close cooperation with governments and real-time data collection and analysis. BGFA aims to synchronise the design of the funding windows with market realities in order to create maximum impact via the RBF. Technical assistance is also provided to the selected companies to ensure that they can meet their BGFA goals and sustainably scale up their operations in target markets.[96]

BOX 2.17 Forgivable loans for pre-financing RBF: CEI Africa

CEI Africa functions as a one-stop shop for green mini-grids, offering a range of financial instruments under a single umbrella, supported by an integrated due diligence process. Financial instruments available include RBF grants, outcome-based grants, junior and senior debt and small equity tranches in partnership with crowd lenders.

A forgivable loan is provided alongside RBF grants. For RBF-funded new connections, the grant may cover up to 60 percent of the capex, disbursed upon verification of new connections. The forgivable loan can be offered for up to 30 percent of the approved grant amount, at an interest rate of 1 percent. Upon reaching 30 percent of the contracted connections, the principal and interest of the forgivable loan are fully forgiven. If, after extensions are granted at the discretion of CEI Africa, developers are unable to reach this milestone, the forgivable loan is converted to a term loan with negotiated tenor and interest rate.

The due diligence process applies rigorous commercial scrutiny to every grant applicant. Priority is given to reputable firms with a proven track record in mini-grid construction and operation, with secure funding structures. Although the due diligence process reduces the risk of projects not meeting the forgivable loan milestone, there remains a risk of non-recovery of the loan in cases of non-compliance. CEI Africa is able to absorb this risk due to its reliance on a capital base entirely funded by grants.

Source: Information provided by Greenmax capital.

Financiers continue to explore guarantees in an effort to mitigate currency risk

Amid the recent depreciations of African currencies and the resulting inflationary pressures across the continent,[97] local currency financing has increased in importance. While most funding is in hard currency, local financing is key in markets with volatile foreign exchange rates, as it substantially reduces the currency risk that often deters investors. By allowing investments to be made in the local currency, these financial instruments align the revenue streams of mini-grid projects with their financing costs, thereby mitigating the mismatch that typically arises from foreign exchange fluctuations. This model is proving to be especially beneficial in countries like Nigeria, where currency volatility has been a major barrier to attracting foreign investment in infrastructure projects, including mini-grids. One of the major guarantee providers in the market is GuarantCo, the credit guarantee arm of the Private Infrastructure Development Group, which aims to mobilise private sector funding in local currency into infrastructure in Africa and Asia. The variety of guarantees offered, such as partial credit, liquidity extension,

[96] REEEP. n.d. Beyond the Grid Fund for Africa.

[97] IMF. 2023. African Currencies Are Under Pressure Amid Higher-for-Longer US Interest Rates.

portfolio, and engineering, procurement, and construction (EPC) contractor guarantees, can be customised to address specific funding obstacles. The ticket size for a single transaction is quite large, between USD 5 million and USD 50 million or the equivalent amount in local currency, thus limiting their applicability to the mini-grid sector.[98] Similarly, InfraCredit provides guarantees to enhance the credit quality of local currency debt instruments. The additional benefit that InfraCredit provides, apart from smaller ticket sizes, is the fixed interest rate,[99] unlike most local currency finance, which is only provided with floating interest rates.[100] This is crucial in the context of local currency debt, because while the foreign exchange risk is mitigated, the high interest rates often make such instruments less attractive. With InfraCredit's guarantee, Darway Coast accessed the domestic debt capital markets for the first time in 2022, successfully raising NGN 0.80 billion (~USD 550,000)[101] through a seven-year bond. This bond is complemented by NGN 800 million in first-loss subordinated concessionary loan capital from the FCDO, aimed at supporting mini-grids to serve off-grid and underserved homes and businesses in Nigeria.[102]

In addition, the overdependence on hard currency financing does not allow for the expansion of local capital markets. Thus, guarantees that offer credit enhancement that improves the risk profile and rating of local currency credit can act as a catalyst for expanding the participation of local banks, pension funds and institutional investors in offering local currency financing to mini-grid projects, where longer maturity profiles are a necessity. This is crucial for closing the substantial investment gap in the infrastructure finance market.[103] It is important to note that capacity building for local financiers is often required to support them in entering this sector. The expansion of the local capital markets could effectively lower the entry barriers for smaller local developers who struggle more to secure funding from international sources, relative to international developers.

Despite the increased importance of mitigating currency risk, there is still limited availability of local currency financing. As Figure 2.24 shows, among the MGF Group, only CrossBoundary Access and UNDP provide local currency financing for the majority of their programmes, while most funders, including donors that have numerous mini-grid programmes, such as the World Bank, GEAPP, AfDB and AFD, do not provide such financing.

[98] GuarantCo. 2024. Enabling Infrastructure Development.

[99] InfraCredit. 2024. InfraCredit's Guarantee Supported by UK-Funded Climate Finance Blending Facility.

[100] AfDB. 2020. Exploring the role of guarantee products in supporting local currency financing of sustainable off-grid energy projects in Africa.

[101] Based on an exchange rate of USD 1 = NGN 1,448.28.

[102] InfraCredit. 2023. Providing distributed renewable energy via solar hybrid mini grid solutions.

[103] GuarantCo. 2020. Enabling local currency solutions in addressing the infrastructure financing gap.

FIGURE 2.16 Share of mini-grid programmes providing local currency financing, by funder

Note: The breakdown represents the final allocation of funding provided by the MGF Group, regardless of the specific channels through which the funds were disbursed.

Source: ECA analysis based on MGF database provided by the Carbon Trust.

Apart from mitigating currency risk, guarantees can also address the mismatch between loan tenors offered in the sector and the longer-term horizon typically required for mini-grid profitability. As explained in Box 2.18, a "tenor extension" guarantee would provide an innovative solution to this mismatch and give mini-grids much needed time to build a profitable customer base.

BOX 2.1816 Tenor extension guarantees

In the United States in the 1930s, where only 10 percent of farmers had electrical connections, the government passed the Rural Electrification Act, which allowed the granting of long-term concessional loans to cooperatives. The loans were provided at interest rates slightly above the government's cost of borrowing, set at around 2 percent.[104] Not only were these loans successful in accelerating rural electrification, but they were also nearly all repaid early, as they stimulated new and unplanned productive uses of electricity.

Africa is in urgent need of similarly easily accessible credit. Currently, investors expect double-digit return in hard currency within five to seven years, backed by physical guarantees from the developers' assets. However, mini-grid projects have durations of 10-20 years, as longer projects allow for the lower electricity prices needed by low-income customers, and for political and regulatory support. Furthermore, the projects are often developed by cooperatives or start-ups with limited physical assets. As a result, **loan tenors and guarantee requirements are woefully mismatched with the needs of mini-grids**, creating cashflow problems in the first five to seven years of otherwise viable projects.

Current financial support tools increasingly attempt to approximate the impact of long-term concessional loans and guarantees: subsidies attempt to lower up-front costs and loan requirements; RBF schemes boost returns in the early years when high loan repayments become due; and some few existing guarantee schemes offer eight year or longer partial guarantees to loans to mini-grid developers. Unfortunately, many of these support mechanisms are dependent on ad hoc and time-limited donor programmes.

[104] US Rural Electrification Act of 1936

Yet, most of the funds come from development finance institutions (both equity and debt) and tend to sit with fund managers, who have at most ten-year mandates for their funds and cannot realistically extend the tenors of their loans beyond their fund's existence. However, if the loans were accompanied by a **tenor extension guarantee**, they could be issued for the much-needed 20 years, giving the mini-grid time to build up profitable customers. Whatever has not been collected on the loan by the time the ten-year fund closes would become the responsibility of the guarantor. The borrower would still be obliged to make repayments, but these could flow into a new vehicle or another fund. Thus, there is not necessarily a loss associated with this type of guarantee, but the lender—the ten-year fund—is made whole by the guarantor.

Stretching out loan repayments, as the government did in the 1930s in the United States, would have the same effect of making access to energy affordable. Once affordable, the many uses of electricity become available to rural customers.

Source: This box was authored by Michael Feldner and Maurice Pigaht of GET.invest Finance Access Advisory.

Leveraging climate finance options as additional revenue streams

New innovative financing mechanisms, such as Distributed Renewable Energy Credits (D-RECs) and Peace Renewable Energy Credits (P-RECs), are being explored to support mini-grid projects. The international social enterprise Nuru, for instance, has successfully sold P-RECs, a form of energy credit that not only represents renewable energy generation, but also carries additional social and environmental co-benefits. Energy Peace Partners[105] plays a pivotal role in this ecosystem, responsible for the verification, validation and processing of these RECs. By selling these credits, Nuru has been able to secure funding for critical aspects of their operations, such as capital expenditure. For instance, the RECs sold to Google helped finance its initial capital expenditure, demonstrating a viable model for funding infrastructure development.[106] Furthermore, Nuru's sale of RECs to Microsoft showcased the versatility of this financing model, supporting the expansion of street lighting projects and enabling the connection of hundreds of new customers.[107] This approach not only contributes to the financial sustainability of mini-grid companies, but also aligns investors like Google and Microsoft with impactful, renewable energy initiatives, creating a win-win scenario for both the energy providers and the corporate buyers of RECs. To catalyse the benefits of P-RECs, the P-REC Aggregation Facility was designed to provide upfront payments for developers, enabling them to overcome financial barriers. With the capability to enter advance contracts and provide advance P-REC financing to developers before reaching the commercial operation date, the facility aims to accelerate project development.

Scale has become a key factor in mini-grid financial sustainability

Aggregating mini-grid projects is emerging as a crucial strategy for securing financing, particularly when dealing with a mix of larger and smaller sites. This approach, which involves bundling multiple projects together, allows developers to leverage economies of scale, making

[105] Energy Peace Partners

[106] Based on consultant's interview with Nuru.

[107] Renewables Now. 2022. Microsoft buys more certificates to back solar mini-grid in DR Congo.

the overall venture more attractive to investors. Economies of scale are reflected both in the hard and soft costs of the mini-grids. In terms of hard costs, by combining the resources and demands of different projects, developers can achieve more favourable terms in equipment procurement by having greater leverage with suppliers and reduce per-unit costs through bulk discount pricing. This effective negotiation with suppliers and contractors leads to cost efficiencies that can significantly improve the financial viability of the projects. In terms of soft costs, aggregation also helps streamline project management. Technical, legal and financial due diligence and monitoring of assets become more time-intensive and cumbersome with multiple small assets compared to the one large asset.

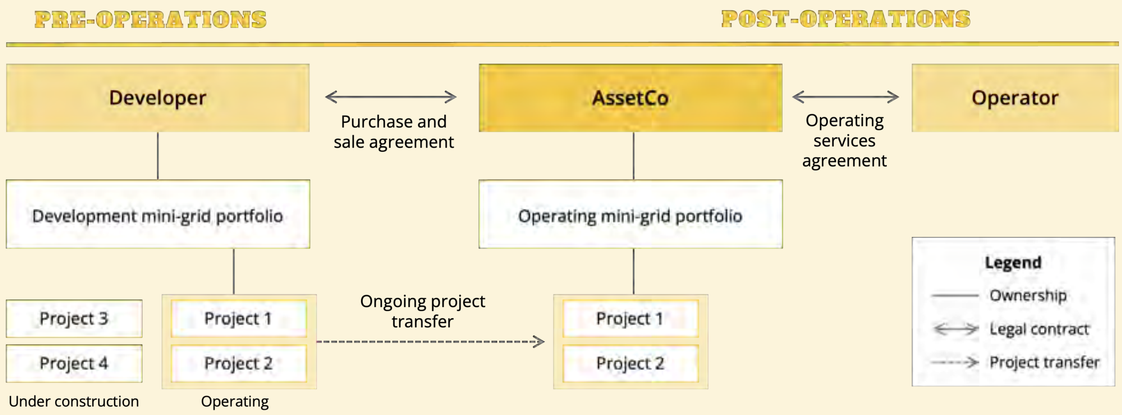
This aggregation can be achieved by bundling sites into portfolios or via aggregation platforms. Aggregators in the space offer opportunities for the aggregation of equipment purchases, procurement and logistics, which makes it easier for smaller developers to achieve economies of scale in mini-grid deployment by allowing them to have a stronger voice compared to operating individually. This strategy also presents a more compelling case to financiers, who often prefer investing in larger, diversified portfolios that offer reduced risk and enhanced return potentials. Aggregation thereby not only makes individual mini-grid projects more economically feasible, but also paves the way for a more systematic and efficient development of rural electrification initiatives, contributing to the scalability and sustainability of the mini-grid sector as a whole. Box 2.19 highlights the key role of aggregation in CrossBoundary's financial model.

BOX 2.1917 CrossBoundary's financial model for mini-grids

CrossBoundary's financial model for mini-grids demonstrates how mini-grid investments can be structured to resemble traditional infrastructure investments, thus attracting infrastructure capital. This model emphasises asset isolation, risk allocation and aggregation to match the following needs of infrastructure investments:

- Ring-fencing of the assets (**isolate**): Mini-grid assets are ring-fenced by transferring them, once construction is complete, from the balance sheet of the company that develops and builds them to a company created specifically to hold the assets (an asset company, AssetCo). All contracts, permits and equipment are owned by AssetCo, owned by CrossBoundary.
- Long-term fixed contracts with incentives (**allocate**): Risks and costs prior to commissioning and sale are allocated through the purchase and sale agreement, and risks and costs after commissioning and sale are allocated through a long-term operating services agreement.
- Scale (**aggregate**): To achieve scale, CrossBoundary aggregates multiple AssetCos into a single investment platform (a HoldCo) that is large enough to raise equity and mezzanine debt from investors.

FIGURE 2.25 CrossBoundary financing model for mini-grids



Source: CrossBoundary (2020). Open-sourcing infrastructure finance for mini-grids.

Acknowledging the need to support local players

There is growing recognition of the need to support local players. While international entities may bring valuable assets such as technology, knowledge and access to global finance networks, local companies and leaders often possess unique insights into the intricacies of their communities and can offer valuable contributions to project success. Many successful ventures involve partnerships between local founders and international counterparts. Recognising the importance of nurturing local talent, companies like CrossBoundary are actively identifying and supporting promising candidates within their pipeline of projects. Moreover, initiatives such as investor workshops (see Box 2.20) are facilitating connections between investors and local enterprises, acknowledging the diverse needs and strengths within the market. This growing support for local enterprises not only promotes sustainable development within these communities, but also encourages innovation and competition in the sector, ultimately contributing to a more robust and resilient mini-grid ecosystem.

BOX 2.2018 Investor workshops by EEP Africa

While grant funding plays a critical role in the initial testing stages, achieving scale and financial sustainability requires securing follow-on financing from commercial investors. EEP Africa has been organising investor forums in East and Southern Africa since 2016, which introduce regional and international investors to emerging mini-grid companies, catalysing investment opportunities. Each event is customised for a single investor, including Charm Impact, SunFunder, Camco and Lendahand. Based on the investor's profile—financing offer and ticket size—a small group of companies with appropriate financing needs are invited to present their business case. The forum also allows for discussions on investment criteria and challenges facing early-stage and local companies, aiming to improve understanding of the needs and priorities of both the investors and the companies. This type of tailored matchmaking effectively introduces investors to promising early-stage and local companies and helps foster relationships that should benefit all stakeholders.

Sources: EEP Africa. 2021. Opening Access to Finance through Investor Workshops; and EEP Africa. 2021. Growing Beyond Grant Funding.

The need to support local players should be reflected in the design of the financing mechanisms. For instance, when implementing an RBF, larger, multi-country initiatives often exclude local players, which is contrary to the goal of RBF, namely building an ecosystem of players that tailor their service to local needs and respond to local dynamics.[108] Acknowledging that achieving universal energy access requires more mini-grid companies, and local companies in particular, implies the need for an adaptive approach from RBF managers in which the fund design, eligibility criteria and financing conditions are tailored to supporting the participation of local companies.

Increased need for technical assistance and knowledge sharing in light of strict due diligence requirements

Financiers' bankability and due diligence criteria are fairly standardised in the sector. Thorough due diligence, including financial and environmental, social and governance (ESG) assessments, is crucial for ensuring the sustainability and impact of mini-grid projects. The criteria employed by financiers are similar across the sector. For instance, Oikocredit first focuses on the existence of a broader enabling framework, including favourable policies and regulations and public funding mechanisms. The experience of the developer is then evaluated based on the number of connections achieved so far (at least 5,000 connections are required) and the ability to navigate government levels and structures (such as the kingdoms in Nigeria). Finally, the technical know-how and the provision of follow-up customer service are assessed.[109] These and additional considerations are reflected in two score cards that ensure thorough due diligence: the project viability risk scorecard, which assesses the financial performance of the company; and the ESG scorecard, which analyses the environmental and social impact and the governance of a potential partner.[110]

Apart from financial due diligence, EnDev also looks for a strong local presence and track record from the developers.[111] Charm Impact, a provider of early-stage debt finance, highlights three key aspects of their due diligence process: cash flow (unit economics, operating expenses and profit margins); the company's team and experience; and customer selection and management.[112] However, the sector is increasingly calling for increased sharing of due diligence analyses and documentation among investors, as well as greater alignment on risk and impact monitoring frameworks.[113]

The standardisation of reporting mechanisms and impact monitoring frameworks is gaining traction among the donor and investor community. Fragmentation in the reporting requirements of various donor-funded programmes, as well as in the required mechanisms for managing risk, can pose significant costs for mini-grid developers, slowing capital deployment.

[108] SNV and Sunfunder. 2021. Why localisation matters for financing off-grid energy.

[109] Based on the consultant's interview with Oikocredit.

[110] Oikocredit. 2023. Financial inclusion: How does Oikocredit select its partners?.

[111] Based on the consultant's interview with EnDev.

[112] EEP Africa. 2021. Growing Beyond Grant Funding.

[113] MGP. 2023. MGP newsletter. December 2023.

An example of a standardised approach to the identification and management of environmental and social risk is the IFC Performance Standards, which serve as an international benchmark for evaluating the environmental and social performance of a project. Increasingly, many development financing institutions and investors require IFC Performance Standards compliance from project developers receiving funding to guarantee the environmental and social integrity of the projects.[114]

In line with the need to involve local players, more support is needed for early-stage mini-grid companies, especially local companies, in order to meet financiers' strict due diligence requirements. Through its investment-readiness support activities, Mirova has identified the following gaps in the financial capabilities of small local companies: capital structuring and funding options; cash flow planning; unit economics and financial modelling; accounting support and training to create high-quality financial reports; legal support to help understand loan documentation and training on covenants; end-user data and portfolio health analysis.[115] The smaller loans and accompanying investment-readiness support required by local companies result in high transaction costs, which often makes them unattractive to commercial lenders. Increased support from donors in the form of technical assistance to address these gaps is crucial in helping companies absorb growth investments and scale up their activities.

Further (non-financial) support is required to strengthen corporate capabilities and build a strong track record. These include activities such as market scoping, formulation of a clear business plan and viable growth pathway, as well as ESG and impact methodology and measurement.[116] Joint learning on these aspects can be facilitated through peer-to-peer knowledge exchange between developers, in light of the need to accelerate the time that investment readiness takes. Overall, providing technical assistance to local companies should encourage the scale-up required to achieve universal access and contribute to inclusive growth of the mini-grid market.

Technology Trends

Generation – falling cost of mini-grid components

Over the past several years, the components used to construct mini-grids have seen significant price reductions, improving the financial feasibility of such projects. The declining cost of PV modules, inverters, batteries (specifically lithium-ion), battery inverters and smart meters have been central in driving the overall growth of the sector.

PV prices have fallen in part due to increased supply to meet the demand of much larger projects. In the past decade the average cost of a solar PV panel has decreased by about 90

[114] REPP and AMDA. 2018. Developing Mini-grids to IFC Environmental & Social Performance Standards.

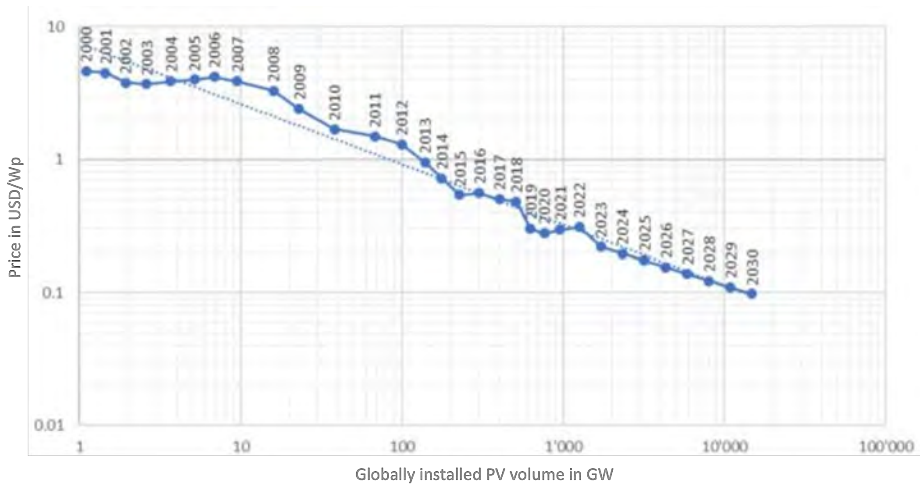
[115] SNV and Sunfunder. 2021 Why localisation matters for financing off-grid energy.

[116] SNV and Sunfunder. 2021. Why localisation matters for financing off-grid energy.

percent.[117] The volume of PV deployed worldwide has doubled every two years over the past five decades. This increased supply has come with a consistent reduction in prices, of around 23 percent with each doubling of volume. Between November 2022 and December 2023 PV prices dropped even further, by about half. Furthermore, the cost of solar is expected to continue declining through 2030.[118]

As seen in Figure 2.26, the period between 2020 and 2022 saw a departure from the decades-long trend of steady price declines. This short-term anomaly can be traced to the impact of COVID-19, exacerbated by Russia's invasion of Ukraine. The global COVID-19 pandemic, starting in 2020, wreaked havoc on global supply chains, resulting in shortages and price volatility for PV. Supply chain disruption was further amplified by the widely felt reverberations of Russia's invasion of Ukraine. Despite this short-term challenge, the last two years suggest that the PV market is back on its longer-term trajectory of steadily declining prices.[119]

FIGURE 2.17 Expected PV volume and module costs to 2030



Source: PV Magazine. 2023. Empirical approach shows PV is getting cheaper than all the forecasters expect.

New materials, such as perovskite cells, and manufacturing methods have also been leveraged to reduce costs by improving the efficiency and durability of PV. Compared to silicon PV cells, perovskite cells require a much less intensive manufacturing process due to their flexibility. However, due to silicon already being heavily invested in and a market incumbent, the transition to wholly adopting perovskite is less straightforward. Over the last five years, "tandem cells", namely PV built by combining both materials in a complementary way, have been adopted as a promising interim solution.[120]

[117] Mordor Intelligence. 2023. Distributed Solar Power Generation Market Size & Share Analysis— Growth Trends & Forecasts (2024–2029).

[118] PV Magazine. 2023. Empirical approach shows PV is getting cheaper than all the forecasters expect.

[119] PV Magazine. 2023. Empirical approach shows PV is getting cheaper than all the forecasters expect.

[120] The Economist. 2018. A new type of solar cell is coming to market.

Inverter price trends tend to be more nuanced, as there are a variety of inverters on the market, including PV hybrid and transformer-based, each with varying types of technology components. In general, though, inverter manufacturing has expanded over the past few years. The growth of new electrification use cases, such as EV charging and maturation of niche markets (including the distributed renewable energy sector), has also prompted innovation in the market. While exact price trends are more difficult to discern, inverter development is trending towards products that require less maintenance and are built for longevity.[121]

Innovations in the market, such as modular design and aggregation, are further reducing mini-grid project costs

Alongside innovations across the specific components used to construct a mini-grid, the overall design of systems has evolved. Developers are opting for more simplified designs, with plug-and-play components and containerised solutions. For instance, Zhyphen has developed its "Instant Grid," which has a unique modular design that can be set up within hours and easily accommodates increases in energy demand.[122] This approach has been leveraged by the Institute for Transformative Technologies (ITT) in India, through their pre-assembled mini-grid system, "Utility in a Box", which can be installed within days. In a similar way, other project developers, such as AlphaESS and JINKO Solar, now offer a turnkey solution that is pre-wired and tested before shipping so that installation on site can be seamless.

- **Further, as the sector has matured, it is less common for a mini-grid project to be developed in isolation.** More specifically, companies have opted to develop portfolios of mini-grids, rather than one-off projects. Notably and discussed later in this section, the shift towards developing a portfolio, rather than a single project, lends itself to technological innovations that can standardise and aggregate site data. Moreover, often these systems are grid interconnection ready and leverage smart technology components, such as smart meters and the latest PV, inverter and battery equipment. Importantly, these projects are increasingly incorporating productive use technologies into their business models.

Storage – increasing prevalence and cost reductions of lithium-ion batteries

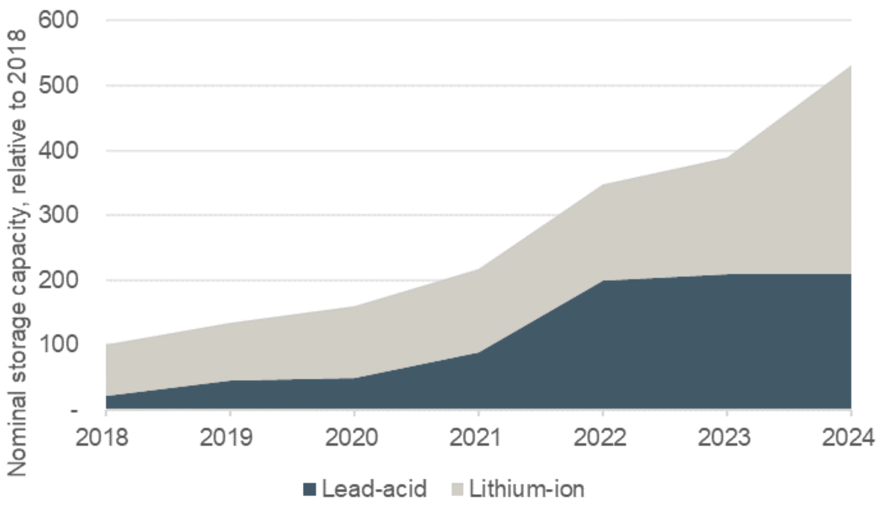
Lithium-ion batteries have increasingly become the preference for mini-grid developers over lead-acid counterparts. As of 2021 lithium-ion battery costs were on average approximately USD 123 per kWh, while lead-acid were about USD 200–220 per kWh. Lithium-ion battery prices are expected to continue declining in the coming decade, with some projections estimating a price of about USD 75 per kWh by 2030. Lithium-ion batteries also tend to have longer lifetimes, higher efficiency and lower maintenance needs in comparison to lead-acid batteries. Still, site-specific differences might cause a mini-grid developer to select lead-

[121] PV Magazine. 2022. 2022 review in trends: Inverters.

[122] Zhyphen. n.d. Africa and Off-Grid Medical Facilities: Malawi.

acid over lithium-ion. For instance, lead-acid might be preferred when the power demand of a system is not very high.

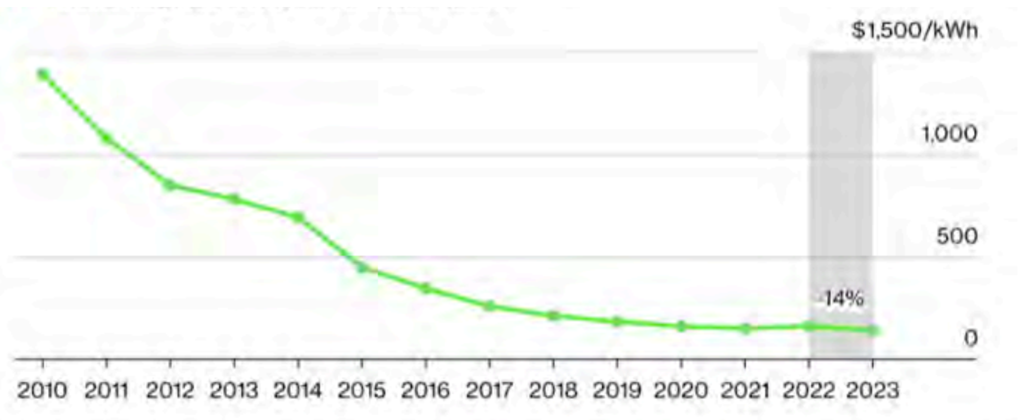
FIGURE 2.18 Nominal storage capacity, indexed to 2018



Source: ECA analysis based on the MGA database.

When it comes to battery costs, the market has seen a price decline over the past decade. According to BloombergNEF's 2023 analysis, the average price of batteries fell by 14 percent in 2023, down to USD 139/kWh on average from USD 161/kWh on average in 2022, as shown in Figure 2.28. Cost reductions for raw materials seem to be the main factor at play, rather than solely technological innovation, which contributed to price decreases in previous years. Experts predict that battery costs will continue to decline through the next few years, with some projections estimating a price under USD 100/kWh by 2027.[123]

FIGURE 2.19 Decreasing lithium-ion battery prices, 2019–2023



[123] PV Magazine. 2023. Battery prices down 14 percent this year, says BloombergNEF.

Note: The green line represents the volume-weighted average price of a lithium-ion battery pack in real 2023 dollars. Source: BloombergNEF.

Alongside these trends, remote monitoring and control technologies, discussed in section 0, are helping to further improve efficiency and optimisation, reducing the need for part replacements and driving down overall costs.

Emergence of other storage technologies

Alongside the growing predominance of lithium-ion batteries, sodium-ion (Na-ion) batteries have emerged as a promising alternative with cost, safety, sustainability and performance advantages. Due to their weight, Na-ion batteries haven not been a practical solution for technologies that require high energy density, such as electrical vehicles. However, when it comes to stationary energy storage, they are emerging as a suitable option, especially due to their production being compatible with existing lithium-ion battery manufacturing methods. With a growth trajectory mirroring that of lithium-ion batteries, IDTechEx predicts that 10 GWh of Na-ion battery capacity will be installed by 2025 and that prices will drop to around USD 40/kWh by 2030.[124]

Commercialisation of Na-ion batteries is relatively new, with only a handful of companies producing at a significant scale, and this is an area to continue watching in the coming years. As IDTechEx noted in their recent report, battery technology diversification would ultimately be beneficial in the long run due to a limited supply of raw materials and growing energy security concerns.[125]

In addition to battery diversification, the use of other technologies in place of batteries or diesel generators has materialised in certain off-grid markets. For instance, in the Sarawak region of Malaysia, H2Energy's hydrogen fuel cell technology has proven itself as a reliable tool to supplement energy produced directly through solar. H2Energy's modular design lends itself to serving rural and remote areas, so is an important trend to watch as various pilot projects are carried out successfully.[126] In a related way, Rutten-NES, a Belgian energy company, has developed its modular, containerised NES-Store for storing and releasing energy through similar mechanisms to pumped hydro. This innovative technology is being tested during the second half of 2024 in a very small, remote village of 300 inhabitants on the island of São Tomé, and is another proof-of-concept project worth following.[127]

[124] IDTechEx. 2023. Sodium-ion Batteries 2023-2033: Technology, Players, Markets, and Forecasts.

[125] IDTechEx. 2023. Sodium-ion Batteries 2023-2033: Technology, Players, Markets, and Forecasts.

[126] Alliance for Rural Electrification. 2024. H2Energy replace batteries with hydrogen in off-grid Malaysia.

[127] Alliance for Rural Electrification. 2024. Rutten NES' innovative hydropneumatics storage technology project in São Tomé and Príncipe.

AC and DC mini-grids – the rising popularity of DC-based systems

Power losses in distribution networks, along with conversion losses at various stages of energy transmission, constitute a major aspect of a mini-grid's efficiency and cost-effectiveness. Alternating current (AC) and direct current (DC) mini-grids vary in their application and usage, and the choice between these systems depends on a variety of factors, including load types, efficiency requirements and environmental contexts. The need for a power inverter is the main distinction between the two types of mini-grid systems. DC systems do not require an inverter because power conversion steps inherent in an AC system are not required.

- DC mini-grids are increasingly gaining prominence in the sector as they can be more efficient for certain types of loads (specifically DC-based appliances) and align with renewable energy requirements. Importantly, DC systems avoid power conversion losses that are required for AC or hybrid AC systems. This helps to reduce the need for additional components and allows DC equipment to be more compact in size. DC systems also tend to be more modular and scalable than AC counterparts; they are not only more compact, but can more easily be incorporated into system designs because lines can run in parallel to each other and are easier to control. As the distributed renewable energy sector continues to mature, DC-based appliances, rather than AC, may be considered to further reduce additional power conversion losses. Still, it is worth highlighting the potentially limited availability of DC appliances in certain markets, thereby reducing developer and end-user choice. [128]

Development and operations – Robust software solutions are streamlining mini-grid development at every stage of the project lifecycle

Digitalisation presents a great opportunity for cost reductions in the mini-grid value chain. Mini-grids are relatively small scale and, therefore, often have higher hard and soft costs associated with them. These include costs related to planning, finance origination, equipment procurement, due diligence and asset management.[129] To minimise these costs, software tools have proliferated and allowed the sector to reach new levels of growth. Digitalisation presents an opportunity to increase transparency, promote standardisation and aggregation, introduce economies of scale and streamline friction points at every stage of the project lifecycle, from site surveying, technoeconomic system modelling and analysis, to ongoing monitoring and reporting.

In the planning phase, low-cost geospatial planning tools have become more widely adopted by mini-grid project developers. Tools such as VIDA's map-based software use satellite imagery data, aggregating key data like population density and existing grid

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[128] Opiyo, N. N. 2019. "A comparison of DC- versus AC-based minigrids for cost-effective electrification of rural developing communities". *Energy Reports* 5: 398–408.

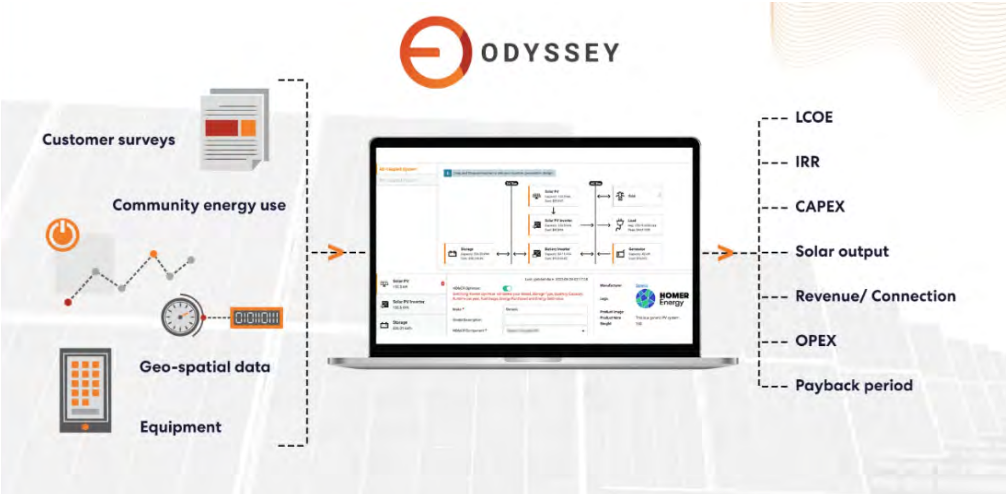
[129] The Green Agenda. 2023. Distributed solar is poised to lift South Africa from the depths of its energy deficit, if only we root out those hidden costs.

infrastructure to help developers assess a project's risk. Innovations in data granularity and availability have allowed VIDA to bring in more data and make the context of a given project more transparent. A developer can assess a variety of factors that might impact a project's long-term economics, such as accessibility-related risks (including road grid infrastructure) and climate-related risks (such as flood zones), as well as where anchor loads are located or planned. The ability for more effective site planning through a digital tool certainly reduces time and costs, and potential site visits. Nevertheless, it is worth noting that in-person visits are still an essential aspect of site planning in order to cross-check GIS data and involve local communities. The cost savings of GIS technologies are even more impactful when considering that robust planning tools can help a project developer avoid selecting a less optimal site. Overall, most aspects of a feasibility study can be conducted through digital tools; this reduction in costs is paving the way for scalability in the mini-grid sector. It is notable that the least-cost solution is different from bankability under existing business models, which implies that the mini-grid sites that are included in least-cost-electrification plans are not necessarily the same as the sites selected based on bankability.

Digital system modelling tools are increasingly being leveraged to standardise data in the sector and to improve transparency for funders, government agencies and project developers. Planning tools streamline the design process for project developers, like HOMER Pro allowing load profiling optimisation and digital generation and distribution mapping, and robust financial modelling mechanisms that pull in dynamic inputs, including capex/opex costs and tariff schedules. In turn, financiers and other key project stakeholders can curate aggregated, standardised portfolios of projects. For instance, EM-ONE partnered with Odyssey to identify 150 viable health electrification sites out of 1,200 in Nigeria to be funded by a large US-based development agency. As part of the project, Odyssey's platform ingested as much relevant data as possible from a variety of external sources, including geospatial data, community energy use data and customer surveys. Further data provided by EM-ONE on site-specific details, including projected capex and opex costs, were used as an additional input for the tools integrated into the platform, such as HOMER Pro, for design optimisation. A standardised financial model was then run across all the sites to determine project economics, such as the internal rate of return and payback period, as shown in Figure 2.29. This tech-enabled analysis lays the groundwork for EM-ONE's work to move into the execution phase.[130] As accessible and standardised technical and financial data continue to demystify mini-grids as an asset class, investment flows into the sector should increase.

[130] Odyssey Energy Solutions. n.d. Breaking ground on a ground-breaking project.

FIGURE 2.20 Financial planning through the Odyssey platform



Source: Odyssey Energy Solutions. n.d. Breaking ground on a ground-breaking project.

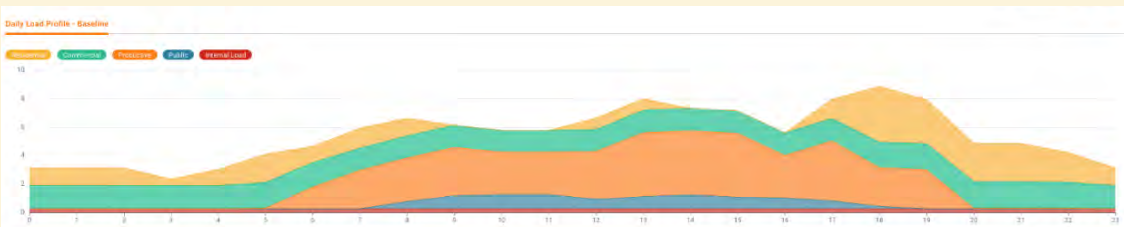
BOX 2.2119 Digital technical and financial modelling tools: Odyssey

Odyssey Energy Solutions offers a suite of digital tools for project developers to model out load profiles, design optimised systems (with HOMER Pro), input various costs and revenues, and generate a robust financial outlook for a specific project.

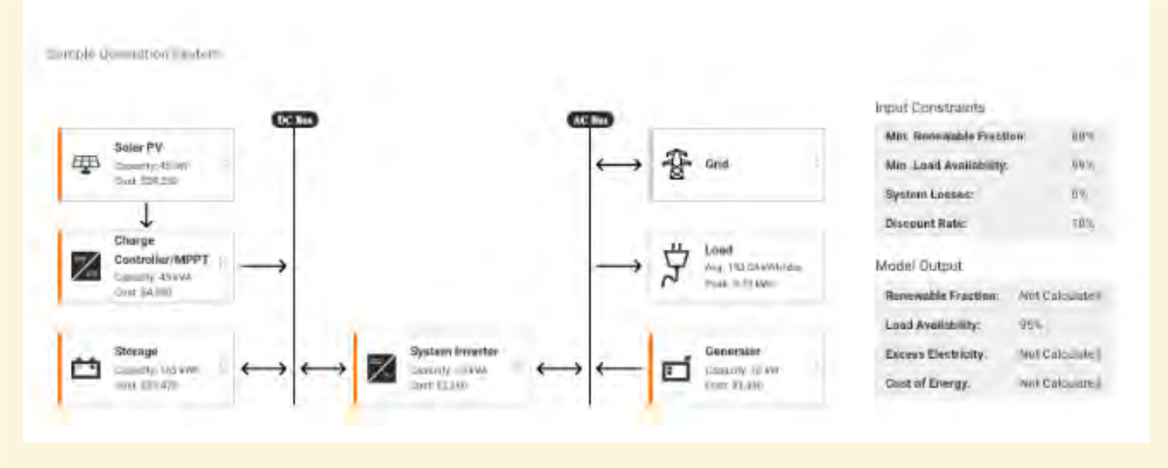
Outsourcing aspects of project development through software saves renewable energy companies time and resources. Specifically, rather than working out their own financial calculations, a company can leverage Odyssey's standardised financial model by simply entering inputs and key assumptions in the platform. Equally, financiers can more easily compare, benchmark and aggregate projects that rely on consistent assumptions and leverage the same model.

Figure 2.30 presents a sample mini-grid's load profile and full generation design, accounting for expected demand and the technical specifications and costs of the system components installed.

FIGURE 2.21 Load profile and generation design on the Odyssey platform



Customer Category	Connections	Avg Daily Wh/Customer	Effective Tariff ($/kWh)	Effective Tariff (NGN/kWh)	ARPU/month
Public	3	2,715	$0.50	NGN 180.00	$39.23
Productive	3	15,454	$0.40	NGN 144.00	$178.62
Commercial	5	7,859	$0.40	NGN 144.00	$90.84
Residential	80	372	$0.50	NGN 180.00	$5.37
Total	**91**				



Source: Odyssey Energy Solutions. n.d. Breaking ground on a ground-breaking project.

Even with digital tools, accurately forecasting future demand is still an area that is being refined. Important developments are anticipated in this regard, given the growing application of machine learning and artificial intelligence. These advancements continue to reshape the way energy demand is analysed and predicted. More specifically, machine learning models can take in a vast array of variables, including historical usage and seasonal weather patterns, making it easier to predict demand and make data-informed decisions about project design.[131]

Digitalisation is also crucial at the procurement stage. Once sites are planned, a mini-grid developer needs to procure equipment, which comes with historically complex processes around ordering, shipping and importing. In the last year, Odyssey launched its procurement platform, intended to streamline the process for mini-grid developers, help them gain access to working capital finance, and ultimately bring down the cost of equipment through aggregated procurement. A secure, digital platform that facilitates procurement can translate into more time and cost savings for a developer, thereby helping the sector scale up further.

Remote monitoring and control tools have advanced to aid project developers in managing and optimising the performance of large portfolios of mini-grid sites

Once sites are commissioned, the remote location of many mini-grid projects and the large portfolios of many renewable energy companies can be impediments to effective operation and maintenance. Mini-grids are most viable in places without traditional grid infrastructure, where transport or communication networks are often lacking. Moreover, renewable energy companies might operate in an expansive geographic area, making travel to individual sites time and cost prohibitive. Until recently, project developers could manage their projects through a more ad hoc monitoring approach. However, as the number of assets in a developer's portfolio has increased, so has the need for more efficient and cost-effective data monitoring and control systems.

[131] Forbes. 2023. Artificial Intelligence: Accelerating Clean Energy Transformation.

Companies are increasingly relying on remote monitoring and data platforms to reduce costs and optimise their operations. Advancements in remote monitoring and control technologies have allowed for even the hardest-to-reach sites to be managed from a distance. These digital tools are reducing costs for renewable energy companies, estimated to be at least 15 percent of O&M, which previously needed to allocate resources to on-site field visits.[132] Even in more urban settings such as Lagos, Nigeria, notorious for its traffic, the ability to troubleshoot issues from afar results in significant time and cost savings.[133]

Issues can also be proactively addressed through logic loops and advanced control algorithms that optimise system performance, further helping to reduce operating costs. For example, battery temperatures might be regulated within specific parameters through smart alerting systems or a diesel generator might be used less as the system is made more demand-responsive through logic loops.[134] As system performance problems are proactively addressed and decisions automated, asset performance improves, by extension improving end-user experience, reducing the need for replacement components and mitigating ongoing project costs. Such rule-based algorithms also help increase productivity and free up time for project developer teams so that they can pursue core business activities, such as scaling up.

Remote monitoring and control technologies can also help mini-grid developers make more data-driven decisions on a system's design. In this way, through the ability to right-size components such as a diesel genset, a project's capex can be reduced. By pursuing these avenues—remote troubleshooting, optimised operations and smarter designs—cost savings might equate to at least 30 percent of overall project costs for a given mini-grid developer. However, to fully realise cost savings, capacity building is critical alongside the technology itself. For instance, Odyssey has found that alongside providing its powerful monitoring suite, establishing a close working relationship with developer teams and equipping on-site engineers with robust training are key to success.

As the number of sites under a developer's purview has increased, so has the complexity of the data they need to manage. Centralised technology solutions have evolved to support the need to clean, process and manage data, from both geographically dispersed sites and various data sources. Large mini-grid developers are keen to have a consolidated view of projects, which might include data from inverters, customer meters, payment system application programming interfaces, customer relationship management tools and on-site hardware. Each of these pieces is vital to a developer's operations. For instance, tracking and analysing consumption data in an automated, efficient way through advanced smart meter technology helps developers verify connections and unlock funding. Thus, modern remote monitoring and control solutions must integrate with and collect granular data on various brands of equipment, as well as ticketing, customer relationship management and payment systems to fully streamline operations.

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[132] Energy for Sustainable Development. 2023. Quantifying impact and benefits of advanced remote monitoring solutions for the operation of mini-grids in sub-Saharan Africa.

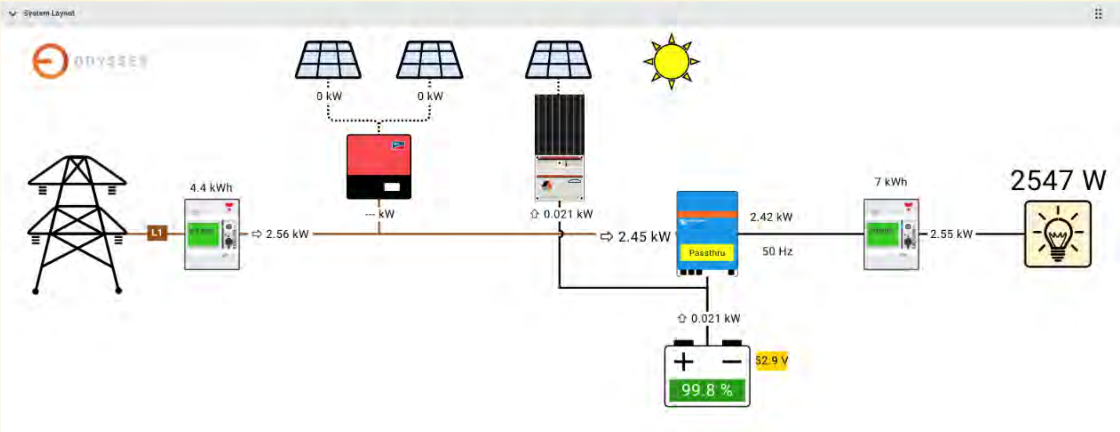
[133] The Mini-Grid Business Podcast. 2024. Managing complexity – digital tools for the mini-grid space.

[134] The Mini-Grid Business Podcast. 2024. Managing complexity – digital tools for the mini-grid space.

BOX 2.2220 Advanced monitoring analytics

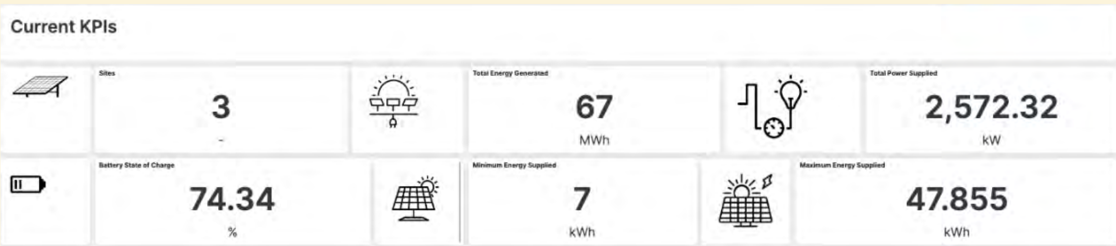
As important as the capacity to collect data is the ability to easily visualise and analyse real-time data. Dynamic dashboards and advanced alerting systems give operations and engineering teams granular insights into specific project sites.

FIGURE 2.22 Sample technical dashboard



With scale, high-level dashboard views also cater to teams managing many decentralised assets. Here, integration with disparate brands and sources allows teams to effectively manage large fleets of projects and to easily track KPIs and overall initiative progress. Additionally, these kinds of impact dashboards offer funders and other external stakeholders a clear picture of project performance, helping them to understand where and how capital is being deployed.

FIGURE 2.23 Sample KPI dashboard



Source: Odyssey Energy Solutions

Remote monitoring can also be a key source of lessons learnt for mini-grid developers as they grow their businesses. One of the main drivers for mini-grid companies to adopt the use of advanced remote monitoring and control solutions is the need to improve future projects by learning from current operations. In this way, and with physical presence at the sites becoming less essential, remote monitoring can also be a catalyst for developers to expand geographically.[135]

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[135] Pittalis, Marco et al. 2023. "Quantifying impacts and benefits of advanced remote monitoring solutions for the operation for mini-grids in sub-Saharan Africa". *Energy for Sustainable Development* 77: 101335.

Software tools are also increasingly being leveraged by mini-grid project developers to manage their customers and to participate in results-based financing facilities

Digital tools are becoming integral in managing customer interactions. Once sites are commissioned, other aspects of project operation beyond direct monitoring and control of systems need to be managed. For instance, mini-grid developers often act as small-scale utilities, simultaneously managing their end customers alongside the mini-grid system itself. To streamline customer management, tools such as Micropower Manager developed by INENSUS have emerged to facilitate bidirectional customer interactions, cash flows, and even the installation and usage of electrical appliances.

In addition, digitalisation streamlines data collection to meet reporting requirements. Mini-grid developers participating in RBF programmes are required to submit data and report on project progress for specific incentives. In turn, concessional funders need to verify the data and make disbursements accordingly. Funders may also need to report on programme KPIs to other external stakeholders. This complex, data-heavy process would, in short, be impossible without digitalisation. In this context, a software platform, such as Odyssey, allows mini-grid developers to upload millions of data points and automatically verify live connections through integrations with on-site smart meters. The platform also streamlines data collection and analysis for funders, as well as the full payout process. Rather than cobbling together disparate Excel data or tracking down one-off emails with developers on a project, funders are given a comprehensive view of an RBF programme's progress and can easily have oversight of a specific project.

Economics Trends

The past few years have been characterised by positive developments in mini-grid economics, including LCOE, capex, opex and development costs, as detailed in the sections below. A reflection of this is the growth in ARPU, which increased between 2020 and 2022, reaching USD 8.30 in 2022 for sites commissioned before 2019, compared to USD 4.44 in 2020, surpassing highly subsidised national grids.[136]

Where feasible, this analysis leverages insights from the MGA database, which was developed in parallel with this report. Nonetheless, it is important to recognise the limitations posed by data collection challenges. The sector's hesitancy to disclose information related to capex and opex has notably impacted data availability. Consequently, the sample size is limited by the modest number of stakeholders willing to provide data. More details regarding the data collection can be found in Annex A4.

[136] AMDA. 2022. Benchmarking Africa's Minigrids Report.

LCOE

In line with broad reductions in mini-grid costs in the past few years, analysed in sections 0–0, **the LCOE has also been falling.** According to ESMAP,[137] in 2018 the best-in-class mini-grid produced electricity with an LCOE of USD 0.55 per kWh, which then dropped by ~31 percent by 2021 to only USD 0.38 per kWh.[138] In cases with a higher load factor, an even larger decrease in the LCOE was observed. This has primarily driven by a decrease in the cost of mini-grid components; the lower costs of PV generation and storage has also allowed for lower fuel usage, further reducing the LCOE.[139] Finally, a crucial factor has been the lower development costs due to economies of scale. For instance, Husk Power has achieved significant LCOE reductions, reporting LCOEs of less than USD 0.30/kWh at its newer sites in India and has set a target of USD 0.17/kWh by 2030.[140]

The LCOE is a crucial metric not only for developers but also for investors, as it represents the potential for mini-grids to compete against the incumbent technology, typically diesel. Bringing down the LCOE, and thus making mini-grids more competitive, requires addressing those factors that have the potential to significantly influence it. A key aspect in this respect is the load factor, which measures the mini-grid's utilisation rate, calculated by dividing the average load by peak load over a year. Data analysis has shown that a higher load factor, for instance through incentivising productive uses of electricity (for which demand is higher during the day), leads to a lower LCOE.

For example, the impact of PUE on the LCOE was explored using NREL's LCOE REopt tool for a 500-household community in Kenya in two scenarios; one without any PUE activity, and one with irrigation and milling loads. The resulting LCOE in the first scenario was USD 0.329/kWh, while in the second scenario USD 0.298/kWh.[141] These reductions are in line with ESMAP's modelling results of three scenarios representing different load factors; the first scenario is the base case (22 percent load factor) representing a typical rural residential load. The other two scenarios represent higher load factors, namely 40 percent (medium case) and 80 percent (high case), through the addition of productive use loads such as water pumping, agricultural processing, cold storage with thermal inertia, and charging of electric vehicles, during the off-peak period. As shown in Figure 2.33 below, higher load factors lead to a consistently lower LCOE.

The choice of mini-grid components, such as battery type, has a large impact on the LCOE. The shift in battery type typically used in mini-grids from lead-acid to lithium-ion, as highlighted in section 0, has affected the LCOE, given that lithium-ion has similar upfront costs but superior performance characteristics, resulting in lower lifecycle costs. Figure 2.33 presents the LCOE for two categories of mini-grids: "Global Li-ion" is restricted to mini-grids that use lithium-ion

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[137] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[138] Unsubsidised, with a 22 percent load factor.

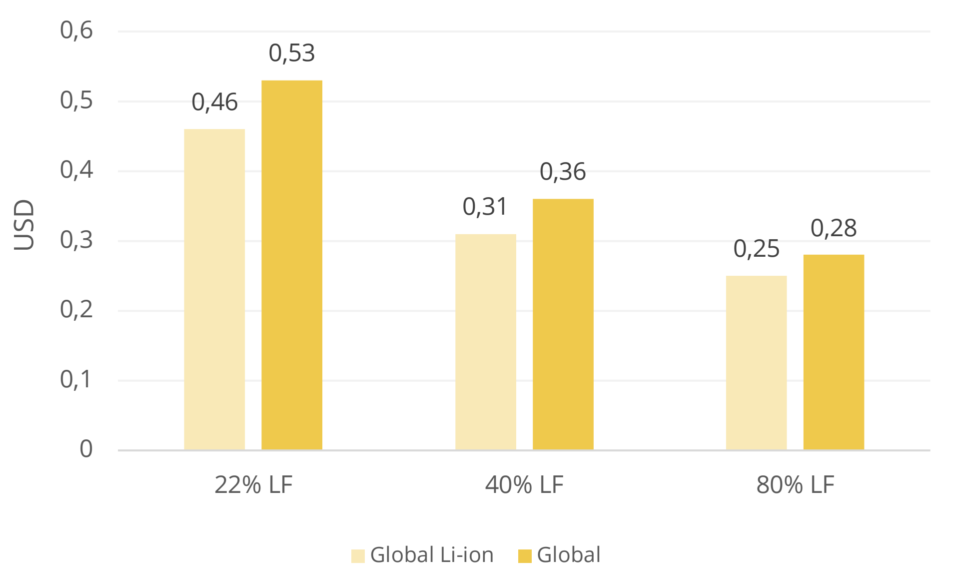
[139] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[140] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

[141] African Climate Action Partnership webinar. 2022. Techno Economic Analysis of PUE Minigrids in Africa - YouTube.

batteries, while "Global" also includes mini-grids with lead-acid batteries. It is evident that the LCOE for mini-grids that use lithium-ion batteries is consistently lower.

FIGURE 2.24 LCOE by load factor and type of storage solution



Note: LF stands for load factor.

Source: ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

Interconnection with the main grid can also bring the LCOE down. According to World Bank cost analysis of six proposed interconnected mini-grids in Nigeria, these mini-grids result in up to 20 percent lower LCOE compared to non-interconnected mini-grids.[142] The actual savings vary depending on factors such as the cost of wholesale electricity from the distribution company and the hours per day that the distribution company can provide electricity. LCOE savings are roughly doubled when the electricity supply from the distribution company is firm.

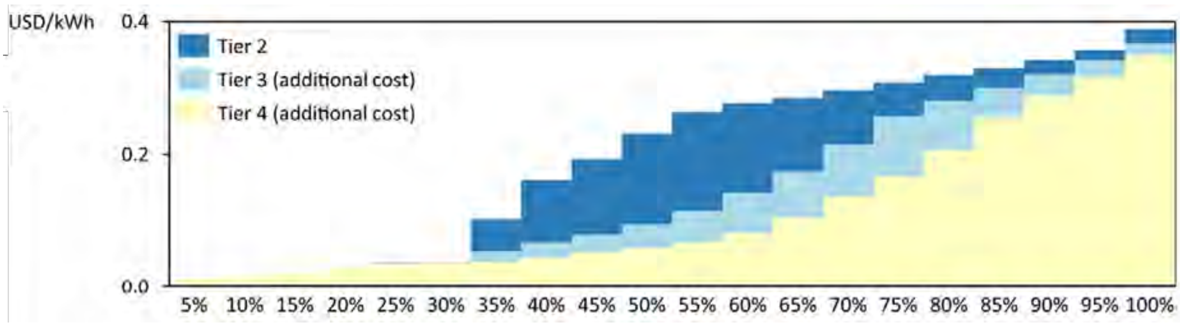
LCOE numbers need to be contextualised in order to be interpreted in a meaningful way. For instance, the LCOE depends on the tiers of electrification; lower tiers result in a higher LCOE, as shown in Figure 2.34, because the capital investment is high in relation to the electricity output over the lifetime of the asset. Tier variations can represent small-scale productive use applications, which would typically be situated between Tier 3 and Tier 4.[143] Similarly, the country context is crucial, as it leads to varying import duties and taxes. In that sense, a distinction can be made between the financial LCOE (including import duties, taxes and all other costs reported by developers in constructing and operating a mini-grid) and the economic LCOE, which does not include these costs. From the private sector operator's perspective, the financial

[142] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

[143] Egli, F., C. Agutu and B. Steffen and T. Schmidt. 2023. The cost of electrifying all households in 40 Sub-Saharan African countries by 2030. *Nat Commun* 14: 5066.

LCOE is more valuable, while policymakers deciding among approaches to electrification are interested in the economic LCOE.[144]

FIGURE 2.25 Electrification LCOE curve for sub-Saharan Africa by tier



Source: Egli, F., C. Agutu, B. Steffen and T. Schmidt. 2023. The cost of electrifying all households in 40 Sub-Saharan African countries by 2030. *Nat Commun* 14: 5066.

A phased approach to technical design can help achieve lower LCOEs. Given the difficulty in correctly estimating demand, oversizing—and thus underutilising the systems— is a key risk that drives the LCOE up. Detailed demand assessments based on data collection on the ground can help estimate the loads more accurately, partially mitigating demand risk, as highlighted in Box 2.23.

BOX 2.2321 A phased approach to system sizing

PowerGen uses HOMER Pro to create simulations of a new mini-grid system, to determine optimal solar and battery system sizes and to calculate the LCOE.[145] In the first stage, given that demand for electricity is a crucial unknown in this modelling exercise, PowerGen uses customer acquisition teams to conduct **site studies and surveys** to determine the community's electrical use. Firstly, the largest loads, including local businesses, hospitals, schools and government buildings, are estimated. Based on experience through mini-grid projects in Africa, survey data can be used to estimate residential electric loads and their growth rates.

In a second stage, the consumption rates of the first tranche of customers are carefully observed and actual consumption data are used to plan the second phase of construction. In that way, PowerGen can determine realistic system requirements and size the generation and storage resources to achieve an optimal cost.

Source: HOMER Microgrid News. 2022. Nigerian minigrids improve power reliability and utility revenues for communities "under" the grid.

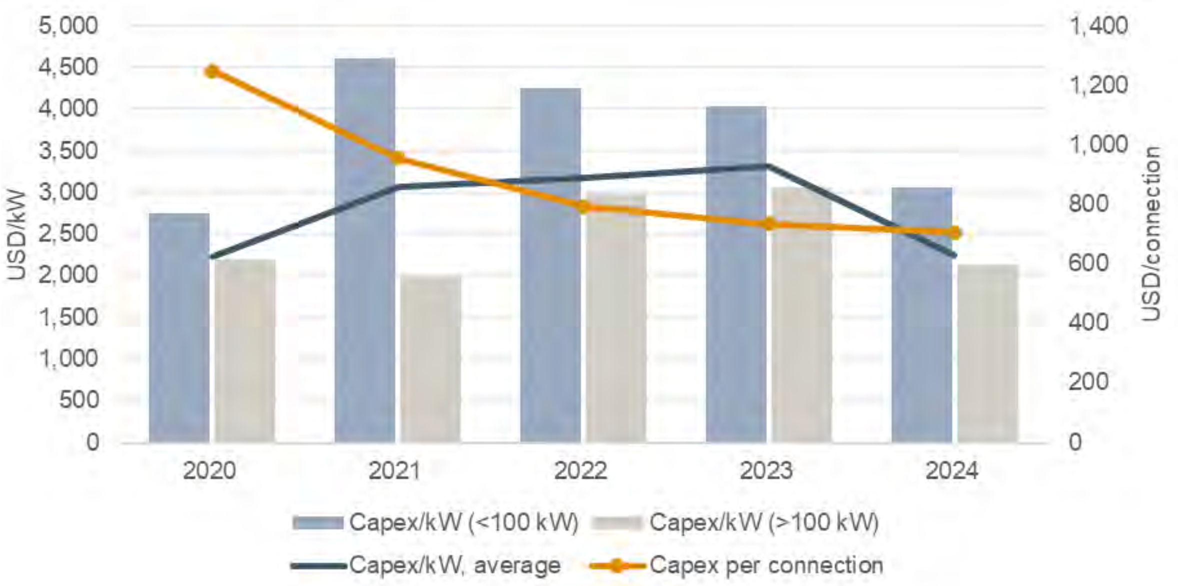
[144] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[145] The LCOE provided by HOMER Pro typically excludes the capex associated with distribution assets unless they are explicitly included in the investment costs. Consequently, the LCOE calculated in HOMER Pro may not align with the financial or economic LCOE mentioned above.

Capex costs

Capex has steadily decreased over the past four years. As indicated in Figure 2.35, the average capex cost per mini-grid connection has dropped by 43 percent from USD 1,250 in 2020 to USD 707 in 2024. Throughout the period from 2021 to 2024, capex per kW remained around USD 3,000, before falling to approximately USD 2,200 in 2024. This downward trend in costs reflects the industry's advancements in technology, procurement efficiencies and the scaling of operations, which collectively contribute to the reduced financial barrier for deploying new mini-grid projects. Throughout the period from 2020 to 2024, the marginal capex cost for sites smaller than 100 kW has been, on average, 50 percent higher than that of larger sites.

FIGURE 2.26 Capex costs per kW installed

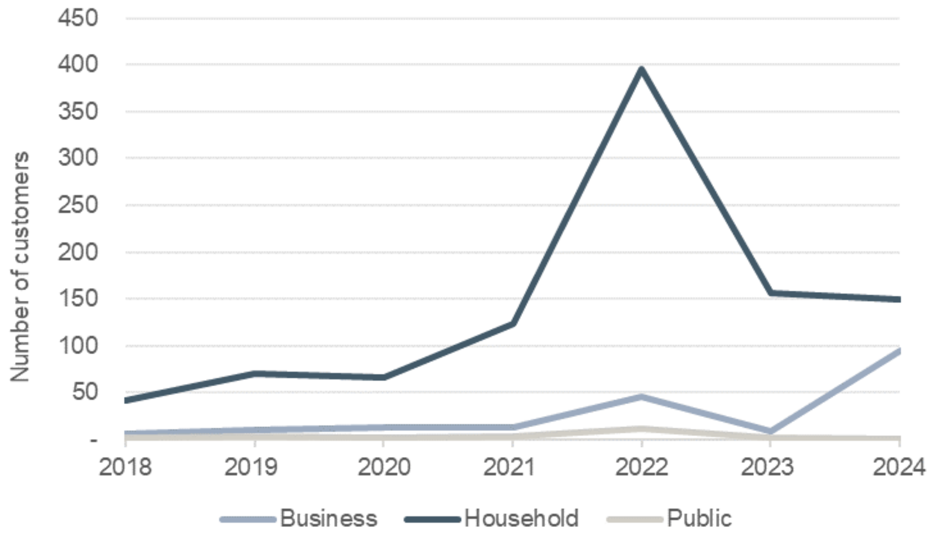


Source: ECA analysis based on the MGA database.

The dynamics influencing capex in the mini-grid sector are shaped by two conflicting trends. On one side, the global market has witnessed a significant escalation in the prices of crucial construction materials since the onset of the COVID-19 pandemic. The price of copper, for instance, has nearly doubled, mirroring similar trends in lumber and concrete prices, while steel, another vital component, has experienced more moderate increases. These materials play a critical role in the construction of mini-grids, thereby directly impacting their capex costs.

On the other side, developers are strategising to mitigate these rising costs by adopting more efficient approaches. One notable strategy includes the development of larger mini-grid projects (see Figure 2.36), targeting more customers, and the creation of vertically integrated value chains, which have proven to reduce marginal costs effectively. A case in point is Husk Power, a company that significantly reduced its capex in India from USD 3/Wp in 2018 to USD 2/Wp in 2020. This reduction was achieved through meticulous management of the supply chain, optimising system designs and refining operational processes from procurement to installation. This approach underscores the sector's adaptability and the innovative strategies being employed to counterbalance the adverse effects of rising global material costs on mini-grid development.[146]

FIGURE 2.27 Average number of customers per reported mini-grid



Source: ECA analysis based on the MGA database.

- **Another factor affecting capex costs is market saturation.** In some countries, mostly in South Asia, market saturation is forcing developers to reach those most difficult-to-reach consumers. For example, in India, extremely high electrification rates mean that those consumers without connections are likely to be those in the most remote, and therefore "expensive", areas. Another aspect to this challenge is that as economies develop, both locally and nationally, consumers of mini-grid electricity start to demand quality of energy provision that requires higher upfront costs. For instance, as economies develop, so too does electricity demand, both in absolute and temporal terms. This in turn raises the demand for stable, reliable connections, placing pressure on developers to ensure their grids are more reliable over time.

Opex costs

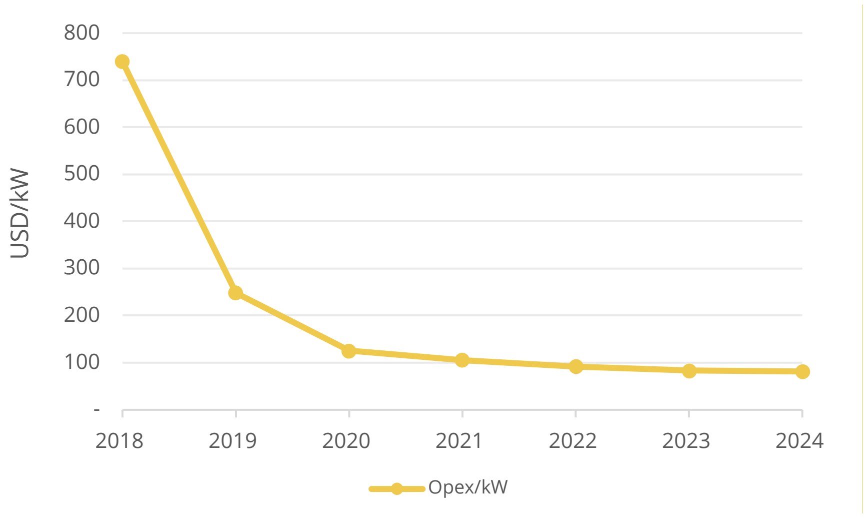
In parallel with the dynamics observed in capex costs, opex costs in the mini-grid sector have also been experiencing a notable decline over recent years. This trend reflects broader industry-wide efficiency gain and cost optimisation. According to data from AMDA, there has been a substantial reduction in opex costs of 41 percent between 2020 and 2022. Specifically, the cost per customer per month saw a decrease from a range of USD 2.50 to USD 6.00 in 2020 to a more affordable range of USD 1.00 to USD 4.00 in 2022. This reduction is a significant

[146] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

achievement, signalling improved operational efficiency and cost management practices among mini-grid operators.

Further illustrating this trend, Figure 2.37 highlights the decrease in opex costs per kW, showcasing a steady decline from approximately USD 250/kW in 2019 to USD 80/kW by 2024. This reduction can be attributed to several factors, including advancements in technology, economies of scale as the sector expands, and the adoption of more effective operational practices. Innovations in remote monitoring and control technologies, for example, have played a pivotal role in reducing the need for on-site maintenance, thereby lowering the overall operational costs. Additionally, as operators gain more experience and the market matures, there is a natural progression towards more streamlined and cost-effective operational models.

FIGURE 2.28 Average opex costs per kW



Note: Opex costs include: O&M, transport, replacement, security, mobile money, metering, local agent and central operating costs (e.g. legal).

Source: ECA analysis based on the MGA database.

Development costs

Data on development costs are difficult to acquire, given the lack of standardisation in how these costs are reported. While some companies appear to report project development costs explicitly, other developers combine them with equipment costs in the form of markups, or internalise these costs and do not report them at all.

Economies of scale are crucial for reducing development costs. ESMAP analysis has shown that mini-grids built separate from a portfolio have substantially higher average soft costs (project development and logistics). In particular, mini-grids built as part of a portfolio saved USD 81,000 in soft costs on average, compared with mini-grids built as one-off projects.[147]

[147] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

Digitalisation is another crucial factor that has led to a large drop in project development costs. Tools that facilitate the project development process include Odyssey, VIDA and the Site Wizard for Analysis, Reconnaissance and Mapping (SWARM) software used by Powerhive.[148] The software enables developers to remotely identify viable site locations over large regions, thus reducing project development costs. By leveraging financial, technical and geospatial data, SWARM identifies optimal mini-grid locations and calculates the required system size, resulting in a prioritised list of the most viable sites.

Towards a holistic approach to electrification

While the analysis of mini-grid economics is valuable in showcasing the potential for mini-grids to electrify unserved areas in a cost-effective way, and also identifying ways to further reduce the cost of service, it is crucial to acknowledge the limitation of relying on the LCOE as a single measurement of mini-grids' success. The LCOE of mini-grids typically incorporates the capex for distribution assets, which can vary significantly between sites. This variation makes comparing an LCOE with other technologies such as off-grid solar products and grid extension challenging, as the cost bases may differ. Also, mini-grids are not just supplying energy, but also stimulating future demand for electricity through robust socio-economic development strategies. Successful mini-grids are, more often than not, those that adopt a holistic approach, helping to grow the surrounding local economy and community—and, in turn, growing the demand for their electricity.

[148] Powerhive. n.d. Technology.

CHAPTER THREE

IMPACTS

Performance metrics and societal impact have consistently showcased the superiority of mini-grids over national utilities. Mini-grids outperform national utilities in the countries where they operate with respect to service metrics, including uptime, power quality, reliable connections and downstream job creation. They have consistently high service uptime, on average above 99 percent, whereas national grids experience significantly more outages.[149]

A consistent approach to measuring impact allows the sector to assess the outcomes created by mini-grid projects in a transparent and coherent manner. Through continuous monitoring and evaluation of mini-grid projects, policymakers, multilateral institutions, companies, investors and other sector stakeholders can evaluate which approaches have worked best, identify potential areas for improvement, and make informed decisions for future projects. In addition, impact metrics are a key component of results-based financing (RBF) schemes, which disburse grant amounts upon achievement of pre-defined results that have to be verified.

[149] AMDA 2022. Benchmarking Africa's Minigrids Report 2022.

Measuring Impact within the SDG Framework

The sector is increasingly adopting all-encompassing monitoring and evaluation frameworks to capture the multi-faceted impact of mini-grids. Mini-grid financiers, including donor agencies and private investors have established impact metrics linked to the UN Sustainable Development Goals (SDGs). Though the sector still lacks a widely adopted or standardised approach to measuring impact, the common theme of the various methodologies is to capture all three key aspects of impact, namely economic, social and environmental. Thus, the metrics encompass progress towards not only SDG 7 (affordable and clean energy), but also:

- SDG 1 (no poverty), SDG 8 (decent work and economic growth) and SDG 9 (industry, innovation and infrastructure) as part of the **economic** impact. For example, a standard mini-grid of 20 kW creates around three full-time jobs.[150]
- SDG 3 (good health and wellbeing), SDG 4 (quality education), SDG 5 (gender equality) and SDG 11 (sustainable cities and communities) as part of the **social** impact. Examples include a reduction in respiratory ailments since mini-grid electricity lessens households' heavy dependency on kerosene, allows longer studying hours for children after sunset, and improves women's safety after dark because of well-lit surroundings, according to a study in India.[151]
- SDG 13 (climate action) as part of the **environmental** impact. For instance, in the EEP Africa portfolio, mini-grids reduced carbon emission by 490 tCO_2-eq per project over their lifetime.[152]

[150] Power for All. 2022. Powering Jobs Census 2022: The Energy Access Workforce.

[151] The Rockefeller Foundation. 2017. Understanding the Impact of Rural Electrification in Uttar Pradesh and Bihar, India.

[152] EEP Africa. 2018. Opportunities and Challenges in the Mini-Grid Sector in Africa.

FIGURE 3.1 SDGs and mini-grids

Relevant SDGs for mini-grids

Source: ECA.

Thus, in addition to the number of connections achieved or the number of mini-grids deployed, the impact metrics capture job creation and the improvement in livelihoods, and the reduction in carbon emissions, with some methodologies also providing disaggregated metrics by gender to capture positive impact with regard to gender equality.

For instance, Energising Development (EnDev) uses a thorough monitoring and evaluation system, which captures impact in terms of social development, economic development and climate change, using the following categories:[153]

- **Beneficiary**: household (HH), social institutions (SI), micro, small and medium-sized enterprises (MSME), average size of HH, share of women in HH/SI/MSME, share of female-led HH/SI/MSME
- **Technology**: mode of electrification (PV systems, mini-/nano-grid, grid), electrical appliances (including e-cooking), expected lifespan, access quality level, installed capacity
- **Type of support**: Business development support, strategic partnership, demand-side subsidy, humanitarian energy, higher-tier cooking, RBF, COVID-19 response
- **Results**: No. of connections, No. of systems sold, No. of people newly connected/ with improved access, jobs in productive use of energy (PUE), jobs for women, CO_2-eq emissions saved, biomass saved.

In addition to the above, EnDev adopts a "**leave no one behind" approach**, which aims to reach disadvantaged groups, such as refugees, internally displaced persons and host communities,

[153] Consultant's interview with EnDev and EnDev. 2022. Progress Report 2022.

socio-economically disadvantaged women, the poorest of the poor and people with disabilities, as well as indigenous groups and ethnic minorities. This strategy is vital given the current unequal distribution of electricity access; less affluent consumers continue to experience lower levels of access compared to their wealthier counterparts, and disparities also exist along gender lines, with men comprising the majority of those with access.[154]

Similarly, the Global Energy Alliance for People and Planet (GEAPP) uses an "impact dashboard", which tracks direct and indirect impacts by tracking delivery in real time against its core strategic targets. GEAPP's impact dashboard draws a distinction between short-term indicators, which focus on capacity installed (namely, MW installed, mini-grids deployed and C&I solar systems deployed), and long-term indicators, which encompass three core categories (also shown in Figure 3.2):

- **Connecting people**: Measured by the number of people and businesses with new or improved access. The indicator is aligned with the World Bank's multi-tier framework, focusing on quality, reliability and affordability as the most relevant indicators of improved access in areas where universal coverage is reached or almost reached.
- **Creating jobs**: Measured by the number of jobs and livelihoods supported through GEAPP-supported projects, the indicator captures direct job creation through renewable energy investment and the transition away from fossil fuels, as well as improved livelihoods linked to GEAPP-funded renewable energy provision.
- **Cutting CO_2 emissions**: Measured by the cumulative tonnes of CO_2-eq reduced or avoided across the lifecycle of projects.[155]
- GEAPP also measures direct and indirect financial mobilisation, which is the primary support mechanism through which it creates impact. Through its blended finance strategy, GEAPP has achieved a leveraging rate[156] of 2.4 against its investment portfolio in the renewable energy sector, triggering public and private investment that may not have occurred without its support.

[154] 60 decibels. 2020. Why off-grid energy matters.

[155] GEAPP. 2023. Impact Report 2023.

[156] USD mobilised directly or indirectly per USD 1 of GEAPP's investment.

FIGURE 3.2 Snapshot of GEAPP's impact metrics

	Cumulative Tons CO2E Reduced or Avoided	Jobs/Livelihoods Supported (FTE)	People/Businesses With New/Improved Access	USD Financial Mobilization (Direct and Indirect)
LONG-TERM INDICATORS	147,000	605,000	1,285,000	$1.07B
TARGETS IN SIGHT	43,300,000	2,175,000	77,300,000	$6.12B

Source: GEAPP. 2023. Impact report 2023.

Finally, EEP Africa reports standardised indicators (including savings on energy-related expenditure; people with enhanced energy access; CO_2-eq emissions reduced or avoided; direct job creation; and women in leadership, shown in Figure 3.3) per country of initiative. In addition to the key metrics, the fund also tracks leveraged finance, sales of energy-efficient appliances and access to energy for productive use purposes.

FIGURE 3.3 Snapshot of EEP's projected impact for its active portfolio, framed within the SDGs

€15M	47%	1.5M	6,700	427k
ANNUAL SAVINGS ON ENERGY-RELATED EXPENDITURE	WOMEN IN LEADERSHIP	PEOPLE WITH ENHANCED ENERGY ACCESS	DIRECT JOBS CREATED	TCO2E GHG EMISSIONS REDUCED OR AVOIDED

Source: EEP Africa. n.d. Results.

In relation to the environmental impact of mini-grids, the sector lacks a standardised methodology for measuring the carbon emissions displaced by mini-grids. Existing methodologies calculate the emissions avoided based on the energy generated by mini-grids and one default emissions factor, which assumes that all mini-grid consumers previously used a single energy source, such as a diesel generator, while in practice consumers typically use a variety of sources. Furthermore, calculating emissions on the basis of energy generated can lead to misleading results if some of that energy is not consumed.[157] To address these issues,

[157] SEforALL. n.d. Mini-grids emissions tool.

SEforALL has developed the mini-grid emissions tool, used by Universal Energy Facility (UEF), which offers a harmonised approach to quantifying the mitigation benefits of mini-grids, based on realistic assumptions.

With regard to environmental, social and governance (ESG) considerations, while funders have adopted similar ESG measurement frameworks, the core metrics used still vary from one funder to another. ESG risk identification and mitigation is usually conducted according to the eight IFC Performance Standards, but the metrics and the reporting templates used are not standardised, thus imposing a significant cost on developers. This cost is particularly high when it comes to supply chain due diligence for human rights issues. As the mini-grid sector is scaling up, forced and child labour issues in mining and by extension in battery supply chains need to be addressed. However, developers currently lack guidance from financiers on mapping and addressing such risks, while also passing the cost of tracing the supply chain on to the consumers.

Finally, it is worth noting that sometimes achieving the SDGs is in conflict with the existing business models. Given that profitability is still a key driver for mini-grid developers, it is often the case that the number of connections is reduced to increase profitability. More specifically, developers of larger mini-grid sites are adopting a strategic approach to achieve full utilisation within the first 12 months of operation, whereby they initially undersize the infrastructure slightly, aiming to reach 100 percent utilisation rapidly. This approach minimises the risk of stranded electricity, a scenario where generated power remains unused due to lack of connected customers or sufficient demand. Upon achieving full utilisation, developers can then present a compelling case to investors for expanding operations, demonstrating both the demand and the efficiency of the site. Nuru's approach exemplifies this, as they commit to a 75 percent renewable energy fraction across sites. However, as they ramp up towards 100 percent utilisation, there is a need to temporarily increase the diesel share in the mini-grid to ensure consistent power supply.

Customer-Focused Approaches to Measuring Impact

Innovative approaches to measuring impact also include third-party companies that use surveys to measure social impact across the world. For instance, 60 decibels, an impact measurement company, has developed a survey-based off-grid energy index that provides benchmarked social performance data on the impact of solar home systems, lanterns, appliances, mini-grids and clean cook stoves. Zooming into the mini-grid sector, the findings shown in Table 3.1 are based on surveys of 2,445 customers served by seven companies across five countries. The results are encouraging regarding access, with 84 percent of customers accessing electricity for the first time, 97 percent of customers not being connected to the grid, and 94 percent of the customers transitioning away from traditional sources. However, *equitable* access remains a challenge, with only 27 percent of the customers being female and lower-income customers being underserved.

TABLE 3.1 60 decibels impact metrics for the mini-grid sector

METRIC	DESCRIPTION	IMPACT OF SURVEYED COMPANIES
PROFILE		
Poverty reach	Percentage of customers living below the international World Bank poverty line of USD 3.20 per person per day	57 percent
Inclusivity ratio	Degree to which low-income customers are served relative to the country population (1 = parity with national population, > 1 = over-serving, < 1 = under-serving)	0.9
Female reach	Percentage of female customers	27 percent
Rural reach	Percentage of customers living in rural areas relative to peri-urban and urban areas	69 percent
No access to grid electricity	Percentage of customers not connected to the national grid	97 percent
IMPACT		
Quality of life very much improved	Percentage of customers whose quality of life has very much improved because of the energy service	43 percent
Experiencing heavy repayment burden	Percentage of customers saying payments for the energy service are a heavy burden	16 percent
Moved up the energy staircase	Percentage of customers who have moved from more traditional/basic energy sources	94 percent
First access	Percentage of customers accessing the energy service for the first time	84 percent
Productive use	Percentage of customers using the energy service for income-generating activities	21 percent
EXPERIENCE		
Customer challenge rate	Percentage of customers who have experienced a challenge using the energy service	36 percent
Unresolved issues	Percentage of customers experiencing a challenge whose issues have not been resolved	55 percent

Source: 60 decibels. 2024. Why off-grid energy matters.

According to the surveys conducted by 60 decibels, the top three impacts that are most important to mini-grid customers are access to (better) lighting, reliability, and access to appliances.

A survey-based approach is also used by Oikocredit (see Box 3.1), in addition to their standard impact metrics that are framed within the SDGs (connections, CO_2 emissions reduction, jobs created).

BOX 3.1 End-line surveys by Oikocredit

Impact investor Oikocredit leverages its close engagement with its partners and uses end-client surveys as a way to identify the impact of their investments on end users. In 2022 Oikocredit conducted an end-client survey in collaboration with 19 partners and other organisations, interviewing 16,500 clients. The surveys posed 30 questions focusing on their wellbeing, the impact of financing and the effects of climate change and were conducted in the local languages.

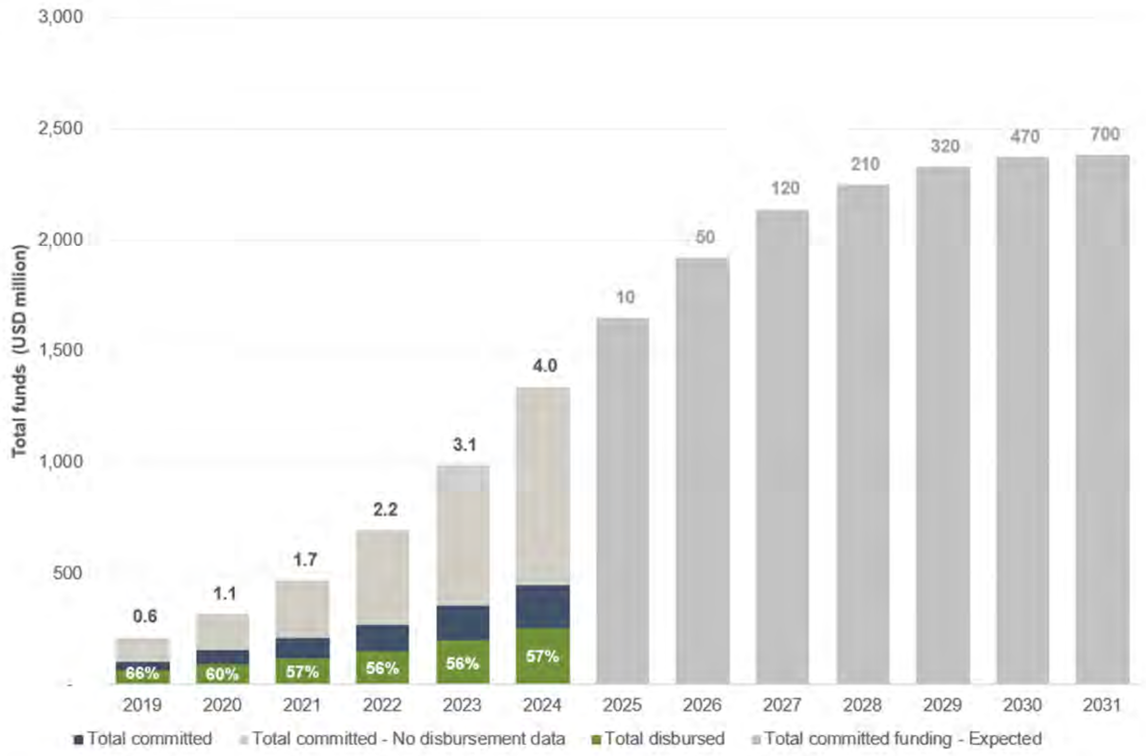
Source: Oikocredit. 2023. Financial inclusion: How does Oikocredit select its partners?.

Measuring Progress in Donor Deployment

Tracking disbursed versus approved financing is crucial to capture the full picture of the global mini-grid market. Tracking and reporting disbursements compared to commitments is crucial for ensuring transparency and accountability. Measuring progress will enable enhanced stakeholder collaboration towards shared goals by recognising challenges that need to be addressed in order to foster sustainable growth in the mini-grid sector.

Total funding committed has been increasing, while the disbursement rate has remained above 50 percent. Total committed funding has increased sixfold between 2019 and 2024, as seen on Figure 3.4. In projects for which disbursement data were available, the disbursement rate has increased slightly between 2022 and 2024, reaching 57 percent. However, this rate might be lower because disbursement rates have not been provided for programmes that constitute a large portion of the overall committed funding. By 2031 the total committed funding is expected to reach USD 2.4 billion.

FIGURE 3.4 Total funding committed vs disbursed per year



Note: Total disbursement rate (green) is provided only for programmes where disbursement rates are available.

Source: ECA analysis based on the MGF database.

The disbursement rates for 2019 and 2020 presented here differ from those in the previous publication (State of the Global Mini-Grids Market 2020) due to methodological differences and variations in the sample. This report's methodology accounts for the duration of funding programmes, ensuring that the disbursement rate for each year is relative to the portion of total funding available from each programme during that year.

BOX 3.2 Tracking donor deployment: Power for All

Power for All[158] recently launched "Accelerating Energy Access: Unlocking Catalytic Capital for Mini-Grids", a two-year campaign to boost support for mini-grids through awareness, communication and advocacy. It seeks to increase political, regulatory and financial support for the solar mini-grid sector. The KPIs described below are a necessary step to measure and track the sector's current support and progress.

The KPIs will offer insights into the effectiveness of current initiatives and identify areas needing more support. Tracking progress will enhance transparency and accountability, building trust among stakeholders and promoting collaboration towards shared goals. Additionally, measuring support allows stakeholders to monitor progress, recognise challenges, and make decisions that foster sustainable growth in the mini-grid sector and progress towards universal energy access.

The KPIs for Power for All's mini-grid campaign include:

1. Approved vs disbursed funding
2. Share of sites receiving donor funding
3. Disbursed funds per site
4. Donor money per connection in focus countries.

Power for All's analysis highlights that while there is donor commitment (with promised capital growing over time), the funds disbursed for mini-grid projects are only a fraction of the total allocated, averaging 14 percent in recent years. Large projects like KOSAP in Kenya and the UEF face significant delays and low disbursement ratios. The analysis also shows a funding bias toward larger and remote projects, with multi-site operators receiving more funding per site. The KPIs provide a critical tool for tracking progress, ensuring coordinated efforts to address inefficiencies and maximise donor impact to end energy poverty faster.

Source: Information provided by Power for All

[158] Power for All is a stakeholder coalition campaigning to rapidly scale up the deployment of decentralised renewable energy to achieve universal electricity access before 2030.

CHAPTER FOUR

MARKET OUTLOOK

This section builds upon the insights and results discussed in the previous sections to provide a forward look for the sector, in respect of enabling environment, business models, financing, technology and economics, as summarised in Figure 4.1.

FIGURE 4.1 Market outlook

Enabling environment

- Integrated energy planning
- Regulatory approaches that acknowledge the need for recovering costs in a de-risked way
- Standardisation in regulatory approaches and tools
- Comprehensive approaches to asset valuation for grid arrival
- Interconnected mini-grids

Business models

- A need for innovative business models to reach the last mile
- A more proactive approach to PUE

Technology

- Technological advancements driving opex cost reductions
- Increased data availability required to scale up the sector

Financing

- Aggregation as the key factor for mini-grid financial viability
- Increased cross-sector collaboration to scale up the sector

Economics

- Further LCOE reduction

Notes: LCOE stands for levelised cost of electricity; PUE stands for productive use of energy.

Enabling Environment Outlook

Integrated energy planning

The sector is expected to gradually move away from the co-existence of the three modes of electrification (on-grid, mini-grids and standalone systems) in silos towards an integrated framework for energy planning. An example of this approach is the Integrated Distribution Framework (IDF), which advocates that an "entity" (comprising one or more actors, such as the existing distribution company in partnership with the private sector) should be held responsible for distribution in a given area (under a contract like a concession) and ensure universal coverage. Under this model, "integration" becomes a multi-faceted concept, which includes integration of the three modes of electrification, all types of end customers, and the public and private sectors in the distribution sector.[159] See Box 2.1 for further detail.

- Similarly, the Utilities 2.0 project by PowerforAll advocates a shift from the classic utility approach by combining centralised and decentralised technology into an integrated, intelligent and interactive energy network that can deliver customer-centric, clean energy solutions at the lowest cost. This approach acknowledges that utilities need to collaborate with market actors that excel at customer service (in the first mile or last mile), who would have the freedom to choose which technologies best satisfy consumer demand.[160]

Regulatory approaches that acknowledge the need for recovering costs in a de-risked way

We anticipate a shift of focus from the traditional approach to cost recovery, via tariffs based on cost-of-service assessments for individual projects, towards a more comprehensive and flexible way of recovering costs in a de-risked way. An example of this approach is implementing automatic tariff adjustments to account for large changes in costs that are outside the mini-grid operators' control, such as inflation and currency fluctuations. Similarly, regulations should increasingly acknowledge the need for scale as a key factor of mini-grid viability, for instance by allowing portfolio applications for licences and tariffs and adopting fit-for-purpose technical standards adapted to the scale of the project.

Standardisation in regulatory approaches and tools

Given the need for a speedy scale up of the sector, we can anticipate the standardisation of certain regulatory aspects, such as tariff-setting methodologies based on the principle of cost recovery or grid arrival arrangements. Given the maturity of certain approaches and the lessons learnt so far, the sector can comfortably claim to have established blueprints that can

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[159] Global Commission to End Energy Poverty. n.d. Integrated Distribution Framework; Integrating Isolated Mini-Grids With an IDF-Compliant Regulated Distribution Sector.

[160] PowerforAll. 2019. Universal Renewable Energy Access: The Utilities of the Future.

be adjusted to market and project conditions. A good example is the work of the African Forum of Utility Regulators (AFUR) in collaboration with the Africa Minigrid Developers Association (AMDA) on developing a standardised mini-grid tariff tool. In light of the establishment of the African School of Regulation, harmonisation can be expected to increase through close engagement with development partners, regulators, ministries of energy and the private sector, with the aim of establishing a consensus across the sector on core regulatory aspects.

More comprehensive approaches to asset valuation in case of grid arrival

Mini-grid asset valuation methodologies are gradually evolving. Grid arrival is one of the key sources of uncertainty for mini-grid developers and investors. Without guaranteed compensation, these private investments are less secure, leading to reluctance from private investors to engage in the sector. Moreover, the absence of a clear and enforceable compensation mechanism can discourage long-term investment and innovation, further stalling the growth and development of mini-grids.

To address this, an increasing number of countries are adopting regulations that specify the entitlement to compensation for the mini-grid assets in case the distribution company arrives earlier than agreed to or expected, including Nigeria and Sierra Leone. However, as yet no African mini-grids have received compensation under any of these rules. Indeed, most distribution companies and rural electrification agencies in sub-Saharan Africa do not have the money to buy out isolated mini-grids, while donor funding for main grid utilities is typically dedicated to new distribution facilities, with only limited or no funding allocated to mini-grid asset takeover and compensation.[161] As the sector matures, we expect to see examples of such grid arrival arrangements in practice, and the establishment of innovative approaches to asset valuation that encourages private sector involvement in the mini-grid sector.

Interconnected mini-grids

- Greater attention is being paid to the issue of the quality of service received by end users, as opposed simply to nominal energy access. Access statistics are based on electrical connections and do not capture those customers that are "electrified" but received very poor, or sometimes no, service. Thus, published electricity access rates often paint a rosy picture of the electrification landscape that is far from complete. Interconnected mini-grids are set to play a key role in filling this gap, as already highlighted in Nigeria, where poor quality of service, including lack of reliability and wide variations in voltage and frequency, is a critical issue. The Rural Electrification Agency, with new funding from the World Bank, has initiated the Nigeria Electrification Project to create interconnected mini-grids (to Nigeria's privately owned distribution companies), as well as the Nigerian Energy

[161] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

Support Programme, which is providing grants and technical assistance to Nigerian developers that propose to build interconnected mini-grids.[162]

Business Model Outlook

A need for innovative business models to reach the last mile

Given the major cost savings that can be achieved through economies of scale, many developers are seeking to electrify larger sites with 5,000 plus connections. However, this approach leads to cherry-picking the most commercially viable sites, where the electricity gap can be most easily closed, leaving less viable sites behind. This presents a challenge for subsidy policy, as to ensure efficiency it is important to determine appropriate subsidy levels based on commercial attractiveness.

- One innovative approach to electrifying the last mile is mesh grids, which are set to gain traction in areas with low population densities. The reduced distribution costs resulting from the close proximity of houses and the expedited deployment rate (due to the absence of land acquisition requirements) represent a largely untapped opportunity for the private sector. By organically connecting households, this approach offers a replicable and scalable method for reaching last-mile customers in sparsely populated regions, thereby allowing significant savings on capital expenditure costs.

A more proactive approach to PUE

PUE continues to be a key aspect of mini-grid development. However, its focus is expected to expand, requiring developers to take on a more proactive role in increasing customer loads and thus mini-grid revenues. As regards business models, this would be reflected in the shift from the traditional energy supply model towards the business acceleration model and supplier-offtake model. For instance, Husk Power provides education, training and business development for customers who operate MSMEs, while it is also experimenting with forming and operating its own enterprises using the mini-grid electricity.[163] The dual benefit of PUE—sustaining mini-grid profitability and empowering communities—continues to be a powerful narrative in the evolution of the mini-grid sector.

[162] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

[163] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

Financing Outlook

Aggregation as the key factor for mini-grid financial viability

Aggregators are expected to play an increasingly critical role in helping smaller companies achieve savings through economies of scale. For instance, GEAPP's Demand Aggregation for Renewable Technology (DART), which was recently launched, is one of the main aggregation platforms that helps smaller companies, who would not otherwise have negotiating power, access affordable equipment. DART addresses this challenge by aggregating demand, thus allowing companies to benefit from economies of scale and secure equipment at a discounted rate of up to 30 percent, while also providing collateral-free working capital financing to support equipment purchase and providing a customs-clearing service.[164]

Increasingly, we also expect to see specialist funds aggregating mini-grid portfolios across countries. The model used by CrossBoundary Energy Access is a prime example of such a fund that aims to achieve scale by aggregating multiple asset companies into a single investment platform that is large enough to raise equity and mezzanine debt from investors.

Increased cross-sector collaboration to scale up the sector

We can anticipate the donor community forming partnerships to break down silos, pool resources and encourage innovation in the sector. The trend towards large cross-funder instruments, exemplified by the UEF, is expected to continue in response to the need for continuity in funding, rather than the stop-and-go approach experienced so far. Different sectors are also set to increasingly join forces to leverage synergies between the SDGs. In this context, climate finance plays a key role; the recently launched Finland-IFC Blended Finance for Climate Programme serves as an example of the climate and energy sectors coming together to help scale up the sector. The programme seeks to catalyse innovative investments and unlock private financing of climate-smart projects in low-income developing countries.

Technology Outlook

Technological advancements driving opex cost reductions

Remote monitoring technologies have already begun transforming how renewable energy companies manage and optimise their mini-grid operations. These digital tools facilitate real-time tracking and control of remote sites, ensuring operational efficiency and reducing the need for costly on-site visits. As these technologies continue to advance, we can expect them to become even more integral to the operation of mini-grids. The trend towards digitisation and

[164] GEAPP. 2024. DART 3.0 Kicks Off in Nigeria for DRE Companies.

IoT (Internet of Things) integration means that remote monitoring will not only become more mainstream, but also more sophisticated, allowing for predictive maintenance, improved energy management and enhanced customer service. This technological shift is expected to further drive down O&M costs, which currently benefit from an estimated 15 percent reduction due to existing remote monitoring capabilities.[165]

Increased data availability required to scale up the sector

The role of data sharing tools in the mini-grid sector is becoming increasingly critical. Data sharing tools and platforms can play a pivotal role in scaling up the sector by demonstrating the viability and bankability of mini-grid projects to potential investors and funding bodies. Despite the current hesitancy among companies and institutions to share sensitive performance data, the establishment of secure and anonymised data sharing frameworks can mitigate these concerns. Such frameworks would not only facilitate the sharing of vital operational data, but also enable stakeholders to benchmark performance, understand market dynamics and identify areas for improvement and investment.

Enhanced data sharing and remote monitoring capabilities can contribute significantly to achieving universal electricity access by 2030. By providing clear and tangible evidence of mini-grid performance and efficiency, these technologies can help attract the necessary investments to scale up the number of mini-grid installations worldwide. Additionally, the integration of advanced analytics with remote monitoring data can offer deeper insights into consumer behaviour, energy usage patterns and system performance, enabling more targeted and effective electrification strategies.

In sub-Saharan Africa, AMDA, through its AMDA 2.0 strategy, is working to take the lead in facilitating data sharing of aggregated and anonymised information from its members to different stakeholders in the sector.

Outlook for Economics

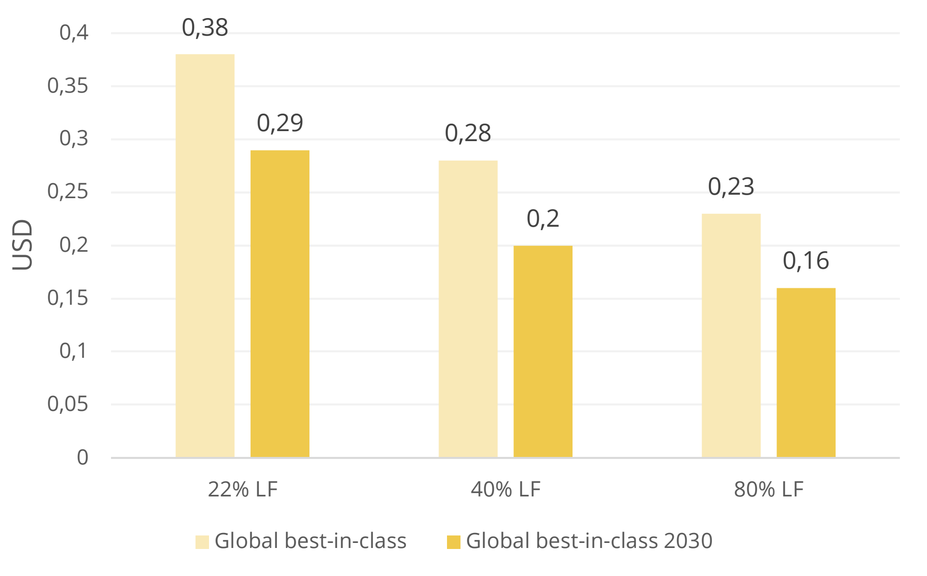
Further LCOE reduction

According to ESMAP's modelling results, further reductions in the LCOE are anticipated. Figure 4.2 presents the LCOE for what would currently be considered best-in-class mini-grids, i.e. high-performing mini-grids based on component costs and load magnitude. For comparison, the LCOE of best-in-class 2030 mini-grids is shown, based on equipment cost reductions expected in 2030. These reductions are driven by the mini-grid industry (and associated industries) achieving scale, resulting in cost reductions for mini-grid components

[165] Interview with Odyssey Energy Solutions.

such as solar panels (through global solar panel deployment in solar farms) and Li-ion batteries (through global expansion of EVs and utility-scale electricity storage).[166]

FIGURE 4.2 Expected reductions in LCOE by 2030



Note: LF stands for load factor.

Source: ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

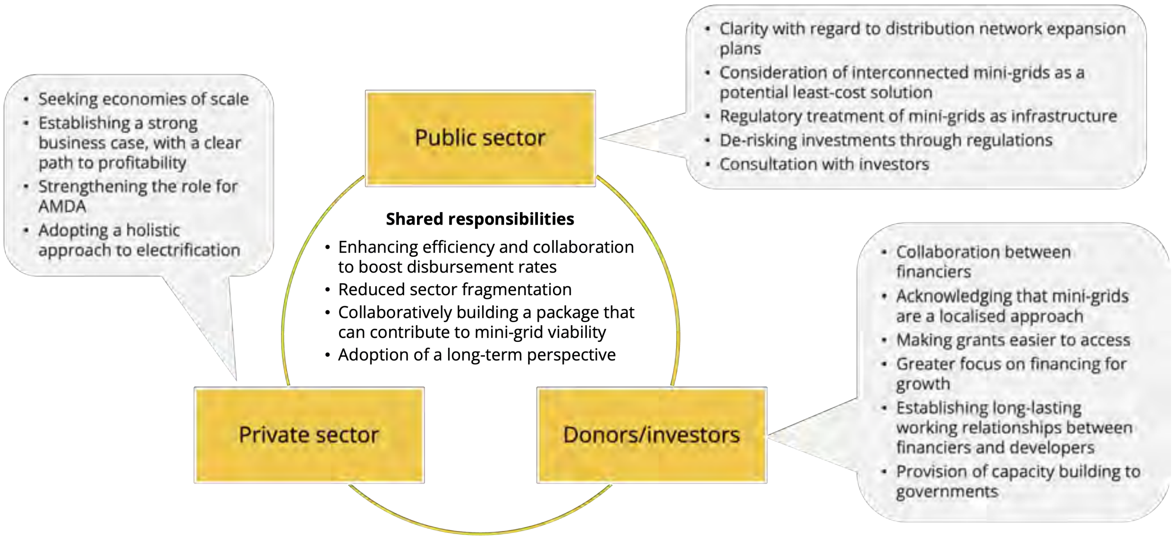
[166] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

CHAPTER FIVE

RECOMMENDATIONS AND CONCLUSIONS

While the mini-grid market is poised for growth and innovation, it must navigate a labyrinth of financial, regulatory, and operational challenges. Overcoming these hurdles is crucial for the sector to realise its full potential in contributing to global energy access and sustainability goals. The sections below translate the challenges identified throughout the report into plans of action for each stakeholder group, namely the public sector, donors and investors, and the private sector, as well as their shared responsibilities (summarised in Figure 5.1). The public sector encompasses not only the government agencies responsible for policymaking, but also includes rural electrification agencies, public–private partnership (PPP) units, and utilities, all of which play crucial roles in the development of the sector.

FIGURE 5.1 Areas of action



Areas of action for the public sector

Clarity with regard to distribution network expansion plans: Policymakers need to go beyond integrating mini-grids into their national electrification plans towards ensuring that there is sufficient clarity and predictability regarding distribution companies' network expansion plans. This would provide the necessary certainty to developers on potential areas for mini-grid development.

Consideration of interconnected mini-grids as a potential least-cost solution: The models currently used for least-cost electrification planning typically identify the distribution companies as the recommended option for grid densification and extension, without considering interconnected mini-grids. This option should be considered as it often provides a more cost-effective and reliable alternative for consumers in areas where the grid infrastructure is poor.

Regulatory treatment of mini-grids as infrastructure: This entails aligning the regulatory arrangements for mini-grids with their nature as long-term investments and acknowledging the increasing importance of project finance. As such, the duration of permits and licences should aim to reflect the tenor of financing agreements and allow enough time for preparatory activities. A duration of at least 10 or 15 years is thus required.

De-risking investments through regulation and contracting: Even though financial instruments are important for de-risking mini-grid investment, regulatory provisions (such as tariff indexation mechanisms to partially mitigate key risks such as currency depreciation and inflation) are crucial for providing investors with confidence. Since the development of such regulations can take time, contracts need to include specific clauses that address these risks directly. By incorporating terms that allow for tariff adjustments and other risk-mitigation measures, contracts can ensure that investors are protected against unforeseen economic changes, thereby fostering a more secure investment environment even before comprehensive regulations are established.

Consultation with investors: Involving investors early in the process of developing the regulatory framework is crucial for gaining insights into what constitutes a bankable framework, thus encouraging private investment flows.

Greater collaboration between regulators at a regional level: This would support the sector's scale-up by reducing the resources required to develop a bankable mini-grid framework from scratch, but also by allowing developers to work in different countries while minimising their development costs.

Areas of action for donors and investors

Collaboration between financiers: The sector remains fragmented, with multiple donors and investors considering investment in the market and conducting due diligence studies in parallel. Enhanced collaboration and data sharing would increase the efficiency of the process, saving resources both for the donors/investors and the mini-grid developers.

Acknowledging that mini-grids are a localised approach: The financial viability of the mini-grid hinges upon a deep understanding of the local context and energy needs, including potential productive use of energy (PUE) activities. As there is no one-size-fits-all approach to mini-grid development, it is crucial for financiers and development partners to develop more targeted approaches that do not exclude local players when implementing mini-grid programmes.

Making grants easier to access: The purpose of grants is to assist developers to get off the ground and, as such, the requirements and conditions of grant provision should be easier than those for equity or debt. Additionally, donors should aim to standardise grant application processes, thus improving efficiency and reducing the costs of financing for developers.

Increasing the duration of programmes: Donors often implement programmes that are project-based and have defined timeframes, typically ranging from two to five years. However, when it comes to developing the entire mini-grid sector in a country where there are no established mini-grid companies, this process often requires a significant amount of time. Some donor programmes have time constraints and disbursement goals that do not align with the longer timeframe needed for this endeavour. Extending the duration of donor-led programmes not only provides more time for developers to develop mini-grid projects, but also reduces the risk of donor support ending prematurely, ensuring continuous support until developers have recovered their investment costs.

More focus needed on financing for growth: Currently, the stages of growth capital and scaling to profitability (or so-called "valley of death") are neglected by financiers, exemplified by the fact that it took Nuru five years to obtain funding for expansion.[167] While project finance for mini-grids is an important financing approach for commercial scaling, finance for company growth should also be given sufficient attention.

[167] GEAPP

Establishing a long-lasting working relationship between the financier and the developer: Such relationships can play a vital role in ensuring the continuity of finance. Engaging in regular face-to-face meetings with developers can enhance financing partners' trust in the mini-grid business model and lead to a better understanding of the developers' operations and impact on the ground, potentially leading to repeat loans.

Provision of capacity building to governments and distribution companies: Given the need for political buy-in and strong commitment from governments for the successful implementation and sustainability of mini-grid projects, more technical assistance targeted at governments is required as part of donor-funded programmes, focusing on aspects of mini-grid regulatory framework development, including transaction advisory support. Support for distribution companies is also essential, particularly in the context of mini-grids aimed at serving underserved customers.

Strengthened role for AMDA: AMDA, with the help of donors, should take on the crucial role of building capacity within its membership, especially early-stage local companies, with a focus on strengthening their ability to access grants and engage in other capital-raising activities, as well as enhancing their corporate capabilities, such as impact monitoring and reporting.

Areas of action for the private sector

Seeking economies of scale: Aggregation is key to securing better commercial terms. This can be achieved, for instance, through creating a portfolio consisting of larger, less risky sites, bundled with smaller higher-risk sites. This approach is valuable in mitigating currency risk as well, when aggregating across countries.

Establishment of a strong business case, with a clear path to profitability: A strong and transparent business case should provide investors with information on key business model assumptions and strategies for scale-up, including key metrics such as average revenue per user (ARPU) and utilisation, profitability expectations, and PUE strategies. This serves to highlight commercial viability. At the same time, though often inconsistent with profitability, developers need to showcase their willingness to achieve SDG 7 through key impact metrics.

Prioritise PUE for economic empowerment and community: Developers should continue to look at promoting PUE, but view it as a concept that goes beyond just identifying an anchor load and towards economic empowerment and community development. Innovative financing models such as equipment leasing, on-bill financing and KeyMaker models can significantly enhance the accessibility and sustainability of PUE initiatives. Special attention should be given to magnifying impact through the electrification of public institutions.

Shared responsibilities

Enhancing efficiency and collaboration to boost disbursement rates: Funders can improve their processes and procedures to enhance efficiency. Sharing lessons, templates and tools among programmes and with partner governments can help speed up programme implementation. The roles of partner governments and developers are also crucial.

Governments can set favourable policy and regulatory conditions, and clear public–private arrangements on tariffs are needed to ensure projects can reach financial close, so that funds are disbursed quickly.

Reduced sector fragmentation: Despite efforts to disseminate information and the latest developments on mini-grids, the sector remains fragmented, with a general reluctance to share data on mini-grid economics. Major obstacles in obtaining data were faced in the development of this report, in spite of confidentiality guarantees. This is, however, an important result in itself. Only through data sharing can stakeholders in the mini-grid sector gain valuable insights into market dynamics, identify emerging trends and address challenges more effectively. Breaking down silos within the mini-grid sector is crucial for optimising resource allocation, improving decision-making, designing targeted interventions and driving sector-wide progress. This collaborative approach also promotes transparency and accountability, building trust among stakeholders and creating a conducive environment for innovation and investment.

Collaboratively building a package that can contribute to mini-grid viability: There is no single element that can make mini-grid projects more attractive to investors. Relevant stakeholders need to work together on providing a comprehensive enabling framework for mini-grid development, including supportive regulations, tailored financing instruments and access to long-term capital.

Adoption of a long-term perspective, grounded in commercial viability: A viable commercial model is crucial for the sustainability of mini-grid projects. Across Africa, there are numerous examples of mini-grid projects funded solely by donors that have ultimately failed, due to the lack of a sustainable commercial model to ensure their profitable operation. This underscores the significance of blended finance, where impact investors are aligned with commercial investors seeking returns. A successful and sustainable model requires commercial viability at every stage of the project lifecycle, including developers, engineering, procurement, and construction (EPC) contractors, and long-term operators. In assessing commercial viability, it is important to acknowledge that mini-grids, as infrastructure investments, do not yield immediate profits; returns are realised over an extended period, typically beyond the first few years of operation. This long-term perspective is essential for the sustainable development of the mini-grid sector. However, universal and equitable access requires a strategic focus not only on areas where there is commercial viability, but also where mini-grids can have the most significant impact. This necessitates striking a delicate balance between profitability and the SDGs.

ANNEX – CASE STUDIES

The final section of the report includes three deep-dive case studies:

Country	Reasons for selection
Sierra Leone	• Several funding programmes and business models for mini-grids have been implemented with varying levels of success • One of the lowest electricity access rates in the region • Comprehensive regulatory framework for mini-grids
India	• The greatest nominal number of mini-grids in Asia • Widespread access to grid electricity, but concerns regarding reliability of supply lead to continued demand for mini-grids
Kenya	• Enabling policy framework • Plans to develop more than 400 mini-grids to achieve universal access

Each case study is divided into four sections:

- Country context (including electrification and key mini-grid operators and projects)
- Policy framework
- Regulatory framework
- Economics (including business models, tariffs and affordability, as well as productive use of energy [PUE]).

A1 Sierra Leone

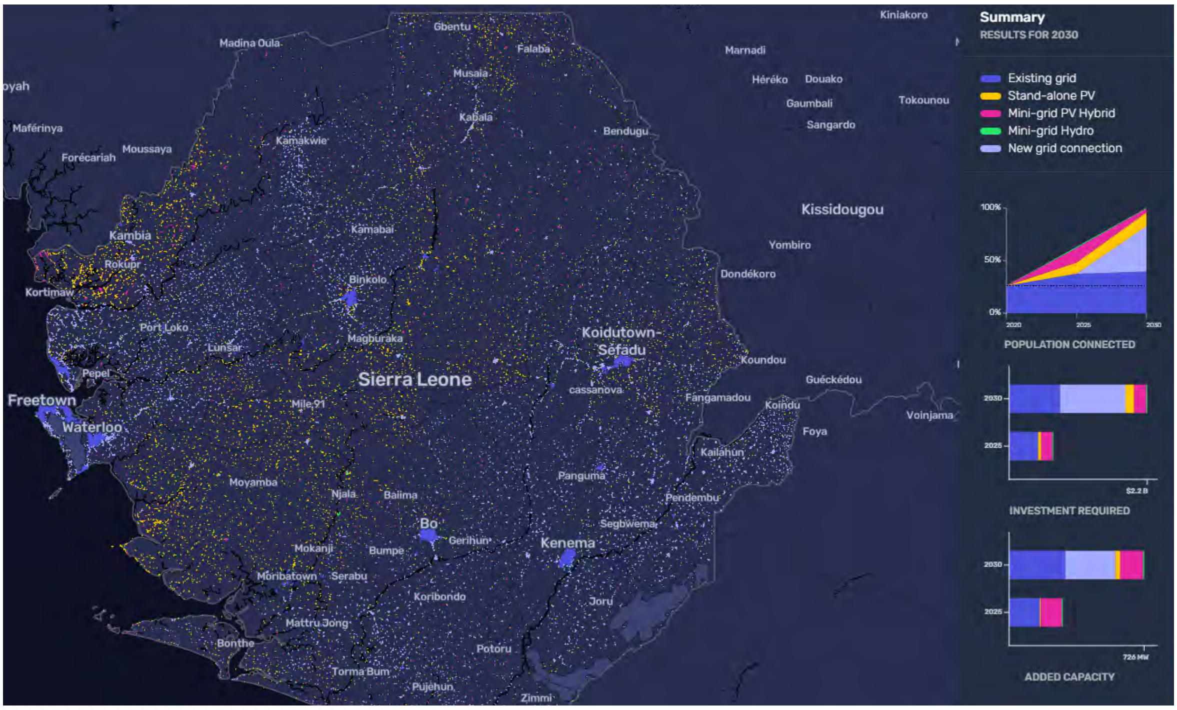
A1.1 Country context

A1.1.1 Electrification

Sierra Leone has a national electrification rate of 27 percent, but only a 5 percent rate in rural areas, where most of the population lives.[168] Figure 6.1 presents the strategy for full electrification of the country by 2030, as presented in the Global Electrification Platform (GEP).

The nationwide least-cost approach adopted by GEP first ramps up connections in settlements already grid-connected, and then prioritises unelectrified settlements based on lowest investment cost per capita, until the target electrification rate is reached.[169]

FIGURE 6.1 Sierra Leone least-cost electrification plan



Source: Global Electrification Platform.

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[168] ESMAP. Tracking SDG7. Country reports: Sierra Leone.

[169] A generation capacity limit is applied to keep grid expansion to sensible levels.

To reach universal access by 2030 on a least-cost basis,[170] PV hybrid mini-grids need to electrify 1.3 million people, with an additional 19,000 people connected through hydro mini-grids. In terms of added capacity, 124 MW of PV hybrid and 6 MW of hydro mini-grids are required by 2030 (out of a total of 726 MW of added capacity). The corresponding investment required by 2030 is USD 198 million for PV hybrid mini-grids and USD 15 million for hydro mini-grids.

According to the latest data published by IRENA,[171] 104,000 people have Tier 1 access and 85,000 people have Tier 2 access through solar mini-grids in Sierra Leone.

A1.1.2 Key mini-grid operators and projects

There are four mini-grid operators currently in Sierra Leone,[172] namely Winch Energy, Off-Grid Power (PowerGen), Power Leone (Energicity) and Power Ned. Solar PV is the predominant mini-grid generation technology for three out of the four operators, with Power Ned operating a hydro mini-grid.

As regards donor-funded projects, Sierra Leone has four main mini-grid projects. The first is **Promoting Renewable Energy Services for Social Development** (PRESS-D), funded by the European Union, Oxfam and GIZ, which installed mini-grids in Gbinti (79 kW), Panguma (66 kW) and Segbwema (127 kW). The project lasted until 2021, when it was handed over to the Ministry of Energy, which intended to bring in private operators to operate and maintain the mini-grids in the three chiefdoms to ensure sustainability of the three mini-grids.[173]

The United Nations Office for Project Services (UNOPS) has played a key role in supporting the government's goal of achieving universal access to electricity by implementing the **Rural Renewable Energy Project (RREP) project**, funded by the UK Foreign, Commonwealth and Development Office (FCDO). The first two phases of the project provided electricity access to communities across 14 districts of Sierra Leone through the construction of 94 mini-grids.[174] The project is being implemented in work packages:

- As part of Work Package 1 (WP1), UNOPS installed 6 kWp solar PV mini-grids at 54 community health centres, which were later extended up to 36 kWp in 50 sites (out of 54) to convert the systems to small mini-grids covering the nearby communities (WP1+).
- WP2 provided larger mini-grid installations to a further 44 communities, leading to a total generation capacity of 5 MW with over 97 mini-grids.[175] This work package introduced the

[170] To obtain these estimates, we have used the bottom-up electricity demand target (expressed in kWh/capita/year) instead of a top-down target, which assigns a unique demand target in each settlement, based on local poverty rate and GDP level.

[171] IRENA. 2023. Off-grid renewable energy statistics.

[172] SLEWRC. 2021. Public Registry: Electricity.

[173] Ministry of Energy. 2021. Request for Expression of Interest for the Operation, Maintenance and Management of the Solar Mini-Grids in Gbinti, Panguma, Segbwema.

[174] UNOPS. 2022. Policy brief: Improving access to renewable energy in rural Sierra Leone.

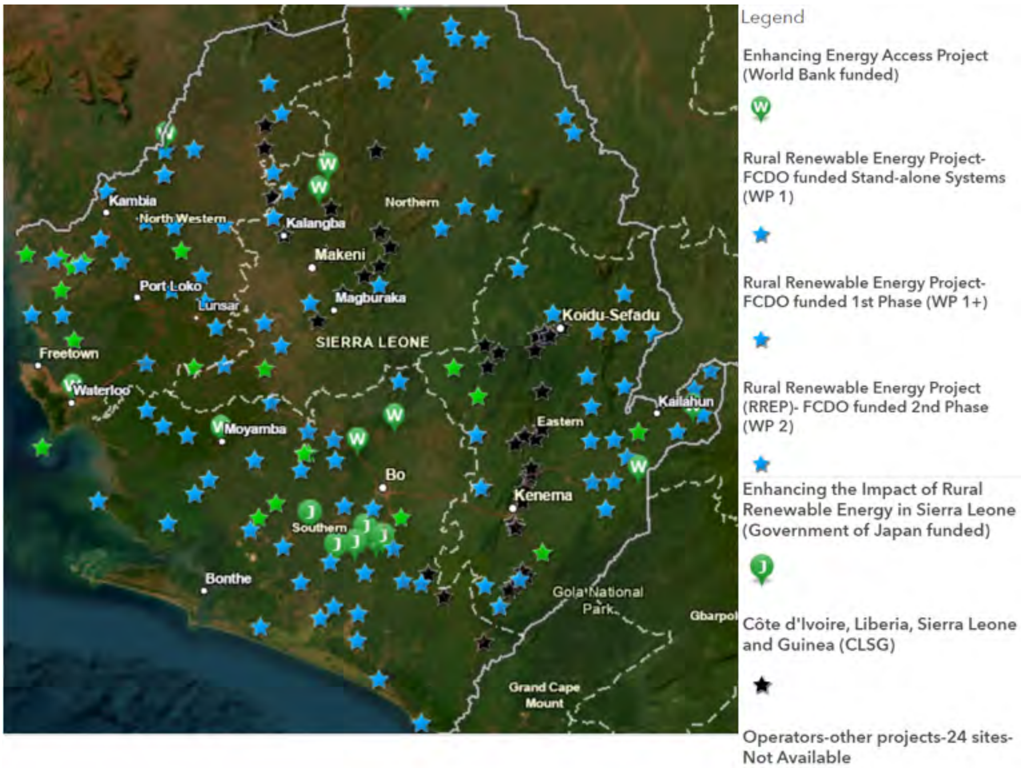
[175] AfDB. 2019. Mini-Grid Market Opportunity Assessment: Sierra Leone.

split-asset delivery model (see section A1.4.1), whereby the generation assets are privately owned, whereas the distribution assets are owned by the Ministry of Energy.

In addition, UNOPS is implementing the **Enhancing the Impact of Rural Renewable Energy in Sierra Leone** project**,** funded by the government of Japan, which aims to install six solar PV mini-grids in the Bo district.[176]

Finally, the World Bank-funded and UNOPS-implemented **Enhancing Sierra Leone Energy Access** project is aiming to install ten solar PV mini-grids with battery storage capacity in the town of Moyamba and selected communities.[177] The mini-grid locations for the mini-grids implemented by UNOPS are shown in Figure 6.2.

FIGURE 6.2 UNOPS mini-grids



Source: ArcGIS. n.d. The UNOPS mini-grids.

A significant addition to the mini-grid landscape is the arrival of the **Universal Energy Facility** (UEF) in Sierra Leone, a multi-donor results-based financing (RBF) facility implemented by SEforALL, established to significantly scale up energy access in sub-Saharan Africa. The facility provides incentive payments to companies providing verified end-user electricity connections through mini-grids based on pre-determined standards (USD 592 per electricity connection).[178] Its activities in Sierra Leone were launched in 2020 and are currently at implementation stage,

[176] UNOPS. 2024. Enhancing the Impact of Rural Renewable Energy.

[177] World Bank. 2021. Enhancing Sierra Leone Energy Access.

[178] SEforALL.n.d. Universal Energy Facility.

with a grant agreement signed with one developer that will deliver 1,385 connections in the country.[179]

A1.2 Policy framework

The government of Sierra Leone, with the support of development partners, most notably the UK FCDO, has established a supportive policy framework and comprehensive regulations to increase electricity access through mini-grids. The responsibility for policymaking lies with the Ministry of Energy.

The policy framework acknowledges the important role of mini-grids in increasing energy access and sets specific targets for mini-grids to be met by 2030.

The **National Renewable Energy Action Plan 2015** considers off-grid solutions (mini-grids and standalone systems) as part of the electrification plan and sets an ambitious target of 27 percent of the rural population to be served by 65 mini-grids by 2030. The corresponding installed capacity is 134 MW based on the plan's targets and estimated trajectory.

The **Renewable Energy Policy of Sierra Leone 2016** showcases the government's commitment to mini-grids as a way of electrifying the rural parts of the country and proposes a series of measures aimed at strengthening the institutional capacity for planning and implementing mini-grids, promoting the training of local agencies for operation and maintenance of mini-grids and sensitising local communities on the benefits of renewable energy mini-grid projects.

Finally, the updated **National Energy Policy 2019** acknowledges the issue of limited electricity access in rural areas and its negative impact on economic activity (including agriculture and business), gender equality and poverty. In this context, the policy clearly states the government's intention to develop mini-grids through public–private partnership arrangements to increase electricity access in rural areas.

A1.3 Regulatory framework

The Sierra Leone Electricity and Water Regulatory Commission Act 2011 established the body responsible for regulating the provision of electricity (and water) services and set out the guiding principles for the licensing of such services.

A1.3.1 Mini-grid regulations

The regulatory framework for mini-grids is set out by the **Sierra Leone Electricity and Water Regulatory Commission (SLEWRC) Mini-Grid Regulations 2019**, which applies to both isolated and interconnected mini-grids.

[179] SEforALL. 2023. Understanding mini-grid tariffs in Sierra Leone: A Quantitative and Comparative Analysis of Price Drivers.

The 2019 mini-grid regulations simplify the mini-grid regulatory and tariff setting framework, allowing for two licence categories and cost-reflective tariffs.

Basic and full licence

The regulations draw a distinction between a basic and a full mini-grid licence by setting a threshold of cumulative distributed power of up to 100 kW, above which a full licence is required. This distinction is crucial in practice, as it influences the regulatory treatment of mini-grids in terms of tariff setting and grid interconnection.

A **basic mini-grid licence** applies to isolated systems of up to 100 kW and includes a generation licence and a sale licence for an otherwise unserved area, while a **full mini-grid licence** applies to mini-grid projects between 100 kW and 10 MW and includes a generation, a distribution and a sale licence for a designated unserved area.

The Commission can also approve an **interconnected mini-grid contract** signed with a main grid utility to construct, install and operate an interconnected mini-grid in an underserved area.

Licensing

The regulations clearly set out the licence application process, including the relevant fees and required forms for a basic and full licence, as well as for a licence covering multiple sites. **The short timeframe within which a decision needs to be made by the Commission ensures the efficiency of the licence application process.** More specifically, the Commission has 30 days to decide on the licence upon receiving the application or the additional documentation requested for the application's completeness.

To approve the application, the Commission assesses, apart from the completeness and accuracy of the application itself, the **financial, technical and managerial capability** of the applicant.

The regulations specify two reasons for suspension, cancellation or revocation of a licence, namely a breach of the terms and conditions of the licence and "public interest". The latter concept allows for a flexible legal interpretation and could cause uncertainty to potential investors, unless it is rarely applied in practice. The licence could also be cancelled or revoked if it is not utilised within a year of its granting.

The general conditions that have to be met by the licensee include:

- Provision of a service that is safe, adequate, efficient, reasonable and non-discriminatory.
- Compliance with the applicable standards[180] for activities related to the licence, including engineering, construction, commissioning, operation and maintenance.

[180] Generation Code and Distribution Code, or IEC standards, or British standards applicable at the time of application.

- Approval of tariffs by the Commission.
- The non-discriminatory provision of service is further defined as a requirement for the licensee to not discriminate "between consumers of the same category, or consumer categories or set terms which are unduly onerous". However, the regulation does allow for **tariff differentiation** based on differences related to load factor, power factor, the level and timing of peak demand, location, voltage and other relevant factors.
- The regulations set out a comprehensive consumer protection framework, including provisions for quality of service, accountability, health and safety, and environmental protection.

Grid arrival

Basic licence holders are required to decommission and remove their assets without any compensation, while full licence holders must either convert to an inter-connected mini-grid or transfer assets to the utility in return for financial compensation.

- **The regulations address the risk of grid arrival through clear provisions regarding compensation mechanisms.** The extent of protection differs depending on whether the licence is basic or full. In the former case, no compensation is required if a main grid utility or a full mini-grid licensee extends its distribution network to an area served by the basic licensee. Conversely, the full licensee is entitled to choose one of the following options:
- **Convert to an interconnected mini-grid** based on a mini-grid interconnection contract between the full mini-grid licensee and the main grid utility.
- **Transfer all assets that the main grid utility wishes to retain on the respective site in return for financial compensation** from the main grid utility before distribution grid arrival. The methodology for calculating the value of the assets offers three options, according to which the compensation should be equivalent to the following:
- **The residual value of privately financed assets after depreciation** (as calculated according to the tariff-setting methodology analysed further below), including privately financed assets transferred to the utility and privately financed assets decommissioned, removed and disposed by the utility from the mini-grid site.
- **The residual value of activated and amortised privately financed project development cost** for the mini-grid site (as calculated according to the tariff setting methodology analysed further below).
- **The audited revenue of the full mini-grid licensee** generated from the mini-grid for the 12 months before the grid arrival.

Tariffs

Tariff approval

- **The tariff approval process differs depending on whether the licence is basic or full.** For basic licences, the licensee can freely agree on a tariff with the consumers, subject to informing the appropriate community authority. Thus, the regulations follow a light-handed approach to regulating mini-grids of smaller capacity, without the need for regulatory approval. However, as is the case in many jurisdictions that have introduced exemptions from regulatory approval for smaller mini-grids, the Commission retains the right to review the tariffs if it receives a petition signed by 60 percent of the consumers of a community served by the licensee. For full licences, the Commission sets the tariffs by applying either the **standard tariff determination methodology** or a methodology that was requested by the licensee and approved by the Commission.

The standard tariff methodology follows a cost-plus approach that enables operators to recover their costs of service and a return on investment commensurate with the investment risk.

The standard tariff determination methodology entails a bottom-up calculation of the costs of service, adding a reasonable return on the privately financed regulatory asset base that adequately reflects the risks faced by the mini-grid operator. In particular, the methodology takes into account the costs related to private financing of the regulated services (power generation, distribution and sales activities), operation costs, depreciation, specific reserves for repair, replacement and extension, and taxes. In summary, the following formula is used for the calculation of the revenue requirement:

- *RR = O&M + D + T + (r * RAB) + (PRPM * E)*
- where RR is revenue requirement, O&M is operations and maintenance, D is depreciation, T is taxes, r is rate of return, RAB is regulatory asset base, PRPM is performance-related profit margin (SLE/kWh) reflecting grant financing and E is electricity sold (kWh).
- The **Multi-Year Tariff Order (MYTO) tool** is currently in use in Sierra Leone. Feedback from developers indicated that the tool does not allow for adjustments for currency depreciation and inflation over the five-year period. In addition, the tool is challenging to use for the purpose of reviewing applications and checking the model's inputs and outputs.[181]
- The financing structure (private finance, grant financing, etc.) is considered as part of the tariff-setting methodology. Only full mini-grid licences with more than 50 percent grant or donation for capital investment are eligible for the performance-related profit margin,

[181] SEforALL. 2023. Understanding mini-grid tariffs in Sierra Leone: A Quantitative and Comparative Analysis of Price Drivers.

and the higher the grant contribution the higher the performance-related profit margin per unit of electricity sold.

- Acknowledging the licensees' need to achieve commercial viability, the Commission can approve:
  - retail tariffs for specific consumer categories that take into account the ability to pay
  - a retail tariff structure based on the amount of electricity sold or the power provided/consumed or the number of connections (i.e. SLE/kWh, or SLE/kW, or SLE/connection), excluding technical losses, or
  - **connection charges** to be paid in instalments or fully charged upfront.

Tariff adjustments

For full mini-grid licences, adjustments can be made to the input parameters to reflect the actual values when there is deviation from the values of the tariff calculation.

A1.3.2 Finance Acts

The government of Sierra Leone has made considerable efforts to promote mini-grids through tax incentives. In particular, the key exemptions that have been implemented include an import duty exemption and a goods and services tax (GST) exemption for PV systems and equipment, a GST exemption for the consumption, supply or use of renewable energy from solar mini-grids and corporate tax relief for energy suppliers through mini-grids.

More specifically, the **Finance Act 2016** introduced a **waiver on import duty** (25 percent) for "PV system equipment and low energy or energy-efficient appliances that meet relevant International Electrotechnical Commission (IEC) global standards for resale or use by third parties", while the **Finance Act 2017** introduced their **exemption from GST** (15 percent).

Additionally, the **Finance Act 2021** introduced a **GST exemption** for the consumption, supply or use of renewable energy from solar mini-grids, as well as five-year **corporate tax relief** for suppliers of energy through solar mini-grids in Sierra Leone.

The introduction of the **Finance Act 2023** marks a partial reversal of this favourable fiscal treatment, as the 15 percent GST was reintroduced on all IEC-certified solar products. The import duty exemption, however, is still in place.

A1.3.3 Public Private Partnership Act

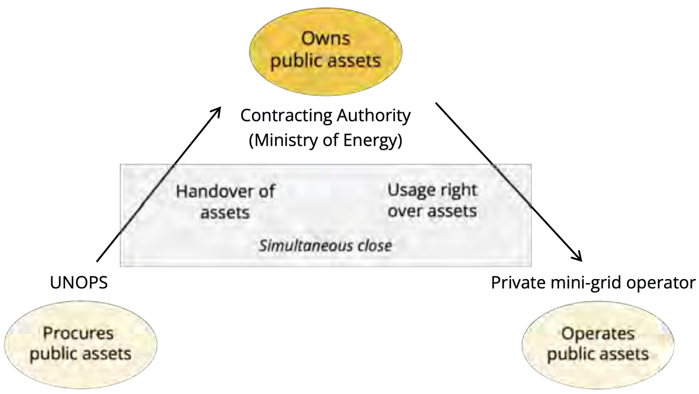
The **Public Private Partnership Act 2014** was introduced in order to promote, facilitate and streamline the implementation of public–private partnership (PPP) agreements and established the Public Private Partnership Unit, which provides transactional support to the Ministry of Energy. It is supported by the National Public Procurement Authority, in charge of regulating public tender processes, including mini-grid tenders.

A1.4 Economics

A1.4.1 Business models, tariffs and affordability

The **split-asset mini-grid delivery model** (shown in Figure 6.3) has been introduced under WP2 of the RREP to attract private financing, whereby distribution assets (including household connections) are financed and owned by the Ministry of Energy, while generation assets are financed and owned by the private sector.[182]

FIGURE 6.3 RREP (WP2) split-asset model



Source: IRENA. 2018. Policies and regulations for renewable energy mini-grids.

In practice, **the split-asset model is equivalent to providing in-kind subsidies** through UNOPS with FCDO funding, in the form of distribution assets, which are excluded from the regulatory asset base in the tariff model. This exclusion lowers the depreciation charge and the return on investment, leading, in turn, to lower end-user tariffs. The quantifiable impact on tariffs is dependent on the value of the distribution assets and the number of connections benefiting from the distribution grid.[183]

Table 6.1 shows the mini-grid tariffs charged by the three key operators of the systems installed through RREP, namely Winch Energy, Off-Grid Power (PowerGen) and Power Leone (Energicity). The average tariff (USD/kWh) in 2020-2021 was between **USD 0.74 and USD 0.82**.[184] The end-user tariff initially covered not only the generation assets and operational costs, but also the contribution of the private operators to a reserve account for the replacement and maintenance of publicly-financed assets.[185]

[182] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

[183] SEforALL. 2023. Understanding mini-grid tariffs in Sierra Leone: A Quantitative and Comparative Analysis of Price Drivers.

[184] SEforALL. 2023. Understanding mini-grid tariffs in Sierra Leone: A Quantitative and Comparative Analysis of Price Drivers.

[185] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

TABLE 6.1 Mini-grid tariffs for the three operators

WINCH ENERGY	POWERGEN	ENERGICITY
WP1		
• Flat tariff SLL 11,238/kWh	• Residential SLL 7,960/< 3 kWh • Residential SLL 6,000/> 3 kWh	• Residential SLL 6,128/kWh
WP2		
• Flat tariff SLL 7,329 /kWh	• Residential SLL 6,699/kWh • Productive User SLL 3,500/kWh	• Residential SLL 6,715/kWh • Large business SLL 7,482/kWh

Source: SLEWRC. n.d. Electricity mini-grids tariffs.

All three operators have adopted tariffs based on the units of energy consumed (per kWh), following complaints by the customers regarding the lack of transparency and financial flexibility over their consumption under alternative schemes, such as time- and energy-bound tariffs (allowed by the mini-grid regulations 2019).[186] Nevertheless, the impact evaluation[187] conducted after the first two phases of RREP revealed that people find the tariff structure unclear.[188] Thus, sensitisation in communities is necessary to familiarise community members with the tariff structure and connection fees.

Affordability has been a central issue in RREP,[189] with the low-income per capita of the rural population in Sierra Leone resulting in a low uptake of electricity, even for productive users, who have largely been relying on alternative sources of electricity, such as diesel gensets, to cover their electricity needs.[190] The average tariff is substantially higher compared to the main grid tariff, which stands at USD 0.21/kWh for the normal band of residential customers (consumption between 25 kWh and 200 kWh).[191] The government of Sierra Leone has acknowledged the issue and has taken steps to improve affordability, including financing the reserve account for public asset replacement and maintenance for four years of operation (2020-2023) through donor funds.[192]

Based on the aforementioned impact evaluation, connection rates were high in the first phase of RREP, with 65 percent of respondents being connected. A typical connection fee was approximately USD 13.64, while households paid approximately USD 0.30 on average per day on electricity consumption.[193]

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[186] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

[187] Based on data collected during baseline (2019) and end-line (2021) surveys, using a representative sample of households in communities where mini-grids have been installed versus a representative sample of households in statistically similar communities where no mini-grid was installed. In total, 6,010 households across 14 of Sierra Leone's 16 districts were interviewed.

[188] UNOPS. 2022. Policy brief: Improving access to renewable energy in rural Sierra Leone.

[189] UNOPS. 2021. Project dashboard.

[190] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

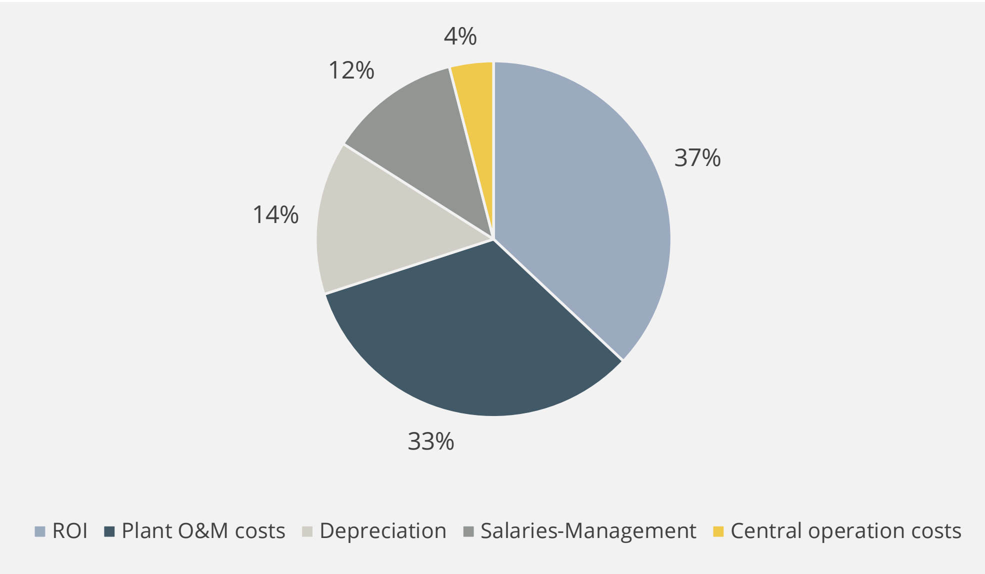
[191] Sierra Leone Electricity and Water Regulatory Commission. Approved tariffs for ESDA.

[192] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

[193] UNOPS. 2022. Policy brief: Improving access to renewable energy in rural Sierra Leone.

Recent macroeconomic challenges, including high inflation and local currency depreciation have further exacerbated the affordability of tariffs. Figure 6.4 presents the main cost components of tariffs as an average for the three operators (Winch Energy, PowerGen and Energicity). The main cost contributors are the return on investment and the plant O&M costs. Given the affordability issues, financing support to reduce tariffs should be targeted at those cost components. The local currency depreciation should be taken into account when selecting a suitable financing instrument, because lower tariffs in US dollar terms would not translate into any gains for end users in real terms if they are not shielded from foreign exchange losses.

FIGURE 6.4 Tariff cost build-up based on average costs of the three operators



Note: ROI stands for return on investment.

Source: SEforALL. 2023. Understanding mini-grid tariffs in Sierra Leone: A Quantitative and Comparative Analysis of Price Drivers.

By comparison, economic sustainability rather than affordability has been the main issue for the operation of the mini-grids developed under the PRESS-D project. The PRESS-D tariff varied between regions according to the estimated affordability of the respective communities and the presence of commercial customers. In Segbwema, for instance, the tariffs include a fixed connection charge and an additional fee between SLL 2,500 and SLL 3,500/kWh (USD 0.3 to USD 0.42/kWh) depending on the customer category. Most customers[194] have a maximum usage allocation per day. The revenue is collected via prepaid and post-paid meters for residential and industrial/commercial clients respectively. The prepaid meters are set up as PAYG systems of 5 kWh, 28 kWh or 56 kWh, with the 5 kWh cards being the most popular. However, the tariffs are said to be too low to be self-sustainable and attract private sector interest, which has resulted on the PRESS-D mini-grids being highly dependent on donor funds for maintenance.[195]

[194] Except for industrial three-phase.

[195] AfDB. 2019. Mini-Grid Market Opportunity Assessment: Sierra Leone.

A1.4.2 PUE

To improve mini-grid economics and drive electricity demand in rural mini-grid communities, the RREP has focused on PUE under the supplier-offtaker model. UNOPS commissioned a feasibility study to identify productive use hotspots in Sierra Leone (30 kW systems and above), such as food processing, cold storage applications and fisheries, which could be anchor loads for the RREP mini-grids and support the long-term sustainability of the operations.[196] Emphasis was put on the supplier-offtaker model, whereby the energy service provider fills the demand gap by establishing and operating a commercial or industrial activity, serving as the primary offtaker for the mini-grid's electricity supply.[197] Under this model (explained in section 0), operators procure raw materials from the local community, process them to produce final goods using the electricity from their mini-grids, and sell them to a given market, typically in urban areas where demand is high.[198] This PUE business model creates a win-win scenario for both the operator and the community, as it integrates the mini-grid energy supply into the local economy, securing mini-grid energy consumption and improving both operators' and the community's revenue.

The feasibility study identified the following PUE applications in Sierra Leone: rice milling and processing, palm oil production, cassava processing, refrigeration for cold fish storage, and solar water pumping and irrigation. Under the RREP, WP1 did not provide any subsidies for PUE, while WP2 placed increased emphasis on PUE for site development. This was reflected in community consultations with potential productive use customers; under WP1, the main concerns were high tariffs, as well as the large distance between the mini-grid connection point and the location of their agricultural activities. Under WP2, the key barrier seemed to be the need for training and equipment financing.[199] To promote PUE applications, the government of Sierra Leone offered grants to potential productive users of electricity to acquire equipment that is to be utilised with the mini-grid's electricity.[200] A lease-to-own model could also be used to facilitate the acquisition of PUE equipment where the upfront cost of such equipment is prohibitive.

Mini-grid developers in Sierra Leone have also been promoting PUE. For instance, Energicity has played a key role in the Solar Harnessed Entrepreneurs (SHE) Project, which is supported by The Rockefeller Foundation and GEAPP. In particular, Energicity has been facilitating the leasing of freezers to women entrepreneurs in seven communities in Sierra Leone, creating avenues for them to earn more income.[201]

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[196] SEforALL. 2021. Increasing energy access in Sierra Leone: Mini-grid survey analysis on tariffs, subsidies and productive use.

[197] EPP Africa and Nordic Development Fund. 2019. Powering Productivity: Lessons in Green Growth from the EEP Africa Portfolio.

[198] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

[199] SEforALL. 2021. Increasing energy access in Sierra Leone: Mini-grid survey analysis on tariffs, subsidies and productive use.

[200] GIZ. 2020. Sierra Leone A Cost-Reflective Mini-Grid Tariff Framework.

[201] Energicity. 2022. Power Leone PUE Team Deploys Freezers in Moyamba Junction.

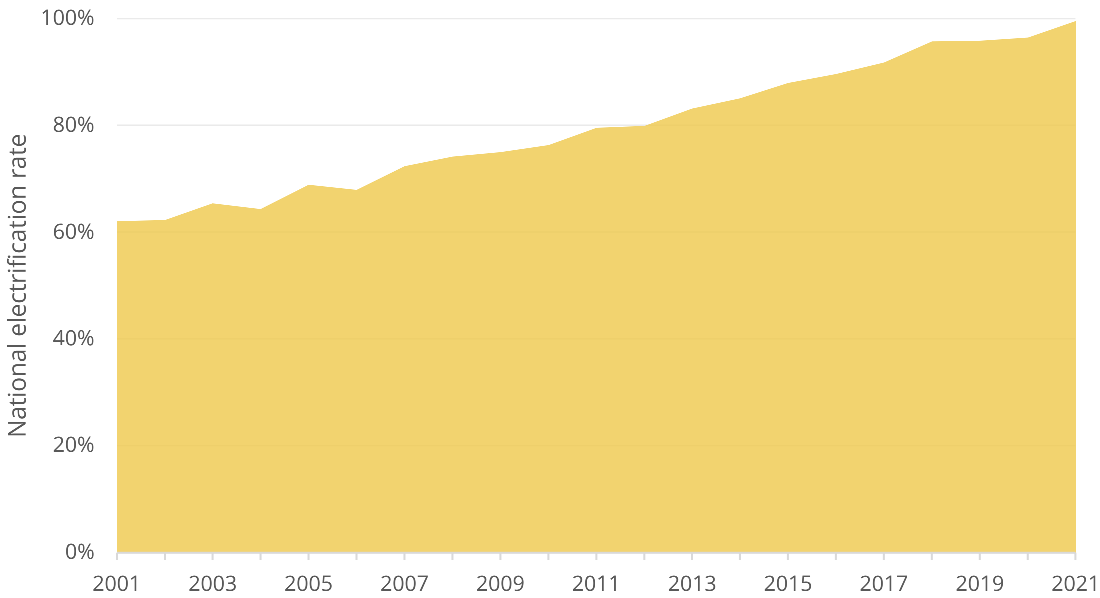
A2 India

A2.1 Country context

A2.1.1 Electrification rates

India's electrification progress has been notable. Official statistics report that just 0.01 percent of those residing in the country have yet to be electrified. In the past two decades, the percentage of the population with access to electricity has risen significantly, from just under 65 percent to near universal access.[202] This achievement is largely due to the government's ambitious rural electrification programmes, which have been successful in connecting even the most remote villages to the grid.

FIGURE 6.5 National electrification rate, India, 2001–2021



Source: The World Bank. 2024. Access to electricity (percent of population) – India.

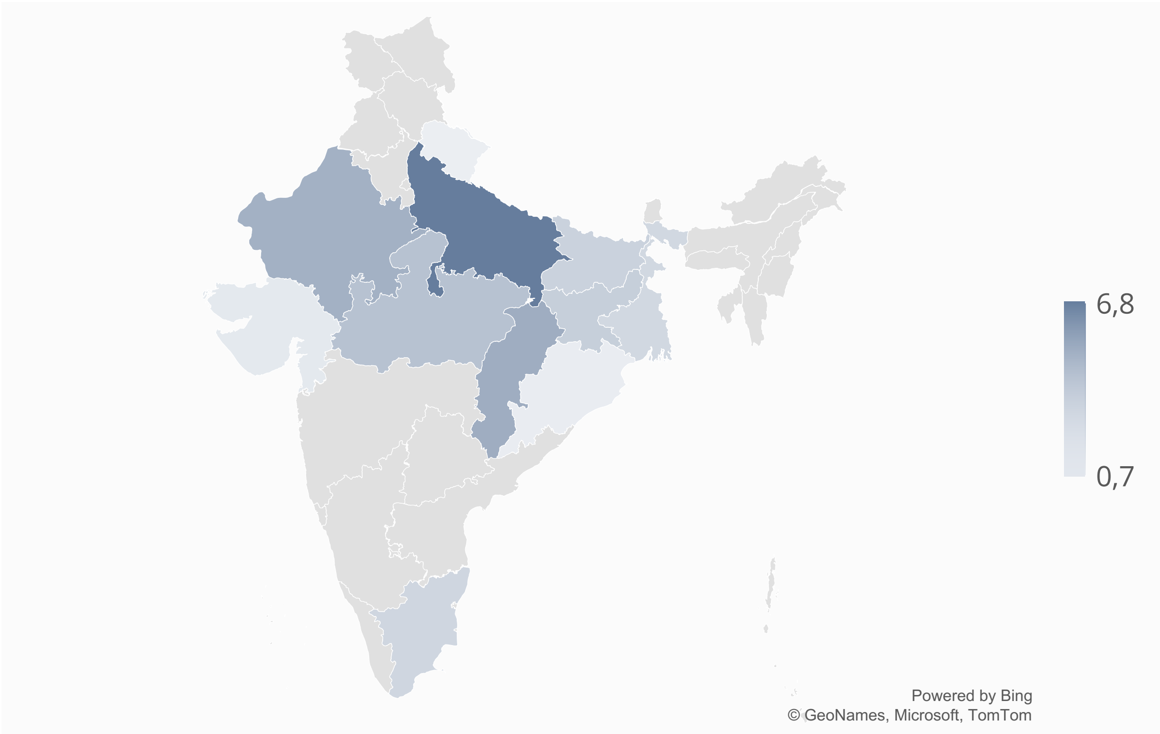
The Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY), initiated by the government of India in December 2014, has been a pivotal scheme for rural electrification across the country. As of February 2023 it was reported that a total of 18,374 villages were electrified under this scheme. For villages where grid connectivity was deemed infeasible or not cost-effective, electrification was pursued primarily via mini-grids.[203] Towards the end of the DDUGJY initiative, the Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya) scheme was launched (in September 2017) aiming to provide electricity connections to all remaining unelectrified households in rural areas

[202] The World Bank. 2024. Access to electricity (percent of population) – India.

[203] Ministry of Power. 2023. Status of DDUGJY.

and all poor households in urban areas. By March 2019 the Saubhagya dashboard stated that all "willing" households in India had been electrified.[204] However, alternative estimates for access to electricity therefore show a notable discrepancy with the official figures. The majority of unconnected homes are based in the north-central states of the country. As seen in Figure 6.6, some states feature relatively low levels of electrification—in contrast to the official claims of universal electrification.

FIGURE 6.6 Percentage of households without electricity access, India by state



Source: CEEW. 2020. State of Electricity Access in India.

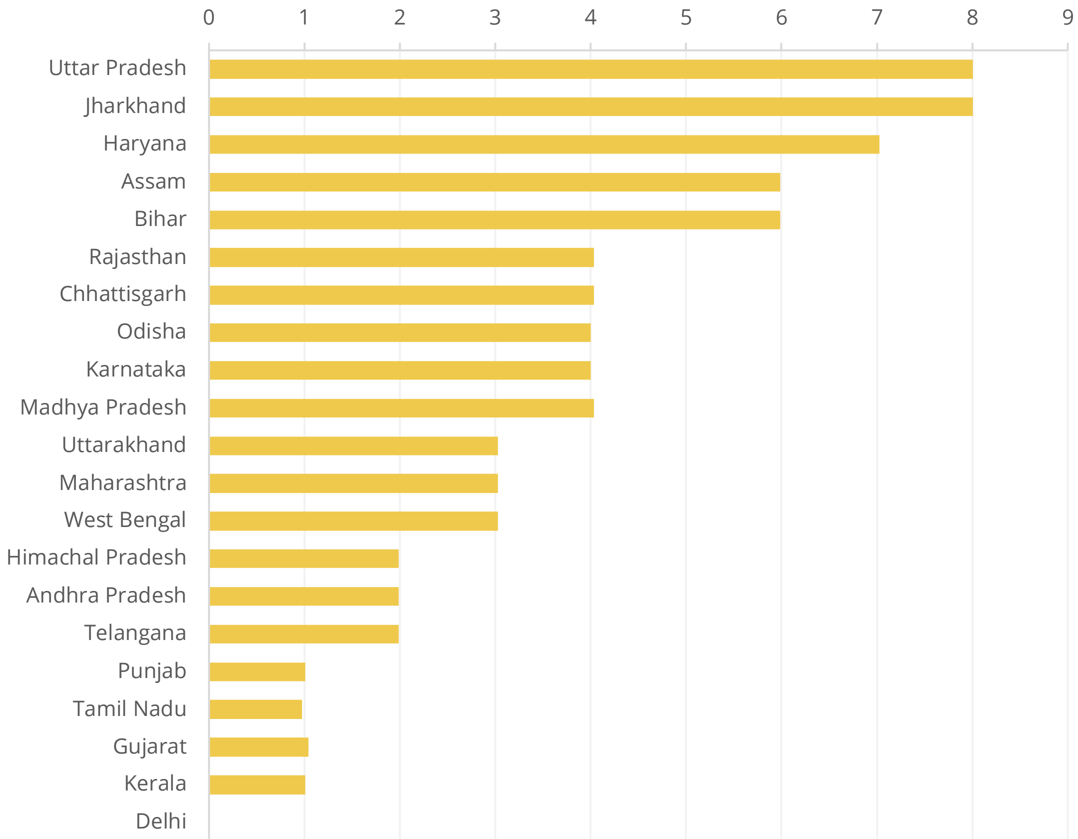
A2.1.2 Reliability of supply

Despite the high electrification rates, many households, particularly in rural areas, still face unreliable and intermittent power supply. Mini-grids have been identified as a key solution to address the issue of energy reliability. Reliability of electricity supply in India has seen significant improvements, but still varies across different regions. In states such as Bihar, for example, despite achieving nearly universal household electrification, the issue of intermittent power supply remains a persistent challenge.[205] Historically, consumers have experienced frequent and long power outages, with daily or weekly load shedding being common.

[204] CEEW. 2020. State of Electricity Access in India.

[205] RMI. 2024. Ensuring Grid Reliability in India.

FIGURE 6.7 Daily power cut, in hours, rural areas



Source: CEEW (2020) State of Electricity Access in India.

This situation has improved over the years, with the peak demand deficit dropping to as low as 0.8 percent in recent years, down from 16.6 percent in 2007, largely due to private sector investment in power generation infrastructure. Despite India being declared a power-surplus nation, the reliability of the electricity grid, particularly in peri-urban and rural areas, remains a challenge due to inadequate distribution infrastructure. The Ministry of Power introduced the Resource Adequacy Planning Framework in June 2023, focusing on ensuring that the power system minimises the risk of blackouts or brownouts. The framework establishes criteria across various factors, including the frequency of outages and the magnitude of outages, through metrics such as loss of load probability (LOLP) and normalised energy not served (NENS), aiming to improve reliability. It specifies that penalty values should be attached to operating reserve requirements.[206]

[206] Ministry of Power. 2021. Guidelines for Resource Adequacy Planning Framework for India.

A2.1.3 Key mini-grid operators and projects

There are several mini-grid operators currently in the Indian market. These range from large, megawatt-scale developers, to smaller, more bespoke companies. Some of the large operators (estimated to control a megawatt or above in productive capacity) include:

- **OMC Power**, which aims to provide and operate 5,000 renewable energy-based mini-grids, with generative capacity of 250 MW, to provide electricity to 50 million people in rural areas of Uttar Pradesh.[207]
- **Hamara Grid**, a relatively young company in the mini-grid space, having been established in July 2020, which already owns and operates 40 solar-powered mini-grids, with a capacity of 1 MW. [208]
- **Husk Power**, which operates over 150 mini-grids in India, primarily in the states of Uttar Pradesh and Bihar, and has over 10,000 customers, the majority of whom are commercial entities. Husk is targeting the operation of over 1,000 mini-grids in the next few years.[209]
- **Mlinda,** a Paris-based organisation with national headquarters in Kolkata, which focus primarily on the installation of solar-based mini-grids. By March 2020 Mlinda had installed 39 mini-grids across various villages, aiming to extend its impact by reaching 49 grids in 50 villages by March 2021.[210]

In some cases, the largest operators of mini-grids in India are driven by donor-funded organisations. The Rockefeller Foundation, for instance, set up Smart Power India, a subsidiary which has been responsible for electrifying just under 500 villages in the country, facilitating the world's largest portfolio of mini-grids.[211] It currently serves around 50,000 customers, 26,000 of which are primarily commercial entities.[212] The work of the organisation has primarily focused on electrification efforts in states such as Bihar, Uttar Pradesh and Jharkhand, areas with high rates of energy poverty. The Rockefeller Foundation has also worked alongside Tata Power, helping to form Tata Power Renewable Microgrid Ltd (TPRMG), the aim of which is to become the world's largest mini-grid developer and operator, with a target of 10,000 microgrids by 2026. If achieved, these mini-grids would provide power to potentially millions across India and could directly impact the lives of 25 million people over the next decade.[213] TPRMG has made significant progress, with 200 operational microgrids by 31 March 2023, within three years of

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[207] OMC Power. 2021. OMC raises USD 12M funding and Impact Contribution to Renewable Energy based Access to Promote Reliable Energy in Rural India.

[208] Hamara Grid. 2024. About Us.

[209] Gupta, U. 2023. Minigrid operator Husk Power achieves profitability with India leading the way.

[210] Mlinda. 2024. Renewable Energy for Rural Communities.

[211] The India Times. 2021. Smart Power India facilitates world's largest portfolio of mini grids.

[212] The Rockefeller Foundation. 2024. Smart Power India.

[213] Tata Power. 2019. Tata Power and The Rockefeller Foundation Announce Breakthrough Enterprise to Empower Million of Indians with Renewable Microgrid Electricity.

its creation. TPRMG plans to install microgrids in other states, such as Assam, Jharkhand, Madhya Pradesh and Odisha.[214]

In addition, various state government entities have financed the creation and operation of mini-grids. However, of the several thousand government-created mini grids, only an estimated 5 to 10 percent are still operating.[215]

A2.2 Policy framework

The Ministry of New and Renewable Energy (MNRE) in India plays a pivotal role in promoting the adoption of renewable energy sources, with a significant focus on the development and deployment of mini-grids in rural areas. These mini-grids are essential for providing reliable and sustainable electricity to communities not served by the national grid. By establishing guidelines and offering financial incentives, the MNRE aims to encourage private investment in mini-grid projects. This effort is part of India's broader strategy to achieve universal electrification and reduce the country's carbon footprint, highlighting the government's commitment to leveraging renewable energy for sustainable development. The MNRE has actively supported several projects and schemes aimed at accelerating the deployment of mini-grids across India.

The policy framework is supportive of mini-grid investments. The National Electricity Policy and the Rural Electrification Policy support the option of decentralised distributed generation with local distribution networks when grid extension is not feasible,[216] providing wider confidence to the sector. Mini-grid policy in India is however often decentralised, with states left to design their own individual policies, both regarding targets, subsidies and supported business models. Figure 6.8 below highlights some of the key aspects of policies, as noted by the Centre for Science and Environment in India.[217]

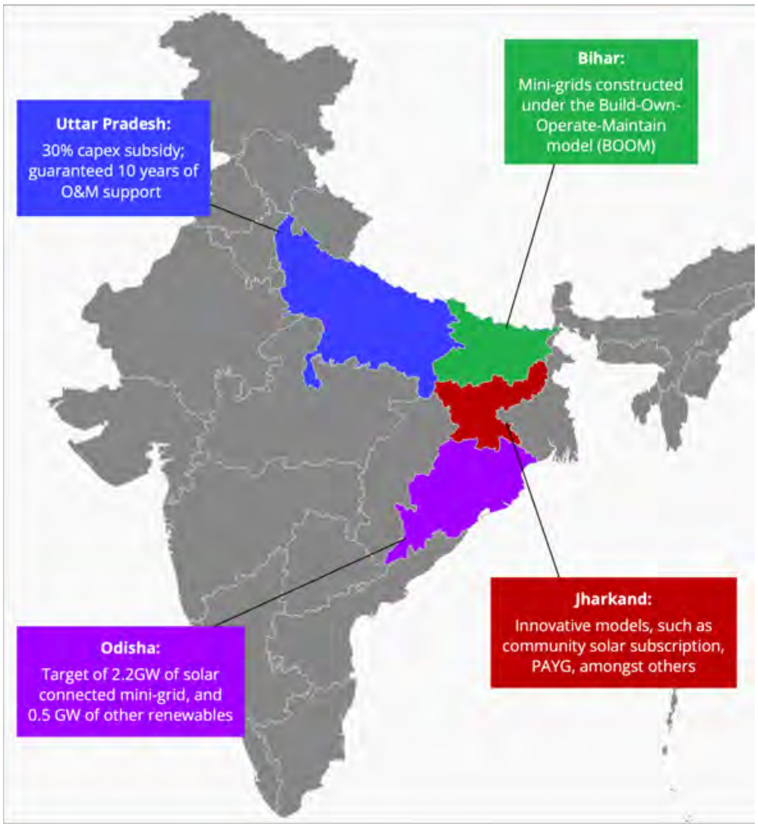
[214] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

[215] Washington Post. 2023. Most of India's rural solar systems no longer work due to poor maintenance.

[216] Bhattacharyya et al. 2019. Solar PV mini-grids versus large-scale embedded PV generation: A case study of Uttar Pradesh (India).

[217] Centre for Science and Environment. 2022. Mini-Grids a Just and Clean Energy Transition.

FIGURE 6.8 Mini-grid policy in India, across states



A2.3 Regulatory framework

In terms of the national regulatory framework, the Electricity Act 2003 allows rural-based mini-grids to be built and operated without obtaining regulatory licensing. In addition, if rural-based mini grids are unlicensed, the state regulator is not allowed to regulate their tariffs. Therefore, retail tariffs charged by mini-grids are effectively deregulated in India. In addition, the Rural Electrification Policy enabled privately owned and operated mini-grids to charge tariffs on a basis mutually agreed upon by the supplier and the consumers.[218] The new tariff policy (2016) has also allowed for the purchase of power by the grid as and when the grid reaches the village.[219]

In addition to the national framework, various state governments have also established regulations to guide the development of mini-grids within the states. For instance, in 2016 the Uttar Pradesh government published its mini-grid policy and the Uttar Pradesh Electricity Regulatory Commission issued the Mini-Grid Renewable Energy Generation and Supply Regulations. The policy and the regulations include provisions for a government subsidy to support mini-grid development, provide exit options to mitigate the risk of grid arrival, and

[218] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

[219] Bhattacharyya et al. 2019. Solar PV mini-grids versus large-scale embedded PV generation: A case study of Uttar Pradesh (India).

specify tariff and supply quality requirements.[220] This policy initiative led to the installation of approximately 206 mini-grid systems in the year following its implementation. The state has since demonstrated significant progress in rural electrification, boasting around 1,850 operational solar and biomass mini-grids. These installations collectively contribute a capacity of roughly 3 MW, highlighting the state's commitment to expanding energy access.[221]

A2.4 Economics

A2.4.1 Business models, tariffs and affordability

In the private sector, build-own-operate-maintain (BOOM) models, or variations of them, are the primary vehicle for private sector mini-grids in India. Alternative forms of this model include build-own-maintain (BOM), and build-maintain (BM). These models conceptually allow developers to take a more controlled approach to the system and its eventual business proposition. In contrast, build-operate-transfer models tend to be the least common, for that same reason.[222]

Those mini-grids that are publicly supported or operated employ community-based models, which generally include Village Energy Committees, or Rural-Electricity Cooperatives. For instance, the West Bengal Renewable Energy Development Agency (WBREDA)[223] has driven a number of mini-grid projects in the region. Private developers are tasked with the installation and oversight of these systems, while the responsibility for setting tariffs lies with the community, done in consultation with WBREDA. These tariffs are collected by the community and then passed on to WBREDA. The initial capex costs for these systems are jointly covered by WBREDA and the MNRE, each bearing an equal share of the expense. Operational and maintenance costs, on the other hand, are funded via tariffs collected from the consumers.[224]

Other community-based models involve a more proactive role for the government agency. For instance, the Chhattisgarh Renewable Energy Development Agency (CREDA) oversees the operation and management of mini-grids, but also selects a local village operator for ongoing maintenance tasks. These include monthly cleaning, operating the systems at designated times, and reporting any technical issues to the authorities. The village operator is compensated with a fixed monthly salary for its services. Oversight and maintenance of mini-grid installations are further supported by an official responsible for the replacement of damaged equipment. The financial model underpinning CREDA's operations allows for the

[220] Bhattacharyya et al. 2019. Solar PV mini-grids versus large-scale embedded PV generation: A case study of Uttar Pradesh (India).

[221] Zebra, E. I. C., et. al. 2021. A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries.

[222] Power for All. 2018. Mini-Grids in India: Mini-Grid Finance and Business Models.

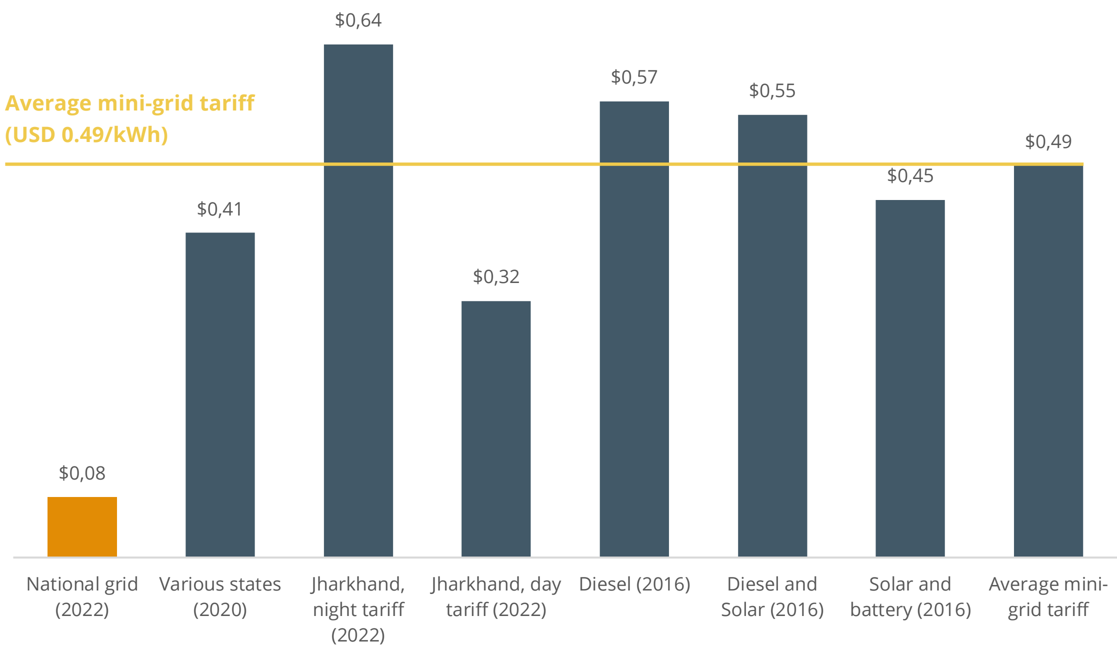
[223] USAID. 2020. Island Mini-Grids in West Bengal.

[224] Zebra, E. I. C., et. al. 2021. A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries.

coverage of capital and operational maintenance costs by the state and MNRE, resulting in minimal fees for end-users.

Mini-grid tariff prices are significantly higher than those of the main electricity grid, but often offer greater reliability, alongside servicing hard-to-reach areas. As discussed earlier in the case study, both the national electricity grid and the local distribution grids are frequently unreliable and often disrupted. Mini-grid tariffs for consumers are a result of the combination of the policy environment, subsidies and regulatory costs, alongside the fundamental costs of building and running a mini-grid. Ultimately, these, combined with the comparative economies of scale that a national grid is able to access, create a huge disparity between mini-grid tariffs and the price charged by the grid (Figure 6.9).

FIGURE 6.9 Analysis of mini-grid tariff rates in India, from various sources



Sources: National grid, and "Various states": Sharma, K. R. et. al. 2020. Mini grids and enterprise development: A study of aspirational change and business outcomes among rural enterprise owners in India. Jharkhand day and night tariffs: McNamara, M. et. al. 2022. Can Time-of-Use Tariffs Increase the Financial Viability of Mini-Grids?. Diesel, Diesel and Solar, and Solar and Battery: Comello, S. D. et. al. 2015. Enabling Mini-grid Development in Rural India.

Efforts have been made to address the issue of tariff affordability through subsidies. For instance, the Uttar Pradesh government, through the introduction of the state mini-grid policy in 2016 (also see section A2.2 above), aimed to encourage the development of a financially viable mini-grid sector by offering 30 percent state subsidy to mini-grid developers in addition to the central government subsidy of 30 percent. In turn, the policy imposes limits on household tariffs, which are only applicable to projects that use this state government funding. For all other projects, tariffs are allowed to be set at a rate mutually agreed upon by developers and consumers. The policy has been unsuccessful, given that developers consider the subsidy to be inadequate to make the mandated tariff viable.[225]

A2.4.2 PUE

There is a growing wealth of evidence pointing towards the positive relationship between PUE-driven initiatives and mini-grid viability—something also found in the Indian context. Businesses in particular stand to benefit from electrical connections, paving the way for increased productivity and consumption, and better business outcomes. Studies have indicated that in some parts of India, solar irrigation systems, combined with electric pumps, increased crop yields by almost 70 percent.[226] Research also indicates that the time gained from the automation of agricultural tasks, which are often performed by women and girls, can have positive outcomes across a wider spectrum of socio-economic indicators.[227]

Private mini-grid developers in India are actively promoting PUE through dedicated programmes in the communities that they serve. For instance, Husk finances the purchase of energy-efficient machinery for productive uses, such as for refrigeration, ice cream production, and rice and maize milling. In addition, TPRMG recently launched a programme to encourage farmers to switch from diesel-powered irrigation pumps to electric pumps, which can lead to savings of up to 30-35 percent compared to their current irrigation costs. TPRMG also offers movable flexible piping, which allows farmers to resell pumped water to neighbouring farmers and earn additional income.[228]

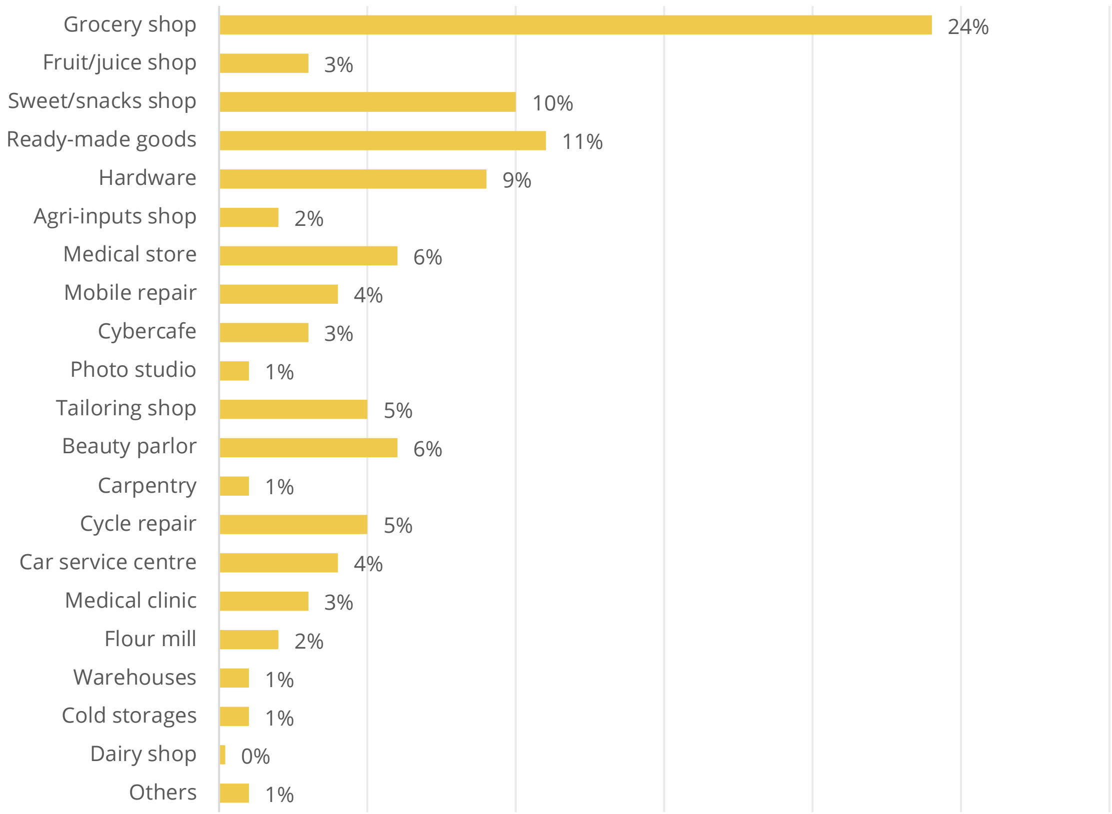
[225] Centre for Science and Environment. 2018. Mini-grids in Uttar Pradesh: Policy Lessons.

[226] ESMAP. 2023. Accelerating the Productive use of electricity.

[227] Power for All. 2020. Mini-grids productive use of energy (PUE) in agriculture.

[228] Tenenbaum, Bernard, Chris Greacen and Ashish Shrestha. 2024. Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India.

FIGURE 6.10 Distribution of rural enterprises in India



Source: Rockefeller Foundation. 2019. Rural Electrification in India, Customer Behaviour and Demand.

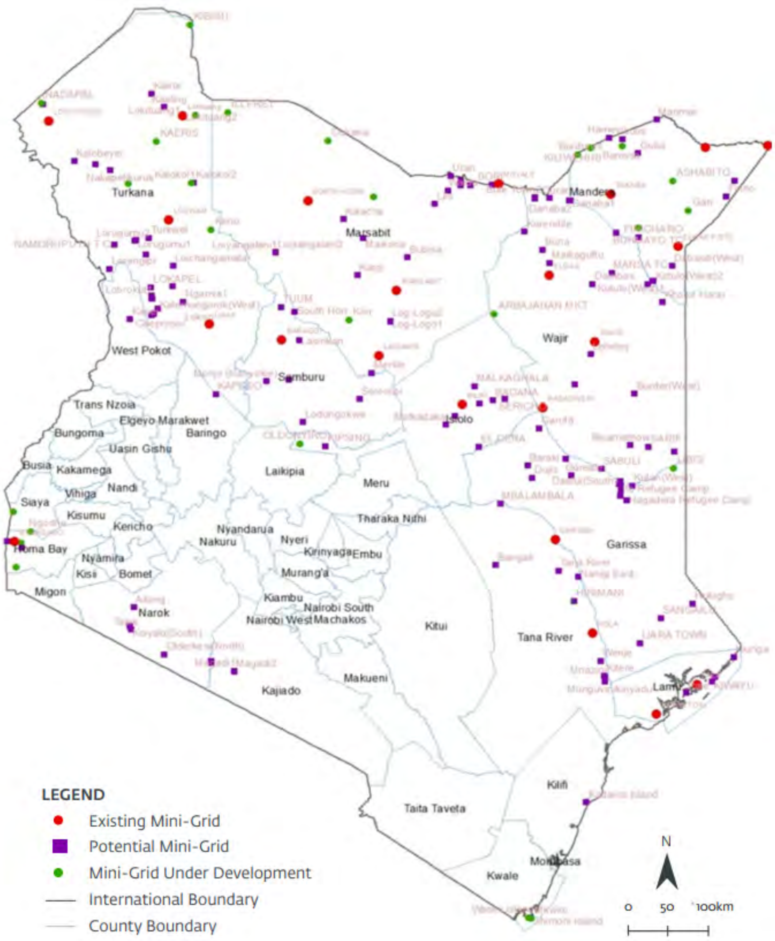
A3 Kenya

A3.1 Country context

A3.1.1 Electrification

Kenya's journey towards electrification has seen remarkable progress from a mere 25 percent access in 2010 to over 70 percent by 2019, divided between grid (51 percent) and off-grid solutions. This leap has been facilitated by concerted efforts from the government of Kenya, development partners and the private sector through a number of rural electrification initiatives. Looking ahead, Kenya plans to develop more than 400 mini-grids to achieve universal access,[229] in addition to the existing ones, as shown in Figure 6.11.

FIGURE 6.11 Existing and potential mini-grids



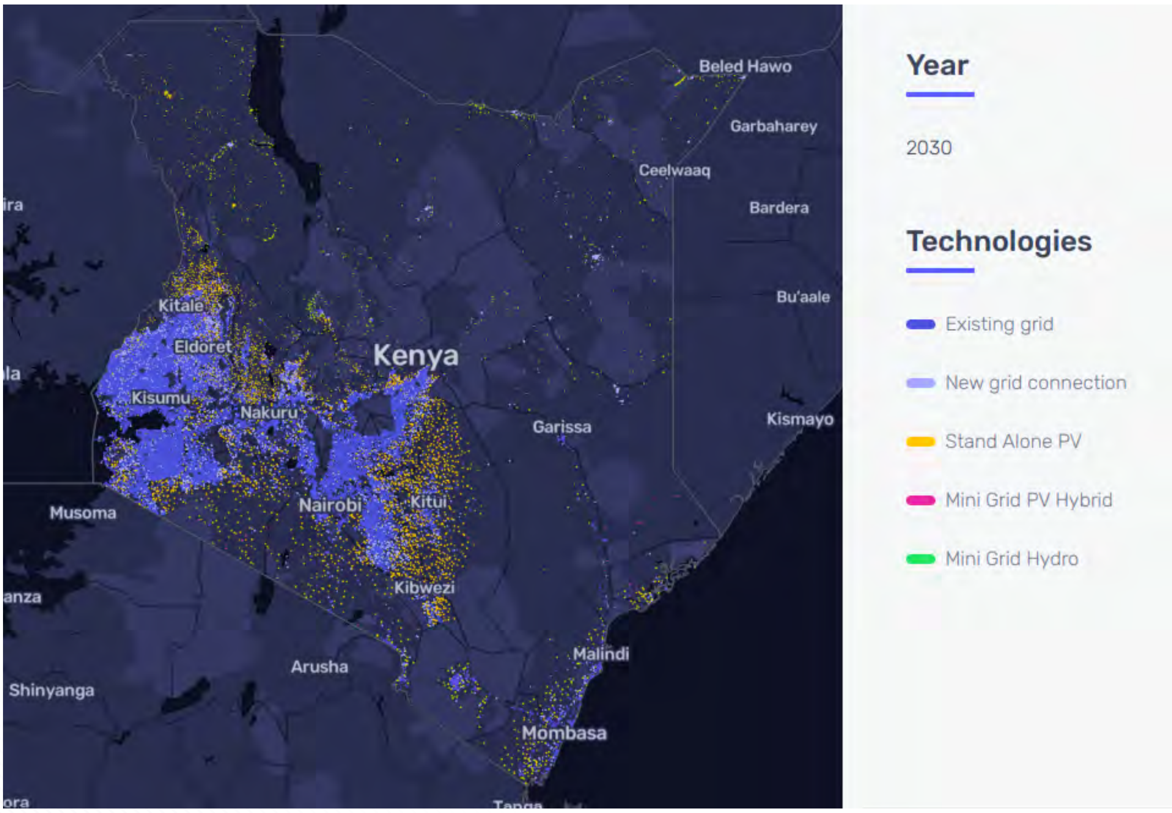
Source: World Bank. 2018. Kenya National Electrification Strategy.

[229] ESMAP. 2023. Expanding Mini Grids for Economic Growth.

Important electrification initiatives include the Last Mile Connectivity Project, financed by the African Development Bank. Its third phase was approved in 2023 and builds on the successful implementation of the first two phases, which provided grid electricity for more than 1.05 million and nearly 1.6 million people, respectively.[230] The programme is spearheaded by the Ministry of Energy and Petroleum and implemented by Kenya Power and the Rural Electrification and Renewable Energy Corporation (REREC).

Figure 6.12 presents the strategy for full electrification of the country by 2030, as presented in the Global Electrification Platform. To reach universal access by 2030 on a least-cost basis, PV hybrid mini-grids need to electrify 1.3 million people, with an additional 13,000 people connected through hydro mini-grids. In terms of PV hybrid and hydro mini-grids, 125 MW and 2 MW of added capacity respectively is required by 2030 (out of a total 1,711 MW of added capacity). The corresponding investment required by 2030 is USD 281 million for PV hybrid and USD 7 million for hydro mini-grids.

FIGURE 6.12 Kenya least-cost electrification plan



Source: Global Electrification Platform.

[230] AfDB. 2023. Kenya: African Development Bank commits more than €101 million to boost access to electricity.

A3.1.2 Key mini-grid operators and projects

Kenya is one of the few countries worldwide where mini-grids serve more than 2 million people.[231] The first mini-grids in Kenya were developed in the 1980s to supply government administrative centres that were far from the main grid.[232] Currently, Kenya has around 500 mini-grids in operation or under construction (of which, 324 are PV-based), mainly serving rural areas. In terms of technology, these mini-grids typically combine solar PV generation with battery energy storage, as well as a diesel generator for back-up power supply.[233]

The Kenyan mini-grid sector has witnessed significant growth over the past decade, with a mix of public, private and community-led initiatives. There is a limited number of public sector larger-scale mini-grids in Kenya. The majority of these are owned by REREC and managed by Kenya Power, while a few are owned and managed by the Kenya Electricity Generating Company (KenGen).[234] Most public mini-grids are diesel-powered, while a few of them have been retrofitted with a renewable energy component. The KenGen-operated mini-grids have been connected to the national grid.[235]

In addition, Kenya has witnessed the emergence of numerous private sector mini-grid projects, generally at a smaller scale than the public systems, with more than 50 operational private mini-grids and 150 under development.[236] The most prominent actors in the market are PowerGen and Powerhive, the first mini-grid developer to secure a licence in 2016. So far, the company has installed 24 operational grids with a total generating capacity of 0.9 MW, resulting in over 24,800 people gaining access to electricity for the first time.[237]

The World Bank's flagship **KOSAP** has been the key mini-grid programme in the country, targeting 14 of the 47 counties in Kenya, which have been identified as remote and underserved areas. The first component of the project (on mini-grids) aimed to mobilise investment in a total of 120 geospatially identified mini-grid locations, with each site having 100-700 prospective users and demand of 20 kW to 300 kW.[238] Depending on the number of users and the service level defined for each type of user (households, businesses, community facilities), the mini-grids' generation system will combine solar PV, battery storage and diesel generators.[239] The programme has been restructured through the years, now targeting 150 new mini-grids in areas with low electricity access rates.[240]

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[231] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[232] EPRA. 2021. Minigrid Regulations Regulatory Impact Statement.

[233] Energies. 2023. Modelling and Validation of Typical PV Mini-Grids in Kenya: Experience from RESILIENT Project.

[234] New Climate. 2019 The role of renewable energy mini-grids in Kenya's electricity sector.

[235] New Climate. 2019. The role of renewable energy mini-grids in Kenya's electricity sector.

[236] ESMAP. 2023. Expanding Mini Grids for Economic Growth.

[237] REPP. n.d. Powerhive.

[238] OECD. 2023. The World Bank Off-Grid Solar Access Project.

[239] World Bank. 2017. Project Appraisal Document: Off-Grid Solar Access Project for Underserved Counties.

[240] World Bank. 2023. Solar Mini Grids Could Sustainably Power 380 million People in Africa by 2030 – if Action is Taken Now.

The proposed project was designed around three core principles: diversification, private sector participation, and flexibility. The first refers to the diverse nature of beneficiaries, including households, public institutions and county offices. The second principle focuses on encouraging private sector participation and investment in order to reach a larger number of beneficiaries, maximise project impact and promote long-term sustainability. Finally, the third principle acknowledges the rapidly evolving market dynamics of the mini-grid sector by incorporating flexibility in the preferred approaches. Thus, the project aims to leverage the comparative advantages of both public and private sectors so as to maximise the likelihood of success.[241]

A3.2 Policy framework

The critical role of mini-grids in achieving national electrification and renewable energy goals is highlighted by the **Kenya National Electrification Strategy 2018**, which proposes a mix of 70 percent grid and 30 percent off-grid solutions, including mini-grids and standalone solar systems, to achieve universal access by 2030. In particular, the strategy set a target of 35,000 connections to be achieved through 121 new mini-grids that would serve housing clusters too distant from the network or too small to be connected to the national grid.[242]

Kenya's Energy Act 2019 laid a robust foundation for the development of mini-grids, introducing clear regulations and guidelines. The act provides for the establishment, licensing and operation of mini-grids, alongside tariffs and subsidy mechanisms to ensure affordability and encourage private sector investment.

Overall, the Kenyan government has clearly acknowledged the vital role of mini-grids in reaching its universal electrification target and has made efforts to establish the required enabling environment to attract private investment flows to the sector. Through REREC, the government has also implemented various initiatives to support the development of mini-grids.

A3.3 Regulatory framework

Kenya established updated mini-grid regulations in 2021,[243] which include comprehensive provisions covering all major aspects of mini-grid development. The regulations were the result of extensive public consultation, as well as feedback from the Renewable Energy Performance Platform on improving the "bankability" of the draft regulations. The aim of the regulations was to harmonise the mini-grid approval requirements of the national government, county governments and relevant regulatory bodies; provide a clear and competitive process for mini-grid site reservation, licensing and interconnection to the main grid; outline the principles and process of mini-grid tariff approval; and provide the technical and reporting requirements for

[241] World Bank. 2017. Project Appraisal Document: Off-Grid Solar Access Project for Underserved Counties.

[242] World Bank. 2018. Kenya National Electrification Strategy.

[243] EPRA. 2021. Mini-grid regulations 2021.

their safe and efficient operation.[244] However, the regulations have yet to be gazetted, which creates significant uncertainty for the private sector.[245]

Speed of regulatory processes

The first key feature of the new regulations is the speed and efficiency of the regulatory processes, given the need for minimising project costs and, in turn, tariffs, as discussed in section 2.2. The regulations specify short timeframes for a number of processes, including:

- Approval of the expression of interest and granting of exclusive site reservation and allocation—within 15 days of submission of complete information.
- Tariff approval—within 60 days of receipt of the tariff application (and other required documents).
- Approval of licence application—within 60 days of the date of application.
- However, there have been complications regarding land acquisition, because many of the potential mini-grid sites are in areas that have not been formally registered under the Ministry of Lands, Public Works, Housing and Urban Development.[246]

Distinction between private and public mini-grids regarding tariff setting

The Energy Act 2019 mandates that the Energy and Petroleum Regulatory Authority needs to ensure tariffs are just and reasonable from the interests of both investors and consumers. Thus, a balancing exercise is required to align tariffs with consumers' ability and willingness to pay, and business sustainability, as well as broader political considerations.

- The regulations draw a distinction between public and private mini-grids, whereby public mini-grids, i.e. those being developed using public funds or in partnership with a development partner, are subject to the national uniform tariff.[247] This model requires subsidies, explored in section A3.4.1. In contrast, private mini-grids are allowed to set cost recovery tariffs according to a standardised tariff model, following a building block approach.[248] The tariff control period is three years from the date of approval.

[244] EPRA. 2021. Minigrid Regulations Regulatory Impact Statement.

[245] Consultant's interview with the World Bank.

[246] Consultant's interview with the World Bank.

[247] EPRA. 2021. Mini-grid regulations 2021.

[248] EPRA. n.d. Standard Tariff Application Model for Minigrids.

Increased focus on consumer protection

The regulations have strengthened consumer protection provisions through a comprehensive Consumer Service Charter, which covers aspects including:

- Process of application for connection of electricity supply to the consumer
- Timeframes for connection to electricity after application
- Expected quality of supply and quality of service parameters
- Determination and payment for electricity supplied
- Consumer obligations and rights
- Attendance to the consumer in service centres, or through community-based consumer service agents.

Interconnection arrangements

Clarity is key when setting out provisions for compensation in case of grid arrival, to ensure investments are repaid. The regulations grant considerable flexibility in the selection of interconnection business models; the mini-grid developer can choose to operate as:

- A power producer selling to the distribution licensee
- A power distributor that purchases power in bulk from the distribution licensee and resells that electricity to the consumers under an energy supply agreement
- Both a power producer and power distributor—the mini-grid operator remains the power distributor for the area and purchases power from the distribution licensee in addition to its existing generation, and sells power to the consumers
- Any other operating model as approved by the authority

1. Alternatively, the mini-grid operator can remove the distribution assets, or sell these assets to the distribution licensee

In terms of compensation, the isolated mini-grid operator is to negotiate compensation before the handover of the mini-grid's assets as approved by the authority, based on the remaining depreciated value of the assets (including construction and development costs), plus any revenue the mini-grid operator is owed by consumers but has not yet received up until the date of the transfer of assets.

In practice, it is not clear whether these interconnection arrangements have been fully implemented, given that the regulations are not yet gazetted, as mentioned earlier. For instance, a developer has not been able to receive compensation following grid encroachment, which has created uncertainty among private sector players.[249]

A3.4 Economics

A3.4.1 Business models, tariffs and affordability

The government of Kenya has largely implemented a public sector-led business model for mini-grids, whereby the private sector is responsible for engineering, procurement, and construction (EPC), while the ownership of the assets, as well as operation and maintenance, lies with the public sector.[250]

Nonetheless, the government has also fostered an environment conducive to private sector participation beyond EPC, with more than 50 private mini-grids being operational and 150 under development.[251]

Finally, hybrid models have also been tested. For instance, under a GIZ-funded pilot project, a solar-diesel mini-grid was constructed at Talek, in Narok county, and handed over to the Narok county government upon completion. The national government then contracted a private operator, PowerGen, to maintain and operate it.[252] This model of public ownership and private operation paved the way for the PPP approach under the World Bank's KOSAP project.[253]

KOSAP envisioned a transition away from purely public or private mini-grids towards is a **PPP approach**. Under this approach, generation assets would be co-financed through private investment and public funds, while distribution assets would be constructed using public funding. The construction (and partial financing) of the generation system and the construction of the distribution network would be the responsibility of a private service provider, under two long-term contracts with Kenya Power:

- A seven to ten-year Power Purchase Agreement for the O&M of the generation system and recovery of the privately financed part of the investment
- A seven to ten-year service contract for O&M of the distribution network.

Once the private investment for the generation assets is recovered, ownership of all assets (both generation and distribution) is transferred to the government of Kenya.

The selected sites, capturing approximately 27,000 consumers in total, were split into lots/service territories, which comprise 20 or more proposed mini-grids located in geographically contiguous areas, with 2,000 or more potential customers. **To enhance**

[249] Consultant's interview with the World Bank.

[250] ESMAP. 2023. Expanding Mini Grids for Economic Growth.

[251] ESMAP. 2023. Expanding Mini Grids for Economic Growth.

[252] Chatham House. 2019. Beyond Construction: The Challenges of Deploying Mini-Grids in Kenya.

[253] New Climate. 2019. The role of renewable energy mini-grids in Kenya's electricity sector.

commercial viability, each lot included a mix of more densely populated and less densely populated sites.[254]

However, the PPP approach has not been well-received by the government and KOSAP has been restructured accordingly. There has been a lot of hesitancy among government officials regarding the idea of leveraging private financing for rural electrification, which they perceive as a public service. Even though the government is concerned about the equity issues arising from the higher tariffs that less affluent populations need to pay, resulting in comparisons between Kenya Power and mini-grid tariffs, the idea of subsidies towards the private sector or leveraging private financing through World Bank funds has not been popular, which has hindered the implementation of the PPP approach initially planned under KOSAP. In the restructured programme, assets are fully funded by the public sector, owned by REREC and Kenya Power (and ultimately transferred to Kenya Power). Thus, mini-grids are envisioned to operate as isolated grids and, ultimately, interconnected with the grid.[255]

As of March 2024, no mini-grids have been constructed under KOSAP. A request for bids was issued by REREC in August 2023 for the design and installation of mini-grids in Turkana, Marsabit, Samburu and Isiolo Counties, combined with seven years of O&M services.[256] As part of the tender, the 137 mini-grids have been split into lots and the selection of contractors is expected to take place in 2024.[257]

A uniform national tariff is favoured by the Ministry of Energy. Under KOSAP, all mini-grid electricity consumers will be Kenya Power customers paying the same tariff as customers connected to the national grid, thus following a national uniform tariff approach.[258] Extending the Kenya Power tariff to mini-grids requires a subsidy mechanism, such as a levy.[259] The Rural Electrification Programme levy has been used to partially cross-subsidise the higher service costs of mini-grids by other national grid customers.[260] For the target of 35,000 households to be reached by mini-grids, the Kenya National Electrification Strategy estimated an annual subsidy of ~USD 16,050,000 required for mini-grids.

A3.4.2 PUE

As discussed in section 2.3, PUE is crucial for increasing customer load. This is highlighted by Vulcan Impact Investing, which owns about 10 mini-grids in rural Kenya; the average revenue per user generated from the 10 percent of its clients that are productive users (such as small businesses) was five times greater than the revenue generated from the other 90 percent.[261] Another example of promoting PUE to increase mini-grid electricity demand is PowerGen in

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[254] World Bank. 2017. Project Appraisal Document: Off-Grid Solar Access Project for Underserved Counties.

[255] Consultant's interview with the World Bank.

[256] World Bank. 2023. Kenya: Off-grid Solar Access Project for Underserved Counties.

[257] Consultant's interview with the World Bank.

[258] World Bank. 2017. Project Appraisal Document: Off-Grid Solar Access Project for Underserved Counties.

[259] World Bank. 2018. Kenya National Electrification Strategy.

[260] New Climate. 2019. The role of renewable energy mini-grids in Kenya's electricity sector.

[261] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

Kenya, which provides refrigerators and freezers to commercial customers, enabling them to provide cold beverages or keep produce longer, thus also contributing to the customers' higher income generation.[262]

Given the prohibitive upfront cost of PUE equipment, financing provided by developers is key to addressing this barrier. For instance, Powerhive introduced a micro-financed poultry programme to customers, which has financed seven chicken brooders and built 25 brooder houses in Kisii County in Kenya, providing livelihood opportunities for more than 130 people, generating an income stream of USD 150–250 per person each month. In addition, brooder owners receive continuous training. The company has also provided financing for electric pressure cookers to encourage clean cooking, and has facilitated the roll out of electric mills, motorbikes and tuk-tuks, as well as hatcheries across its sites, thus enhancing livelihoods and increasing the community's resilience.[263]

RBF by donors can also be crucial for scaling up PUE applications. For instance, CEI Africa launched an outcome-based financing facility in December 2023, which will provide grants for the implementation of PUE strategies connected to renewable energy mini-grids in a number of target countries, including Kenya. Grant disbursement is conditional on two aspects; firstly, reaching certain pre-agreed outcomes such as reduced household/SME expense, increase in incomes of local communities and support for women entrepreneurs; and secondly, verified equipment delivery/installation.[264]

A4 Data Collection

The report follows a bottom-up approach, building upon two separate databases:

- The **Mini-Grid Funders (MGF) database**, which contains information on mini-grid programmes. It covers aspects such as programme duration, type of financing instruments used, total connections planned, and total funding committed and disbursed, included in sections 2.4 and 3.3 of the report. The MGF database was complemented with a database on investment deals provided by the World Bank.
- The **Mini-Grid Asset (MGA) database**, which contains information on 1,097 mini-grid projects across 16 countries. It covers aspects such as technology, customer breakdown and costs, included in sections 2.1, 2.3, 2.5 and 2.6 of the report.

The data collection for the **MGF database** was led by the Carbon Trust. Originally scheduled to take place from December 2023 to January 2024, the timeline was extended until April 2024 to accommodate additional responses.

[262] ESMAP. 2022. Mini-Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.

[263] REPP. n.d. Powerhive.

[264] CEI Africa. 2023. CEI Africa Launches the Smart Outcomes Component Focused on Promoting Productive Use of Energy.

The data template was distributed to all members of the **MGF group and a total of 14 funding bodies contributed data. The Excel data template included the following metrics:**

- Name of organisation
- Country, region
- Programme name
- Grantee or recipient
- Approval and end date
- Funder budget
- Percentage of budget deployed to date
- Funding provided in local currency (yes/no)
- Primary, secondary and tertiary funding instruments and their relevant shares
- What stage of mini-grid development does the funding primarily support
- What additional stage of mini-grid development does the funding support
- Is technical assistance provided as part of the programme
- No. of connections planned
- No. of connections made to date
- Average subsidy per connection
- Average tariff per connection

Data collection for the MGA database was led by Economic Consulting Associates (ECA) from November 2023 to January 2024. An Excel data template was developed to capture the following metrics:

- Project name
- Country, city
- Developer
- Ownership status
- Year of commission
- Technology
- Install capacity for each type of technology (i.e. solar, wind, biomass, diesel, other) in kW
- Battery output (kW) and capacity (kWh)
- Electricity delivered (kWh/year)
- Number of customers by type (i.e. business, households, public)
- Share of consumption by customer type
- Capex and opex costs
- Average outages/month and average length of outage
- Coordinates

The team reached out to 165 stakeholders in the mini-grid sector, including developers, donors and private investors, to distribute the data request template. Despite this extensive outreach, the initial response rate was very low. The consultants then followed up with all non-responsive stakeholders. For those who still did not respond, custom templates with pre-filled information about their mini-grid assets, mostly sourced from publicly available resources, were sent. Additionally, the consultants collaborated with AMDA to encourage developers to share their data. Ultimately, 20 stakeholders responded to the survey request.