State of the Global Mini-grids Market Report 2020

Trends of renewable energy hybrid mini-grids in Sub-Saharan Africa, Asia and island nations

MGP MINI-GRIDS PARTNERSHIP

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About the report

This *State of the Global Mini-grids Market Report 2020* aims to raise awareness about mini-grids, mobilizing investments in the mini-grid sector and serving as a benchmark to measure progress in the sector for decision-makers. It provides the latest updates on the global mini-grids market and highlights key trends in the industry that, together, can stand as the definitive source of information for stakeholders. The authors of this report were commissioned to conduct the research between October 2019 and April 2020 and produce the report on behalf of the Mini-Grids Partnership (MGP).

Goals

This research has three primary goals. The first is to provide stakeholders in the mini-grid sector with the most up-to date information and analysis of the market status and trends in the sector. The second is to propose recommendations for key stakeholders to address the challenges identified in the research in developing the mini-grid market. The third is to build an open source mini-grid asset database.

Scope

The primary scope of this research is mini-grid systems that serve remote and island communities in Sub-Saharan Africa, emerging Asia and island nations. The majority of these systems are isolated, but those connected to the main grid were not excluded. The sizes of the systems are mostly up to 100kW or so as typical consumers are households with low power demand, public buildings and small-scale commercial and industrial (C&I) customers. There are some exceptions of systems above 1MW where the mini-grid serves a number of large power consumers. For the purposes of comparison, the research also investigated mini-grid projects and businesses outside Sub-Saharan Africa, Asia and island nations.

Methodology

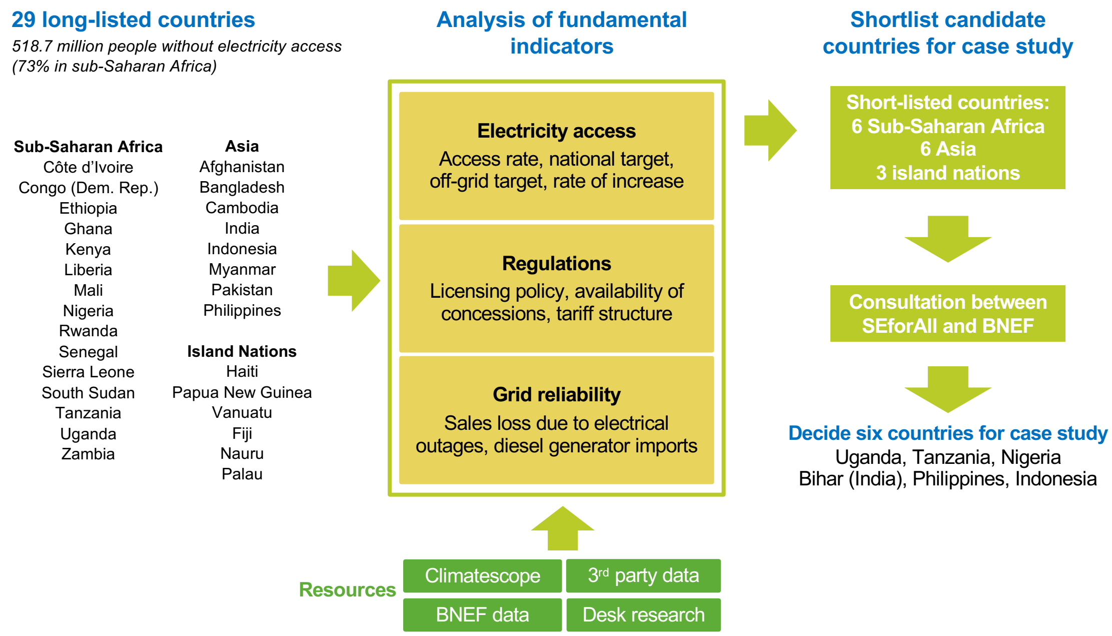
The authors combined various research methodologies to conduct the research. They include literature reviews, semi-structured interviews and quantitative modelling analysis.

The review of existing literature included the authors' existing research publications, academic articles, reports published by other research organizations, news articles and company press releases. The authors conducted structured interviews with 68 organizations to collect information and data from mini-grid developers, financiers, donor agencies, research institutes, non-profit organizations and technology vendors. Information and data gathered were used to analyze the status of the mini-grid market, policy and regulations, financing, economics, impacts and case studies (Sections 4-9 and 11-16). The authors conducted quantitative modelling analysis to calculate levelized costs of electricity (LCOEs) (Section 8) and to analyze the addressable market size of mini-grids by 2030 under business-as-usual and universal electricity access scenarios (Section 10).

The authors also conducted case studies of six countries - Uganda, Tanzania, Nigeria, India (Bihar), the Philippines, and Indonesia (Sections 11-16). The selection process of these case study countries included analysis of fundamental indicators such as electricity access, regulation and grid reliability for 29 countries in Sub-Saharan Africa, Asia and island nations (Figure 1). The authors selected the six countries taking into account opinions from the MGP Advisory Group to ensure diversity of countries across regions, geographies, regulations and coverage by existing research publications. Key findings from the case studies were also used in the analysis contained in other parts of the report (Sections 1-10).

Figure 1

Selection methodology of case study countries



Source: BloombergNEF.

Mini-grid project data collection

A mini-grid is a group of interconnected distributed energy resources (DERs) plus loads or a single DER plus load(s) within clearly-defined boundaries. The main feature of mini-grids is their ability to operate independently, enabling them to be set up in remote locations that the main grid does not reach. Mini-grids can be isolated or connected to a grid.

The primary focus of this research is rural communities in Sub-Saharan Africa, Asia and small island nations. Between October 2019 and February 2020, the authors collected mini-grid project data both for the analysis in this research and in order to build an open-source database. Data were collected on 7,181 mini-grid assets of which 5,544 were operational.

This number of mini-grid assets is much smalller than the 19,000 installed mini-grids for which the Energy Sector Management Assistance Program (ESMAP) collected data in its report, *Mini Grids for a Half a Billion People*. As much as 89 percent of the 19,000 installed mini-grids are in 10 countries: Afghanistan (4,980), Myanmar (3,988), India (2,800), Nepal (1,519), China (1,184), the Philippines (896), Indonesia (583), Russia (501), US (391), and Senegal (272) (ESMAP, 2019). Of these, China, Russia and the US are among the top 10 countries by number of operating mini-grids. The 2,076 recorded projects equate to just over 10 percent of all the projects. In the database built in this research, projects situated in more developed economies including China, Russia and the US were excluded as these mini-grids are most likely used for purposes other than energy access.

In the ESMAP report, the vast majority of the installed mini-grids counted are first- and second-generation mini-grids (e.g., diesel mini-grids and hydro mini-grids). Thousands of these mini-grids are not included in the database in this study, which puts greater emphasis on third-generation systems (e.g., renewable hybrid systems).

In general, first- and second-generation mini-grid systems are often small and not well publicized systems that have been developed by local communities or entrepreneurs. Third-generation systems, by contrast, are far better documented as they often involve non-local investors or others. The data collection for the report focused primarily on renewable mini-grids that are predominant among projects installed in the last five years in order to analyze recent market trends. Mini-grid stakeholders tend to formulate policy/regulation, commit financing, and introduce newer technologies as well as business models with such mini-grid systems in mind.

See Appendix A for more details about the mini-grid database.

Report structure

The report has five parts. The Executive Summary highlights the report's key findings from Parts 1–4 but excludes key points from the case studies (Part 5).

Part 1: Conclusions and recommendations (Section 1) opens the discussion of why the rural mini-grid market has struggled to emerge, by comparing the way in which renewable energy markets for bulk generation have evolved. It points out three fundamental differences between the two markets. It highlights the actions key stakeholders – governments, development finance institutions (DFIs)/donor agencies, financiers and developers – should take for the mini-grid market to scale and provide access to electricity.

Part 2: Mini-grid market status (Sections 2–5) aims to help readers understand mini-grids in general and their relevance to electricity access. It also details the latest status of the mini-grid market including the number of mini-grids installed in Sub-Saharan Africa, Asia and island nations, as well as industry trends, business models and technologies used.

Part 3: Analysis (Sections 6–9) highlights trends in policy and regulation, financing and economics, and describes key challenges that mini-grid developers and investors face. It also describes examples of innovative policies and financing mechanisms. The economic analysis compares levelized costs of electricity (LCOE) of different mini-grid types and discusses why higher utilization of solar hybrid mini-grids is important for mini-grid operators to achieve better economic returns. It also provides a framework to categorize the different impacts that mini-grid projects can have, and highlights impact metrics used in the mini-grid and broader clean energy sectors.

Part 4: Outlook (Section 10) analyzes how mini-grid markets are likely to grow in Sub-Saharan Africa, Asia and island nations. It also analyzes the addressable market size in terms of the number of households that could be connected to mini-grids and the capital expenditure required, comparing business-as-usual and universal electricity access scenarios.

Part 5: Case studies (Sections 11–16) analyzes the current status of the market and key market players, policy and regulations in six selected countries: Uganda, Tanzania, Nigeria, India (Bihar), the Philippines and Indonesia. Findings in the case studies also form part of the basis for the entire research.

List of Abbreviations

AFD	Agence Française de Développement
ARPU	average revenue per user
BMZ	German Federal Ministry for Economic Cooperation & Development
BNEF	BloombergNEF
BOI	Bank of Industry (Nigeria)
C&I	commercial and industrial
CBEA	CrossBoundary Energy Access
CEEW	Council on Energy, Environment and Water
CIF	Climate Investment Fund
DER	distributed energy resource
DFI	development finance institute
Disco	distribution company
DKTI	German Climate Technology Initiative
DNO	distributed network operator
DoE	Department of Energy
DRC	Democratic Republic of Congo
DU	distribution utility
EEP	Energy and Environment Partnership Trust Fund
ERA	Electricity Regulatory Authority
ERC	Energy Regulatory Commission
ERIL	Local Rural Electrification Initiative
ESCO	energy service company
ESG	environmental, social and governance
ESMAP	Energy Sector Management Assistance Program
EWURA	Energy and Water Utilities Regulatory Authority
FiT	feed-in-tariff
GIIN	Global Impact Investing Network
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HFO	heavy fuel oil
IDA	International Development Association
IFC	International Finance Corporation
IPP	independent power producer
IRR	internal rate of return
KIS	Kalangala Infrastructure Services
LCC	life-cycle cost
LCOE	levelized cost of electricity
MEMD	Ministry of Energy & Mineral Development
MTF	Multi-Tier Framework
NEMA	National Environmental Management Authority
NEMSA	Nigerian Electricity Management Services Agency

NEP	Nigeria Electrification Project
NERC	Nigerian Electricity Regulatory Commission
NGO	non-governmental organization
NPC-SPUG	National Power Corporation Small Power Utilities Group
NREL	National Renewable Energy Laboratory
NREP	National Rural Electrification Programme
O&M	operation and maintenance
PLN	*Perusahaan Listrik Nagara*
PPA	power purchase agreement
PPP	public-private partnership
PRES	Philippines Rural Electrification System
PRG	partial risk guarantee
PRI	political risk insurance
PSSEA	Philippines Solar and Storage Energy Alliance
RBF	results-based financing
REA	Rural Electrification Agency/Authority
REEP	Rural Electrification Expansion Programme
REF	Rural Electrification Fund/Rural Energy Fund
REM	Reference Electrification Model
REPP	Renewable Energy Performance Platform
RESP	Rural Electrification Strategy and Plan
RREP	Rural Renewable Electrification Project
SAGR	subsidized approved generation rate
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SIDA	Swedish International Development Cooperation Agency
SPD	small power distributor
SPP	small power producer
SPPA	Standardized Small Power Purchase Agreement
SPV	special purpose vehicle
Tanesco	Tanzania Electric Supply Company
UCME	universal charges for missionary electrification
UEB	Uganda Electricity Board
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company
UKDFID	UK Department for International Development
UNIDO	United Nations Industrial Development Organization

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Executive summary

Mini-grids play a critical role in providing electricity to rural communities and businesses and in helping to connect the 900 million people worldwide who currently do not have access. Today the mini-grid market is nascent, despite being the least-cost option for electricity access in many areas. Two challenges need to be overcome for mini-grids to scale up and realize their potential.

5,544
Installed mini-grids in Sub-Saharan Africa, Asia and small island nations with some in Latin America

Firstly, rural customers in need of electricity access often have limited power demand and sometimes lack the ability to pay. Some developers are targeting small businesses and industrial users alongside residential consumers, to increase the average level of revenues and hence profitability. Others are financing appliances to boost demand, or even becoming off-takers.

$0.49-0.68/kWh
Estimated cost of electricity for isolated solar hybrid mini-grids for productive-use customers plus households

Secondly, there is a general lack of policies and regulations that support mini-grids. Almost all rural mini-grids require public funding, with relatively little private finance in evidence. Fortunately, a small number of countries are setting up clear frameworks designed to expand the mini-grid market, and are attracting private sector interest. The governments of these countries have stated a clear goal of expanding energy access dramatically and are pragmatic and flexible about the tools needed to meet that goal.

111 million
Households that can be served by mini-grids in Sub-Saharan Africa, Asia and island nations by 2030

State of the Global Mini-grids Market Report 2020 is an industry-focused report on the global mini-grid market, looking at technologies, businesses, regulations, financing, economics and impact assessments. It targets not only those working directly in the mini-grid sector but also others who are keen to understand the part that mini-grids can play in ensuring electricity access. The report makes recommendations on the actions needed to realize the full potential that mini-grids offer in developing countries.

Market status and outlook

Why mini-grids? (Section 2, 3)

- By the end of 2018, the total estimated number of people who lack access to electricity globally had fallen to about 900 million (789 million in the *SDG7 Tracking Report*, from 1.4 billion in 2010. Grid extension as well as rapid deployment of off-grid solar kits contributed to this remarkable progress, particularly in Asia. In Sub-Saharan Africa, the number of people who do not have access has hovered at around 600 million in recent years. At current trends, and given continued population growth, universal electricity access will not be achieved by 2030. About 620 million people would still be deprived of access, according to the International Energy Agency (IEA, 2019).
- New technologies are enabling electricity to be provided through much more decentralized networks, as the costs of PV and battery energy storage have continued to fall sharply, and remote connectivity, control and data analysis have expanded the range of options available. Solar

Definition of mini-grids and mini-grid asset data

A mini-grid is a group of interconnected distributed energy resources (DERs) plus load(s) or a single DER plus load(s) within clearly-defined boundaries. The main feature of mini-grids is the ability to operate independently, enabling them to be set up in remote locations that the main grid does not reach. Mini-grids can be totally isolated or grid-connected. The most important customer segments in this research are rural communities in Sub-Saharan Africa, developing Asia and small island nations. The authors collected records of 7,181 mini-grid assets, of which 5,544 were operational. Note that this figure does not include thousands of installed mini-grids that are fossil fuel-based or hydro based. The data collection for the report focused primarily on renewable hybrid mini-grids that are predominant among projects installed in the last five years and represent recent market trends. See Appendix A for more details about the database.

hybrid mini-grids that integrate PV and other DER(s) can complement and compete with main grid extensions in terms of the cost of electricity and the speed of deployment.

- Grid extension has been the predominant approach to provide electricity access. However, the areas that the main grid can reach more economically than off-grid alternatives are slowly being exhausted and the incremental costs of adding new rural customers via this route are becoming prohibitive. It is critical for governments and utilities to take a least-cost approach that takes advantage of the breadth of technology options, particularly given that many state-owned utilities are debt ridden and the need for electricity access urgent.

What is the market size today? (Section 4, 5)

- The authors of the report identified 7,181 mini-grid projects in Sub-Saharan Africa, Asia and small island nations with some in Latin America, as of March 2020. As many as 5,544 mini-grids were operational, of which 63 percent were solar or solar hybrid systems, 21 percent hydro, and 11 percent diesel/heavy fuel oil. The mini-grids already installed today represent only a small fraction of the total needed for full rural electrification.

How has the market evolved? (Section 4, 5)

- The fastest growing segment of the global mini-grids market is that of solar hybrid mini-grids.

Figure 2

Installed mini-grids by region

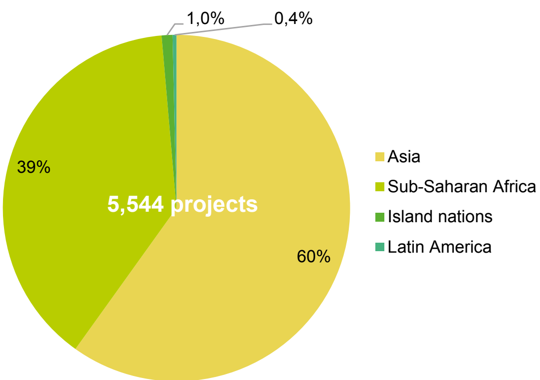
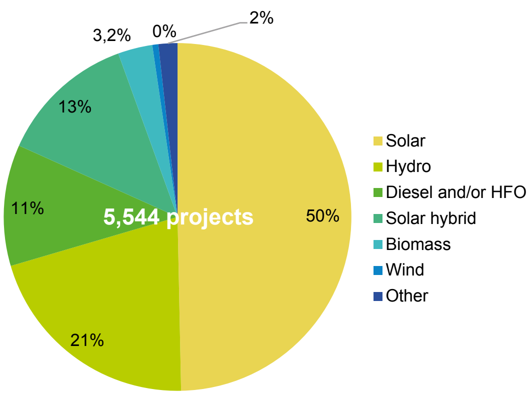


Figure 3

Installed mini-grids by technology



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, surveyed developers.

While 32 percent of installed mini-grids are diesel/heavy fuel oil (HFO) or hydro systems, PV is the generation technology most predominantly used for mini-grids being installed today.

- Typical modern mini-grids installed today combine energy storage with PV. At the moment, developers favour lead-acid batteries because they are more readily available and have a lower upfront cost than alternatives. However, with the sharp decline in technology costs, developers are beginning to use lithium-ion batteries more frequently. The authors estimate that 66 percent of mini-grids with battery storage installed in 2019 used lead-acid while 32 percent used lithium-ion. They do however expect this ratio to change.
- Most mini-grid developers are small-scale companies or start-ups. In recent years, as the solar hybrid mini-grid market has evolved, large and international corporates have also joined their ranks. Some have done this by acquiring companies that offer battery storage systems, uninterrupted power supply (UPS) and control software technologies. Others have partnered with developers or invested in them. Examples include major utilities and oil companies such as EDF, Enel, ENGIE, Iberdrola, Shell and Tokyo Electric. Japanese trading houses such as Mitsui and Sumitomo have also invested in mini-grid developers. Their market participation has partly driven by a desire to contribute to the Sustainable Development Goals (SDGs) adopted by World Leaders at the UN General Assembly in 2015.
- A typical challenge for mini-grid developers is the limited power demand and ability to pay of rural residential customers. Failing to stimulate these customers' power consumption means that it takes longer to reach a breakeven point for mini-grid projects. Business models for mini-grids are diverse, but such models are increasingly looking at ways to stimulate use of mini-grid electricity to make projects viable. In addition to serving residential customers, some developers are also targeting productive-use customers such as small businesses and industrial users, agricultural equipment users and telecom towers that have higher and more predictable power demands than residential customers, to improve average revenue per user (ARPU).
- Some developers have gone beyond selling electricity alone and offer appliance financing that allows customers to use appliances without any upfront costs. Others have adopted a KeyMaker model in which they procure raw products or materials (such as fish) from the local community, use mini-grid electricity to process them, and sell the final product (e.g., processed fish) at higher prices to customers in urban areas.

What is the potential market size of mini-grids by 2030? (Section 10)

- 238 million households will need to gain electricity access in Sub-Saharan Africa, Asia and island nations by 2030 to achieve universal electricity access. Mini-grids can serve almost half of this total – an estimated 111 million households. This will require capital investment of USD 128 billion, 78 percent higher than the estimated capital investment in a business-as-usual scenario. Mini-

Figure 4

Technology use, 2020–30

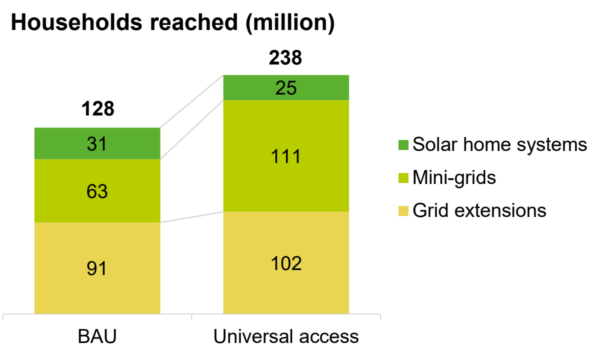
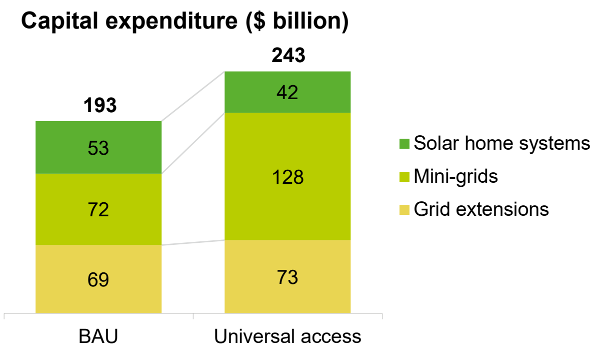


Figure 5

Estimated capital expenditure, 2020–30



Source: BloombergNEF. **Note:** BAU stands for 'Business-as-usual'. Assumes all the mini-grids are solar hybrid systems.

grid technology is the most suitable option for many low- and medium-density areas and can address a larger number of low-income families more economically than the alternative options.

Other findings

Policy and regulations (Section 6)

- ***What is the current status?*** The most impactful policies for mini-grid development are those relating to subsidies, licensing, tariff setting and grid arrival. Two main types of government subsidy have driven mini-grid project development: upfront capex subsidy and results-based financing (RBF). The former is a capex payment disbursed before a mini-grid is installed. The latter pays specified sums on projects only once there is clear verification of a functional electricity connection. This gives the public sector greater control and certainty as it only pays for results. The authors believe that this results-based approach is an important and valuable financing mechanism for the mini-grid sector.
- ***What is working?*** Some governments, such as that of Nigeria, have set regulations to reduce the risks to a mini-grid if the main grid arrives later at the same location. Developers can select from a range of options: receive compensation, continue running and deriving revenue from the mini-grid (including an option that developers receive compensation for only the distribution system), or operate alongside the main grid. Other governments such as that of the Philippines are working on a law that will allow for information disclosure and streamlined procedures for renewable hybrid mini-grids in unserved and underserved areas.
- ***What are the challenges?*** Ambiguous rural electrification policies, lack of flexibility in setting mini-grid tariffs, and complex and lengthy licensing processes are some of the major challenges that hinder mini-grid projects. There is also growing public and political sensitivity to electricity tariffs, making flexible tariff setting difficult (e.g., in Tanzania). In contrast to Nigeria, many governments lack regulations that protect isolated mini-grids if the main grid arrives. Without such regulations, the state may expropriate mini-grid assets with minimal compensation, or in the worst case, they can be stranded. Even when there are regulations in place, governments and state-owned utilities do not always enforce them.
- ***How can these challenges be overcome?*** Governments need to set clear goals for electricity access by technology with strong political initiatives. They need to establish single points of authority with powers to streamline the licensing

Figure 6

Clear rules on the arrival of the main grid across surveyed countries, 2018

Source: Climatescope 2019, BloombergNEF.

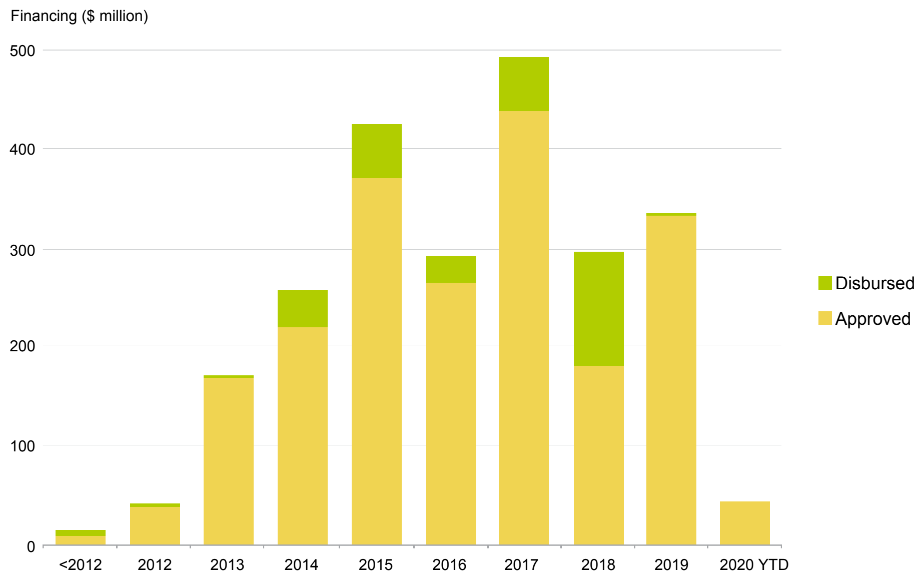
process, relax size thresholds for required licensing, deregulate tariffs, and build a robust set of rules around grid arrival to protect isolated mini-grid assets.

Financing (Section 7)

- ***What is the current status?*** Most mini-grid developers have relied on public funding such as grants from governments, development finance institutions (DFIs), donor agencies and foundations. To date, most committed financing has come from grants and developers' balance sheets, with limited debt financing. RBF has increased significantly and is favoured by developers as well as private investors, because it improves returns, reduces risks of early stage debt or equity finance, and potentially unlocks private capital (e.g., working capital needed to pre-finance connections and project equity needed for pre-development costs), provided the investors are confident of the developer's ability to deliver electricity connections.
- ***What is working?*** Some developers have successfully raised commercial financing. An increasing number of strategic financiers such as utilities, oil majors and trading houses have participated in the mini-grid sector since 2018. In 2019, the first project financing of a portfolio of mini-grid projects in Tanzania was secured (Rockefeller Foundation, 2019). Involvement of public funders for financing (e.g., RBF) or guarantees is critical in encouraging private financiers to participate in the market and in helping them overcome perceived risks.
- ***What are the challenges?*** According to the Mini-grids Funders Group, 14 funders had approved a total of USD 2.07 billion by March 2020, of which only 13 percent had been disbursed. While the picture on the ground is likely to be better than the data suggest, it is clear that there can be significant delays in getting funding, and therefore in projects moving forward. There is also a lack of pure commercial financing as the mini-grid market lacks scale, developers' project track records are limited (hence, project risks are not yet fully transparent), regulations are unclear, and residential consumers have limited power demand as well as limited ability to pay.
- ***How can these challenges be overcome?*** Funding deployment may be quicker as the market matures. This is also linked to the policy and regulations of the countries where recipients of funding are located. Governments need to take strong initiatives and promote robust regulatory frameworks that support the development of

Figure 7

Approved and disbursed financing in the mini-grid sector



Source: Mini-grids Funders Group, Carbon Trust, BloombergNEF. Note: YTD = March 20 2020.

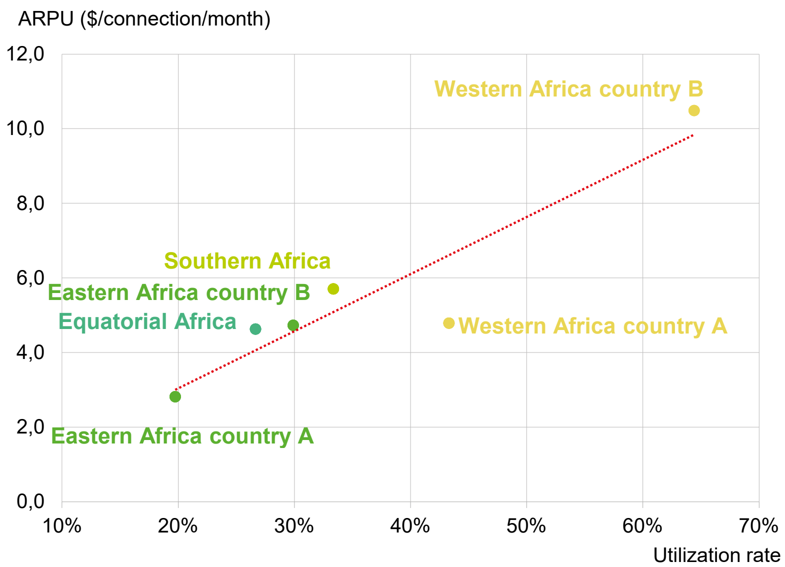
mini-grids. Public funders need to continue and expand financing assistance for mini-grid development, in particular using RBF. These can in turn attract more commercial financing.

Economics (Section 8)

- ***What is the current status?*** Installing PV modules in mini-grids generally improves their economics as compared to just using diesel. Adding day-time demand can cut the overall cost of electricity as it correlates with the generation profiles of PV systems powered by the sun. This boosts the utilization rate of the mini-grid, leading to a lower cost of electricity and higher average revenue per user (ARPU). Levelized costs of electricity (LCOEs) ranged from USD 0.49–0.68/kWh for solar hybrid mini-grids operating in isolated areas and serving both households and productive use customers in the six case study countries. LCOEs are different mainly due to varying prices for diesel, equipment, installation and financing.
- ***What is working?*** Developers increasingly tend to select sites where a certain level of economic activity or anchor load is present within rural communities. Some have adapted their business models to increase revenues by managing tariff structures and stimulating the power demand of their customers (e.g., offering appliance finance) or even becoming productive users of mini-grid electricity themselves (the KeyMaker business model).
- ***What are the challenges?*** The electricity from solar hybrid mini-grids is still expensive for many rural customers who have limited ability and willingness to pay. While rural communities do have productive-use customers (e.g., those using agricultural equipment), who can help boost revenues for the mini-grid, in practice, they do not always use electricity in the day when PV generates electricity.
- ***How can these challenges be overcome?*** Public funding, such as RBF grants, continues to be critical to the economic viability of rural mini-grids. Developers can improve revenues through business models or initiatives that prompt customers to use more electricity in the day. Setting tariff structures that guarantee a certain minimal level of revenue is also an option. Governments should allow developers to set their tariffs flexibly, especially for small-scale projects (i.e., below 100kW). Subsidies for tariffs can be an alternative means to overcome the barrier of high electricity costs to consumers. Such incentives can encourage consumers to increase power consumption, which, in turn, improves the mini-grid operator's revenues.

Figure 8

Correlation between utilization rate and ARPU



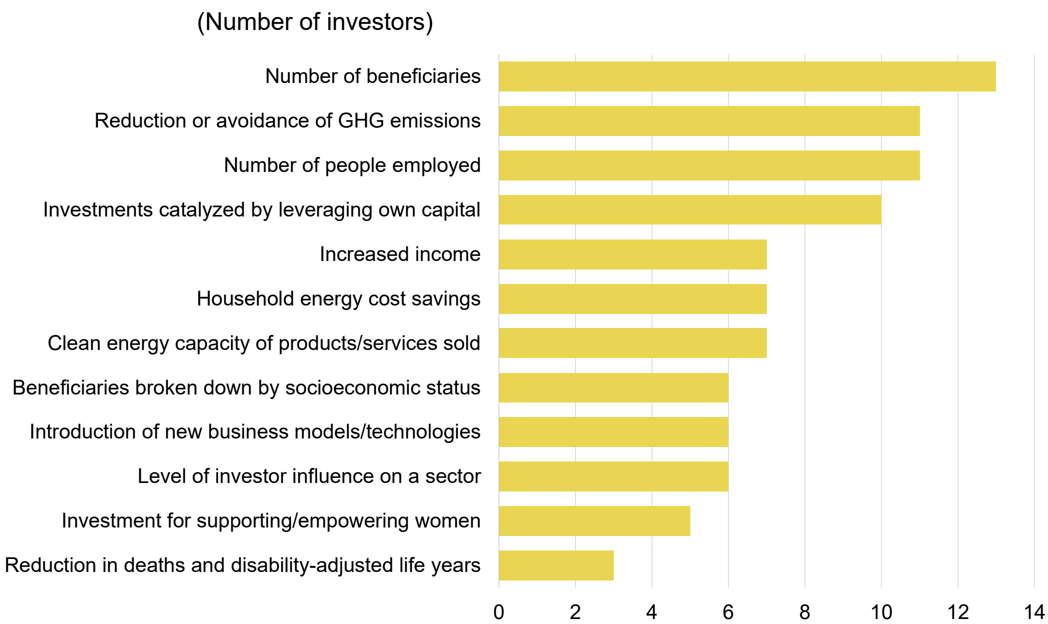
Source: Africa Minigrid Developers Association (AMDA), ECA. **Note:** Each dot represents weighted average ARPU in a specific country in Sub-Saharan Africa. The data were collected from AMDA's member developers who are operating mini-grid projects with 11,882 connections.

Impact (Section 9)

- ***What is the current status?*** Impact metrics that financiers have adopted vary according to their objectives. Metrics are also used selectively for specific transactions for financing according to their relevance to the investee, business model, customers, or type of product or service. Metrics that are easier to measure, for example, the number of beneficiaries, the reduction of greenhouse gas emissions or the number of jobs created are more commonly used.
- ***What is working?*** Some organizations have developed innovative impact assessment metrics for off-grid projects and collected impact data. Acumen developed Lean Data, focusing on changes in the quality of life of the customers who use the products and services of social enterprises, including those implementing mini-grid projects. It invested heavily in remote data collection via mobile phones (i.e., SMS, phone calls and online surveys) to lower the cost and reduce the time needed for gathering data to assess these impacts.
- ***What are the challenges?*** There is no commonly accepted approach to gather and report impact data for electricity access projects. Calculating the number of people with access to electricity is straightforward but does not measure how the lives of rural communities have benefitted from electricity access projects. Some social impacts are difficult to measure as they are complex and may only appear in the long term. More impact data are needed to attract investors who are interested in investing in projects with beneficial environmental and social impacts, and in being able to inform their stakeholders of the results.
- ***How can these challenges be overcome?*** The mini-grid sector needs to assemble impact data for mini-grid projects using some of the established metrics. For example, DFIs, donor agencies and impact investors can insist that the recipients of funds (i.e., developers) collect impact data from the end consumers that they serve. The sector can then use those data in aggregate to understand what is working, and to attract financiers who are interested in investing for impact creation (e.g., in line with the SDGs).

Figure 9

Metrics used for impact assessment by investors in the clean energy sector



Source: GIIN, BloombergNEF. **Note:** Surveyed financiers include Acumen, Bamboo Finance, Calvert Foundation, Deutsche Bank, Doen Foundation, FMO, Global Alliance for Clean Cooking, Gray Ghost Ventures, LGTVP, Lunch Foundation, IDFC (former OPIC), responsAbility, Shell Foundation. Names of some of the metrics have been slightly modified for the sake of simplicity.

Part 1

Conclusions and recommendations

Section 1
Conclusions and recommendations

1.1 Conclusions

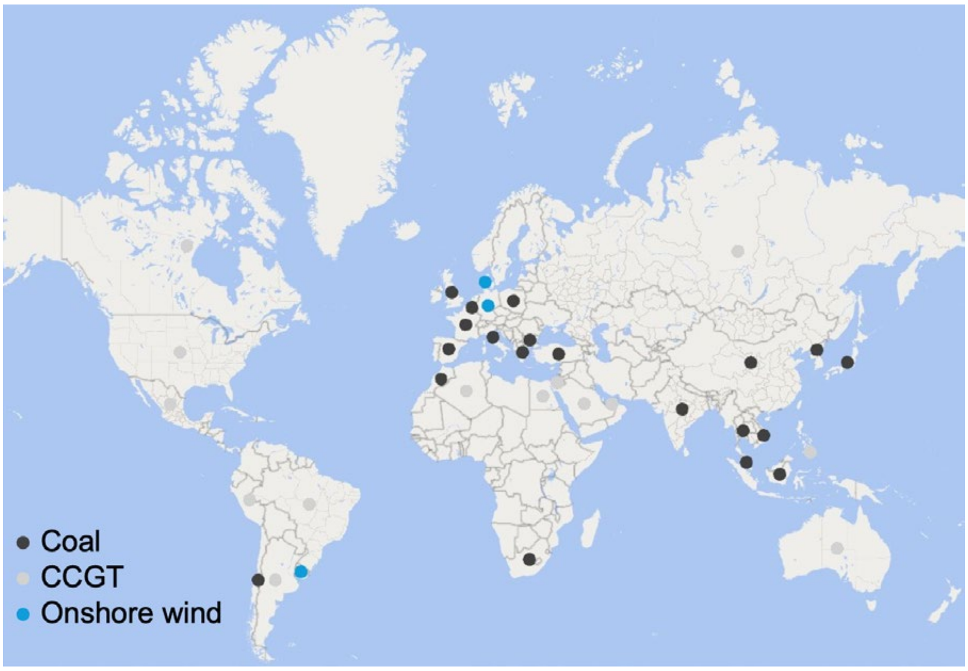
The market for mini-grids remains nascent, and mini-grid projects often offer the least-cost option for delivering power to rural citizens who lack energy access. The mini-grid market has grown from 60 solar/solar hybrid projects installed globally in 2010 to 2,099 at the end of February 2020 in the regions surveyed in this research .[1] Nonetheless, there is still enormous room for growth. Moreover, while commercial financiers and corporations have backed some mini-grids to date, most projects still require some form of public funding or guarantee. The mini-grid sector has not achieved a *tipping point* at which it can expand exponentially without subsidized support.

By contrast, renewable power generated at scale today is largely cost-competitive and can regularly be financed entirely with private capital in both OECD and middle-income nations, based on authors' analysis. This success can in part be attributed to years of substantial subsidies, including feed-in tariffs in OECD nations that created scale and drove down costs. At present, in countries where more than the two-thirds of the global population lives, the most competitive source of new bulk generation is either unsubsidized solar or wind energy (Figure 10, Figure 11).

Modern mini-grids employ many of the same technologies found in a typical utility-scale solar or solar-plus-storage project. The question then is can mini-grids follow in the footsteps of utility-scale

Figure 10

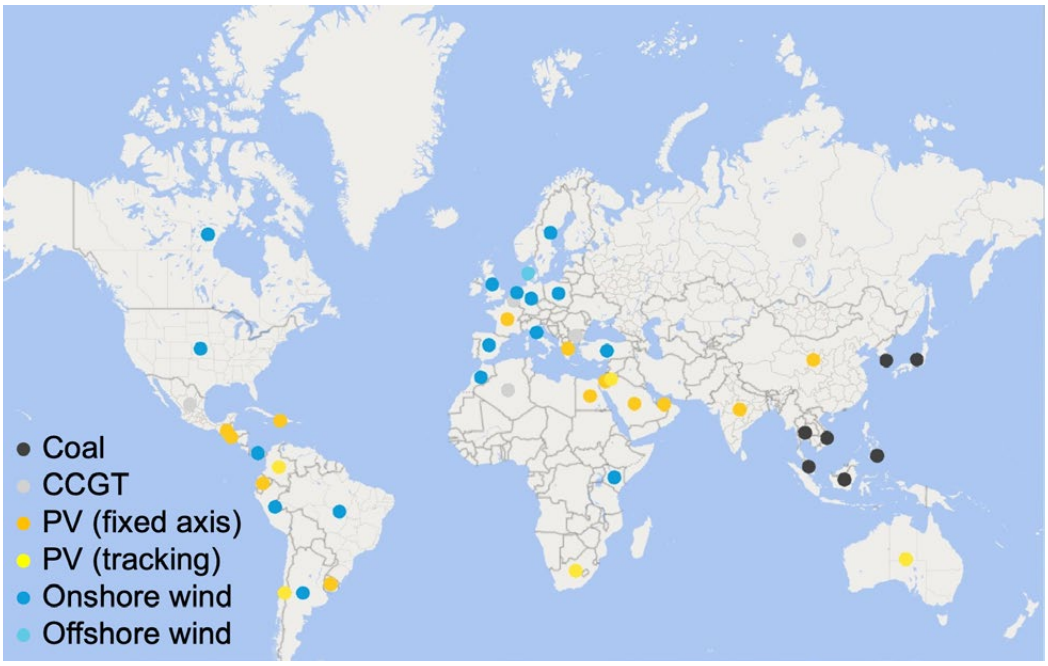
Most competitive source of new bulk generation in 2014



1 This number includes only the projects with a commercial operation date.

Figure 11

Most competitive source of new bulk generation in H1 2020



Source: BloombergNEF. **Note:** Reflective of the cheapest benchmark project for each technology and market. The analysis is based on the authors' study of levelized costs of electricity, which were modelled for projects that have been financed in the last six months or which are currently under construction.

clean power to achieve viability and much larger scale by leveraging private investment?

Before exploring this in greater depth, it is worth highlighting three fundamental differences between utility-scale clean energy and mini-grids: the nature of how the assets in question are de-risked or *protected*; the differing profiles of the customers who purchase the electricity generated from these two types of projects; and the differing sizes of the projects themselves. These differences, which are highlighted in Table 1, show the challenges the mini-grid sector must overcome to achieve significantly greater scale.

Table 1

Comparing market fundamentals – renewables versus mini-grids

	Renewables in 2010	Mini-grids today
Technology	Developing	Mature
Cost competitiveness versus alternatives	Not competitive (in terms of cost of electricity for bulk generation)	Competitive (in terms of cost of electricity to be delivered to rural customers)
Protection of asset cash flows	Power purchase agreements (backed with feed-in tariffs)	Lacking except for some countries
Customers	Grid operators / state-run utilities	Rural households, commercial and industrial users
Size of project	Large (1–1,000MW)	Small (10–100kW)

Source: BloombergNEF. Note: Renewables here refer to solar and wind for bulk generation. Mini-grids refer to renewable hybrid systems or third generation mini-grids in rural areas.

Protection of asset cash flows

Under feed-in tariff mechanisms introduced in the early 2010s, renewable energy developers built solar and wind power plants and sold all the electricity to grid operators at fixed prices for fixed periods of time. These policies gave investors and developers confidence that their projects would generate sufficient cash flows to generate acceptable returns. In essence, the policies protected the value of these assets for investors.

By contrast, few governments in countries that need sustained investment in rural electrification provide regulations that protect mini-grid owners quite so explicitly. While some governments have implemented policies that give developers autonomy to set and maintain tariffs, they barely guarantee cash flows. Not surprisingly, private investors tend to favour markets where policies are most supportive. But even in countries such as Nigeria, where the government has been pro-active in giving developers the right to set local tariffs and protection from being integrated into the main grid (and its tariffs), private investment is not as high as it could potentially be.

Customers

Direct customers for large-scale renewable energy projects in developing countries tend to be grid operators or state-owned utilities who pay fixed tariffs to the operators based on signed power purchase agreements (PPAs). For operators, these customers are hardly risk-free (many have poor credit profiles), but they are typically backed by central governments directly. In addition, in recent years, utility-scale projects have been able to sell their output directly to large corporate customers.

By contrast, rural mini-grid operators sell to customers with little income and limited ability to pay. Demand from these customers can be unpredictable as many rely on agriculture for income. Varying weather conditions, seasonality and crop yields all directly impact the ability of these customers to pay their bills.

For mini-grid operators, such irregular income streams pose significant risks to revenue collection, and risk returns for their financial backers. The unreliability of such customers represents one of the biggest obstacles to mini-grids becoming economically viable without subsidies. It also deters private investors from deploying capital in support of such projects.

Size

Typical utility-scale renewable energy projects are at least 1MW in size. By contrast, the majority of rural mini-grids range from just 10–100kW. Private financiers tend to favour larger deals that allow them to amortize transaction-related costs over larger volumes of capital (and, in many cases, earn larger fees). As a result, many are unwilling to invest the time and effort required to conduct due diligence and provide financing for projects that may require as little as USD 1 million or less.

The mini-grid sector needs to take all these concerns into account as it seeks to reach the point when projects can be financed entirely with private capital and true scale can be achieved. Four stakeholder groups have the potential to address these challenges – governments, development finance institutions (DFIs) and donor agencies, private financiers and mini-grid project developers. Note that mini-grids here refer to the most common type of mini-grids installed in recent years, namely, renewable hybrid mini-grids — primarily, solar hybrid mini-grids or third generation mini-grids — rather than fossil-fuel based mini-grids. Below is a summary of the key recommendations for each group.

1.2 Recommendations

Governments

Policies fundamentally determine whether countries can cultivate enabling environments for mini-grid developers to flourish and for private financing to flow. In countries where citizens have poor access to energy services or where power grids are highly unreliable, it is particularly pertinent that governments develop legislation and regulation to support mini-grids so that they can achieve scale and become economically viable.

While the grid is likely to remain the primary choice for electrification where it is easily accessible or where there is a reasonable expectation of power demand growth, mini-grids will often be cheaper where access is difficult or grid power is expensive, provided power demands can be managed. Additionally, the areas that can easily be reached by the grid are diminishing, and hence the marginal costs of extending the grid to reach more remote and rural customers are becoming prohibitive. This is the main reason why governments' electrification efforts should focus on mini-grids.

This report recommends that governments provide direct financial support for renewable hybrid mini-grids to improve access to clean, reliable and affordable electricity. Direct financial support primarily refers to grants through results-based financing (RBF) or tenders. Governments with genuine financial constraints that hinder such grants may need assistance from DFIs and governments of other countries.

Take a *least-cost* approach

It is critical for governments to pursue *least-cost* approaches to improve rural electrification. Note that the term here refers to the minimum cost in terms of delivery of electricity to end users. In many countries today, that means prioritizing the roll-out of mini-grids over expanding the existing hub-and-spoke power grid. There are two basic reasons why the former is superior to the latter: cost and speed.

By definition, most rural households are located in sparsely populated areas. The cost of building transmission and distribution lines to reach these communities is high and their demand for power is relatively low in general. Taking these two factors into account, the true cost of electricity delivered to remote households is relatively high.

Meanwhile, state-backed utilities charged with grid build-outs are often weighed down by significant levels of debt. Securing additional loans to finance build-outs can be costly or even impossible for some of these entities. The result of all these factors is that grid extension can simply be cost-prohibitive.

In addition, there are basic issues related to organizing and executing grid expansions. Such projects typically require major investment and planning time. Development and construction can take years. There have been some initiatives to develop geospatial modelling tools that compare the cost of mini-grids with grid extensions. Such tools can assist governments in deciding which technologies to prioritize according to location.

Set electricity access targets and roadmaps by technology

Many governments have set national electricity access targets but few have been explicit about how they intend to expand off-grid access to those in rural communities to achieve those targets. This is important as a basis for designing comprehensive policy frameworks. While setting targets, and then creating requisite roadmaps split by technology type requires detailed studies, it can send clear messages to stakeholders about which technologies will be deployed and supported at scale. Setting roadmaps that merely fulfil short-term political priorities is less likely to succeed.

Outline clear *grid arrival* rules to protect value of mini-grids, attract investors

After a mini-grid has been completed and is operating in a remote region, the build-out of the central grid to that area can pose an existential risk to the financial health of that mini-grid. Specifically, developers (and, in turn, their financial backers) worry their projects will be engulfed by the grid and expropriated by the government-backed utility without adequate compensation.

For this reason, governments can establish clear *grid arrival* rules to protect the value of isolated mini-grids. An example of good practice, Nigeria offers three options in the event the main grid reaches isolated mini-grids:

1. The regional distribution company, referred to as the disco, buys any excess electricity generated from the mini-grid beyond what is needed to serve its existing customers.
2. The disco buys all the mini-grid's generated electricity and regards it as part of the main grid system.
3. The disco compensates the developer for the loss of any revenue.

Setting such rules may bring mutual benefits. For the mini-grid owner and investors, it protects the value of the asset after the main grid arrives. For the utility, it allows mini-grids to be integrated directly into the main grid and enables it to avoid capital expenditure.

Establish *light touch* administrative processes

Streamlining licensing procedures can reduce administrative time and cost, easing the burden on governments, as many countries will require hundreds and often thousands of mini-grids. This could mean creating distinct requirements for small-scale projects that differ from those for utility-scale projects and granting developers single licences to develop multiple projects (i.e., portfolio licensing approvals). In some countries, acquiring a generation and retail licence is a complex and time-consuming process. This needlessly increases the development costs for mini-grid operators.

Setting up *one-stop shops* where all relevant permits can be secured can also drive down development costs. Such entities can be equipped to handle administrative procedures across every stage of a project's development. A streamlined process avoids duplication of work and eases the burden on governments. For example, Sierra Leone issues single licences allowing developers to generate, distribute and sell electricity. Tanzania allows developers to obtain a single licence for several distinct sites.

Identify and disclose potential sites for mini-grid development

In an attempt to keep private sector costs , governments can lead on identifying and disclosing locations where they will support mini-grid development. This provides clarity on where and how many mini-grids can be installed and saves developers time and money in identifying project sites. Comprehensive information on candidate sites would also help developers plan mini-grid clusters, which increase operation efficiency and maintenance. Such frameworks should, however, offer developers flexibility in selecting the sites they deem the most economically viable.

Be transparent

Governments in emerging countries regularly fail to provide complete and accurate information on the scope of their energy access problems or even the regulations they have developed to address them. This is important to attract businesses and investors that require such information to make decisions. An effective action to address this would be to disclose data, starting with clear definitions, identification of locations that require improved access, and information on policies that help stakeholders assess local enabling environments accurately.

For example, some governments disclose village-level electricity access data but are unclear about how they define *electrification*. Under the Indonesian government's definition, a village defined as electrified does not necessarily have all its households connected. This can mislead stakeholders to believe the country is close to universal electricity access when it is far from it, and potentially influence investments for electricity access. In Kenya, electrification data differ between the Ministry of Energy, the National Bureau of Statistics and the utility. In Tanzania, electricity access refers to the total population near a locality that benefits collectively from electricity irrespective of the number of households actually connected to electricity (REA, 2016).

It is also important for governments to disclose results of policy interventions such as mini-grid tenders and RBF programmes. This has sometimes, but not always, been the case in the past. Publishing this information on public web sites that are easy to navigate and understand is vital.

Development finance institutions and donor agencies

DFIs and donor agencies today play critical roles in providing governments with financial and technical assistance to install mini-grids. However, these organizations could focus their efforts more strategically on certain types of interventions to ensure their resources are allocated most effectively.

Establish and support RBF programmes to scale mini-grids

RBF programmes disburse funding to developers once they complete mini-grid installations. There have been a number of RBF programmes for mini-grids implemented to date, including in Nigeria and Tanzania. Developers and investors interviewed by the authors said they typically find RBF programmes straightforward to use because they are clear and efficient to implement. Governments can use RBF programmes to exert greater control over how mini-grids are developed in their jurisdictions. The African Minigrid Developer Association (AMDA), with more than 30 members, also recommends the use of an RBF programme in its white paper (AMDA, 2018).

Most existing RBF programmes today are relatively small scale. For instance, in Nigeria, Africa's most populous country, the Performance Based Grant (PBG) programme has made just USD 150 million available to date . DFIs can provide more financial support for existing RBF programmes and work with governments to seed new programmes.

Provide partial-risk guarantees to financiers

The financial position of state-run utilities and the governments behind them can pose major risks to mini-grid developers. Deeply indebted utilities or governments have in the past failed to honour contractual obligations to pay agreed-upon tariffs to developers. As a result, the creditworthiness of governments directly impacts a mini-grid project's viability and its developer's ability to access capital. There also exist legal and political risks with such contracts.

It could be useful for DFIs to provide partial-risk guarantees (PRG) that insure against non-payment from utilities or governments.[2] Such PRGs obligate the DFI to pay back private commercial lenders or even shareholders. They typically cover any outstanding principal and accrued interest of a loan, which can cover both local and foreign currency debt. The payment is made only if the debt service default is caused by a risk measure specified in the PRG agreement.

For example, utility-scale power generation projects in Nigeria have adopted PRGs in cooperation with the World Bank. Based on the agreement, the Bank will compensate the loan provider with any outstanding debt obligation. PRGs in the mini-grid sector could give a layer of protection to commercial lenders so that they will be paid back should a utility or government be unable to fulfil contractual obligations.

2 There also exists political risk insurance (PRI) as provided by, for example, the Multilateral Investment Guarantee Agency (MIGA) and the USA's International Development Finance Corporation (IDFC).

Consider cross-sectoral collaboration

Rural electrification efforts aim to do more than just provide access to energy. They seek to improve communities' social, economic and environmental conditions. The impact can include higher agricultural productivity, longer study hours, improved healthcare services and expanded internet access. This suggests that commitments to mini-grids should encompass not merely energy departments within governments, DFIs or donor agencies but others as well. Energy-, agriculture- and health-focused groups all have a role to play and should collaborate on the design and implementation of effective programmes.

Financiers

Governments, DFIs, donor agencies and foundations have provided the majority of financing for mini-grids to date. Recent years have seen some private capital arrive via commercial financiers, strategic investors and corporate investors. But there is a much larger opportunity for these players, particularly if the mini-grid sector is to achieve real scale.

Finance mini-grid portfolios

Financiers could seek opportunities to support aggregated portfolios of projects from a single developer. Doing so can benefit investor and developer alike. Given that the vast majority of mini-grids are less than 100kW in size, a single project may be a less attractive investment than a large-scale renewables project. Small projects bundled into a single portfolio can not only increase potential economic return, but also spread operational and regulatory risks across the portfolio. There would also be savings in transaction costs if a given number of projects is concentrated in a single or small number of jurisdictions, as opposed to being more widespread. Financing for multiple projects would allow a developer to procure equipment in bulk at lower cost per unit.

Employ advanced impact assessment metrics to evaluate results

Judging a mini-grid's success purely on whether it provides comprehensive around-the-clock electricity access to rural communities can be a rather crude metric as it ignores important social, economic and environmental impacts that mini-grid projects can provide. To add greater nuance, organizations such as the Global Off-Grid Lighting Association (GOGLA) and Acumen have developed advanced metrics to collect data and measure impact.

Financiers including DFIs and donor agencies could mandate their funding receivers to collect data using these advanced metrics, use the data to evaluate whether their investments were successful and report the impact assessment results to the public. Impact metrics provide a framework that enables financiers to look for mini-grid developers that have business models focusing on impact creation (e.g., the KeyMaker model through which developers procure raw materials from the local community, process them using electricity from their mini-grids, and sell the goods to customers in urban areas).

Developers

Best practices demonstrated by the development of some mini-grids to date suggest that developers overall can improve the efficiency of their processes, reduce costs, and create benefits for customers while generating sufficient revenues. Among the lessons learnt and shared with the authors researching this project were the following:

Apply data analytics solutions throughout various stages of a project's lifetime

Technology start-ups exist today to offer innovative data analytics tools that can assist mini-grid project development at various stages. These can be used to screen out unsuitable sites, simulate potential demand, and optimize system size and tariffs. Tools can also be used to analyze electricity consumption data sent via smart meters to assess operational performance. Remote monitoring technology can minimize the time engineers spend reporting, troubleshooting and visiting remote areas. These tools can improve the efficiency of project development and operation and minimize costs throughout the project value chain. Use of such tools will be critical when developers scale their portfolio of mini-grids.

Focus on minimizing operating expenses and stimulating power demand

Developers can improve project economics by minimizing operating expenses (opex) and stimulating power demand from customers. While capex reductions are more dependent on external factors such as regulations and technology costs, developers can minimize opex by designs that minimize use of diesel fuel and use of soft services that support their efficient mini-grid operation and customer management. They can also train local technicians, operate multiple sites close to each other, and use remote monitoring and control technologies. Designing business models to focus on the use of electricity is important to improve average revenue per user (ARPU) by including large power consumers as mini-grid customers (i.e., anchor loads) and/or stimulating productive use of electricity (e.g., financing appliances). Higher utilization of solar hybrid mini-grids enable mini-grid operators to achieve higher ARPU.

Adopting the KeyMaker model is another way to stimulate power demand. Rural consumers typically have low power demand and the demand profile may not align with the generation profile. An advantage of this model is that developers can partly take control over the use of electricity as they take power from the mini-grid to process raw materials (e.g., freezing and milling) procured from the local community. This can help developers to improve the economic performance of the mini-grids while improving the ability of the local communities to generate income.

Consider bundling electricity with appliances via pay-as-you-go models

Offering appliances to mini-grid customers is one way to stimulate their power demand and improve their quality of life. The pay-as-you-go model lowers the barriers for the rural population to use appliances as they do not need to pay for them upfront. Provision of appliances increases demand and can encourage small enterprise, leading to more predictable loads, greater economic growth in rural areas and lower storage costs.

Part 2

Mini-grid market status

Section 2
Mini-grids in context

Power systems first started almost 150 years ago as a decentralized architecture but were later consolidated into a much more centralized structure, with large generation plants benefitting from economies of scale, and transmission and distribution networks relaying the electricity generated to the consumer. Governments in emerging countries have, in the past, tried to use similar, centralized approaches to improve access to electricity, but this has now started to change. The areas that can easily be reached by the main grid are diminishing, and the marginal costs of extending the grid to reach more remote and rural customers are becoming prohibitive. This has led some governments to deploy decentralized forms of energy that benefit from rapid declines in the costs of modular, distributed clean energy generation and storage technologies.

2.1 Electricity access: Centralized versus Decentralized approach

Centralized approach

In the early 20th century, electricity systems were fully decentralized. All electricity requirements for lighting and running machines were generated near the point of use. As demand for power grew, it became economically feasible to build larger and more efficient generation plants and to link them via long transmission lines. This centralized power system was characterized by a unidirectional flow of energy from generation to transmission and to local distribution.

This approach has also been predominant in emerging countries, although the scale of deployment varies. Governments and utilities extend the grid to new households with financial and technical assistance from development finance institutions (DFIs) and donor agencies. However, grid extension is costly, and the economics are highly dependent on local circumstances, population densities and distances. In dense urban areas, connecting a new customer is often a simple matter of extending the distribution line by just a few metres. Conversely, in the most remote areas, the grid operator will have to install additional transmission lines with transformers and poles, often in sparsely populated areas that are hard to access. Complex geographies such as island nations and mountainous countries also pose particular challenges. Laying cable is often not economically viable, even where it is technically possible. Undersea cables to islands are viable only if they are close to a main grid and there is enough power demand to justify the cost.

Customers in remote communities in emerging countries typically have low incomes and limited power demand. Therefore, it can take many years to recover the costs of grid extension through electricity charges (Table 2). The situation is even worse because electricity revenues also need to cover the costs of generation.

Decentralized approach

In some communities, where the main grid is not nearby or is insufficiently reliable, off-grid generators have been deployed. The technological landscape is changing in favour of more decentralization as the costs of PV and battery energy storage continue to fall sharply and as energy efficiency, remote connectivity and data analysis help to reduce operating costs and improve efficiency. Renewable hybrid mini-grids as well as household-sized solar

Table 2

Grid extension fundamentals

Country (Year of project)	Cost of grid extension per household (USD)	Average household consumption* (kWh/year)	Residential retail tariff in 2016 (USD/kWh)	Time for revenue to exceed grid extension cost (years)
Myanmar (2014)	500	729	0.028	24
Kenya (2014)	1,047	380	0.126	22
Mozambique (2017)	690	767	0.065	14
Rwanda (2011)	840	468	0.241	7
Botswana (2011)	615	2,201	0.070	4
Peru (2005)	710	1,589	0.138	3

Source: BloombergNEF, World Bank, Asian Development Bank, Climatescope 2019. *Grid-connected households only. Note: Cost of grid extension per household was calculated by dividing the total project investment for a grid extension project by the number of households who gain connections.

home systems can complement and compete with the grid in terms of the costs of electricity, speed of deployment and profitability. Table 3 summarizes the four main technological approaches to reach populations that lack electricity access.

Cost-efficient technology to deliver electricity

The most cost-efficient technology to deliver electricity depends not just on the distance from the

Table 3

The main approaches to provide electricity access

	Option	Advantages	Risks	Typical MTF level
	**Extending the main grid**	• Cheapest power generation cost • Good for meeting high power demand	• High initial cost • Lengthy process to build • Cost rises with remoteness • Distributed renewables	Tier 3 and above
	**Mini-grids**	• Local aggregation of demand • Higher reliability of electricity than off-grid solar kits	• Main grid arrival • Low power demand makes it difficult to recover costs	Tier 3
	**Solar home systems***	• Deployed through retail channels • Customers can choose from broad range of products • Targeting based on individual credit risk	• Very costly per unit of energy • Limited range of appliances that can be powered	Tier 2
	**Pico PV (single/ multiple light points)**	• Can cost as little as USD 5	• Provides only lighting and possibly phone charging	Tier 0-1

Source: BloombergNEF, Lighting Global. Photo source: Bloomberg, d.light, *The authors define these as plug-and-play solar home systems that do not require an individual selection of components in this report. Note that the MTF levels are indicative.

nearest grid line, but also on the amount of energy that is consumed. For low-income consumers with an annual energy consumption of 70–200kWh per household, amortizing the cost of a grid extension over 20 years can add USD 0.10–0.50/kWh, easily doubling retail tariffs and pushing the upper range of the cost as high as USD 1/kWh (Figure 12). This additional cost makes mini-grids competitive in many places, despite the much higher cost of generating power in a kW-scale installation.

Solar home systems can cost upwards of USD 1.5/kWh in terms of gross generation.[3] Bundled with super-efficient DC appliances and expected cost declines over the coming decade, they are nonetheless expected to become increasingly more competitive. The ease of buying and installing them already makes them desirable for consumers where there is no alternative, and the retail-based distribution model and ease of access is likely to further support them.

The cost of electricity delivered via grid extension is significantly lower for households with a higher energy consumption of 1,000kWh per year (Figure 13). The expense of extending the grid is amortized quickly, adding just USD 0.03–0.11/kWh. In more easily accessible places, or where there is a reasonable expectation of demand growth, the grid is therefore likely to remain the primary choice. Where access is challenging or grid power is expensive, solar home systems are already cheap enough to compete with mini-grids. Electricity delivered from mini-grids will become cheaper if the system is actively managed to add loads during the daytime, through new business and operating models.

2.2 What is a mini-grid?

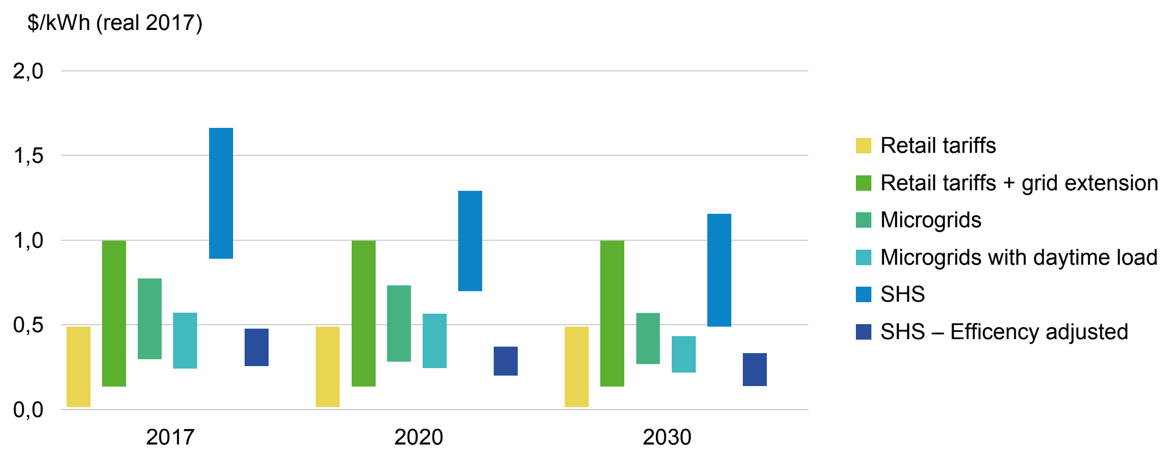
Definition in this research

A mini-grid is a group of interconnected distributed energy resources (DERs) plus load(s) or a single DER plus load(s) within clearly defined boundaries. The main feature of mini-grids is their ability to operate independently, either in remote locations not reached by the main grid (isolated mini-grids) or in grid-connected areas where the electricity supply from the main grid may be interrupted (grid-connected mini-grids).

Mini-grids can incorporate either a single generation source (e.g., a diesel generator) or multiple DERs (e.g., PV and battery storage), and supply electricity to more than one building. Solar home systems and energy generation plants installed at customer

Figure 12

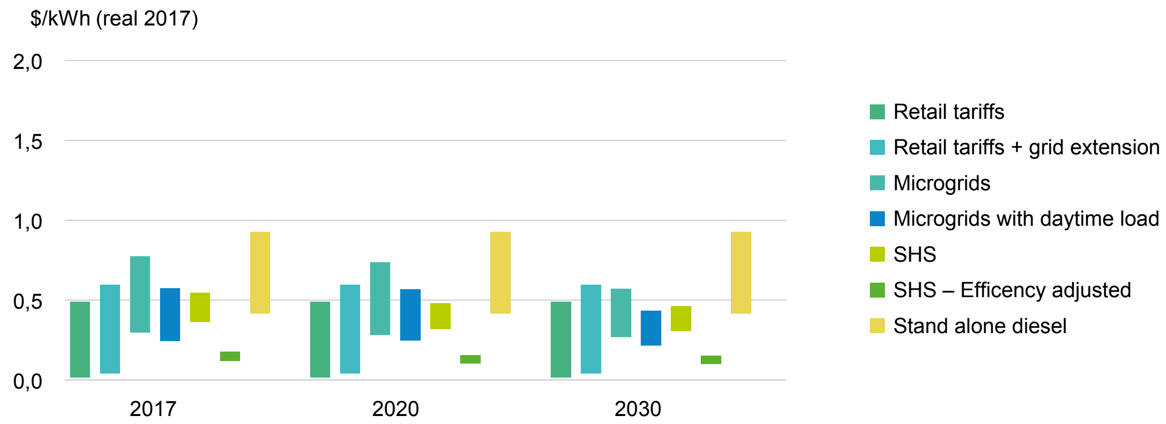
Cost of delivered energy for low-income consumers (200kWh per year)



3 Note that pay-as-you-go solar companies offering solar home systems generally sell energy services, not electricity.

Figure 13

Cost of delivered energy for medium-income consumers (1,000kWh per year)



Source: BloombergNEF. **Note:** Low-income customers are assumed to use 200kWh per year or a 10-35W solar home system. Medium-income customers are assumed to consume 1,000kWh/year or a 200W solar home system. The average grid extension cost per household was derived from past project examples. A mini-grid with daytime load produces additional electricity for non-residential activities. The analysis of low-income consumers does not include stand-alone diesel because the technology is unaffordable. Retail tariffs refer to national utility tariffs.

premises to supply electricity to just one customer are not considered to be mini-grids in this report.

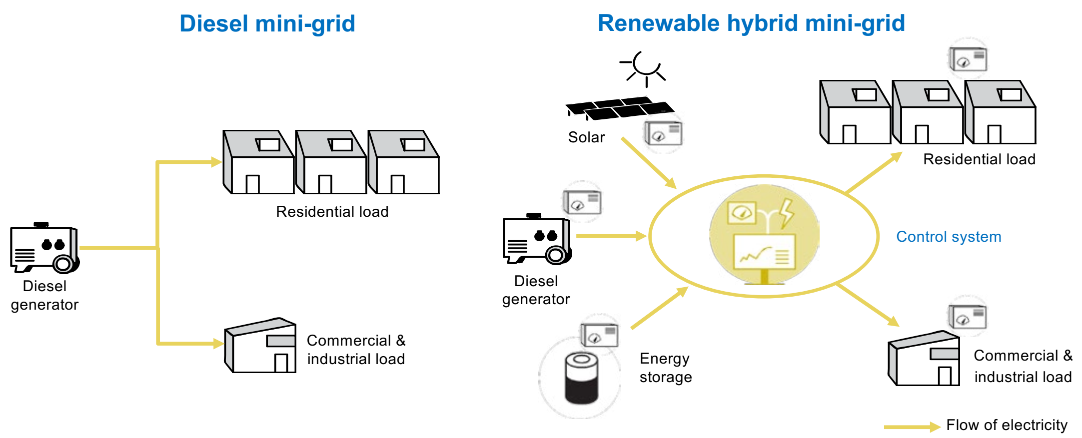
There is no minimum or maximum generation capacity threshold. Systems are larger when more customers, particularly large power consumers, are connected.

Isolated mini-grids

Isolated mini-grids are installed in settings that are physically separate and far from the main grid. Most installed mini-grids in remote areas in emerging countries are isolated. Historically, a typical isolated mini-grid was connected to only a single generator or small-scale hydro power plant, and served residential and/or commercial and industrial (C&I) customers via a local distribution network (Figure 14). Thanks to declines in the costs of PV and battery energy storage as well as advancements in control systems, modern isolated mini-grids usually include more than one DER, allowing mini-grid owners to save on energy costs

Figure 14

Architecture of isolated mini-grid systems



Source: BloombergNEF.

while providing customers with access to reliable electricity around the clock.

Grid-connected mini-grids

Mini-grids can be connected to the grid by extending the main grid to meet them or by installing the mini-grid where the main grid is already located. In emerging countries, some grid-connected customers — who often experience frequent or lengthy outages and voltage fluctuations — use mini-grids to access reliable electricity and to save on energy costs. The control system allows the mini-grid system to switch to island mode when the main grid is interrupted, allowing electricity from the mini-grid to continue to flow to customers. For instance, the market in Sabon Gari in Kano State, Nigeria, has 12,000 shops where grid electricity is available, but is highly unreliable (Victron Energy, 2019). In 2019, a solar hybrid mini-grid incorporating a 1.6MW PV array and 1.6MWh battery storage was installed, allowing customers to access round-the-clock electricity. Export of excess electricity to the main grid is dependent on regulations.

Value streams of mini-grids

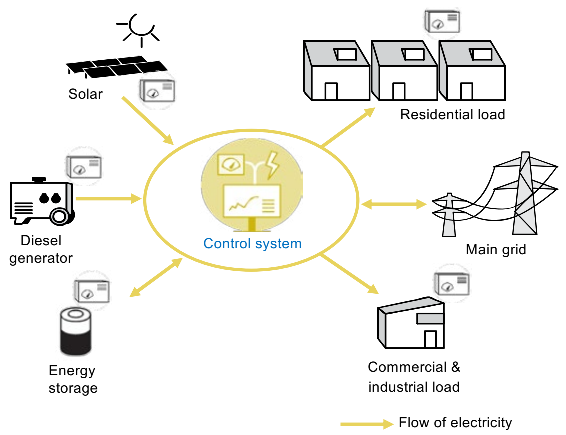
Mini-grids are also expected to reduce the burden on utilities of integrating various small renewable energy assets. They can help address the challenges that utilities face when integrating intermittent renewable energy into the grid, since much of the necessary balancing can instead be done locally, within the mini-grid itself. When there is a market for demand response or ancillary grid services, the mini-grid control system can also determine when it is profitable for the mini-grid to participate.

Mini-grids can also absorb and balance more distributed generation sources on site, deferring capital expenditure on the distribution grid. These systems are typically on a much larger scale in developed countries (megawatts) than those for electricity access in emerging countries (kilowatts). In the US, Go Electric has developed a 400kW mini-grid that offers grid services to help maintain grid stability during periods of peak demand or when grid frequency or voltage changes, while providing uninterrupted power to Parker Ranch as its main customer (Go Electric, 2018). In Australia, the national government is backing mini-grids because they have the potential to reduce costs that would otherwise be incurred in upgrading the grid system. It set up an AUD 50 million (USD 35.6 million) fund to examine the viability of up to 50 mini-grids in remote and *fringe-of-grid* communities (Department of the Environment and Energy, 2019).

Figure 16 summarizes the value streams of a mini-grid. They depend on: location (e.g., whether connected to the main grid or isolated), reliability of main grid electricity, grid electricity prices and regulations and power market conditions. The total value of these will be highest in areas with high demand for resilience, reduced energy costs, sustainability and balancing services.

Figure 15

Architecture of a grid-connected mini-grid system



- Customers primarily use power from the mini-grid, or when outages occur on the main grid.
- Exporting electricity to the main grid is allowed if there is a net-metering scheme.

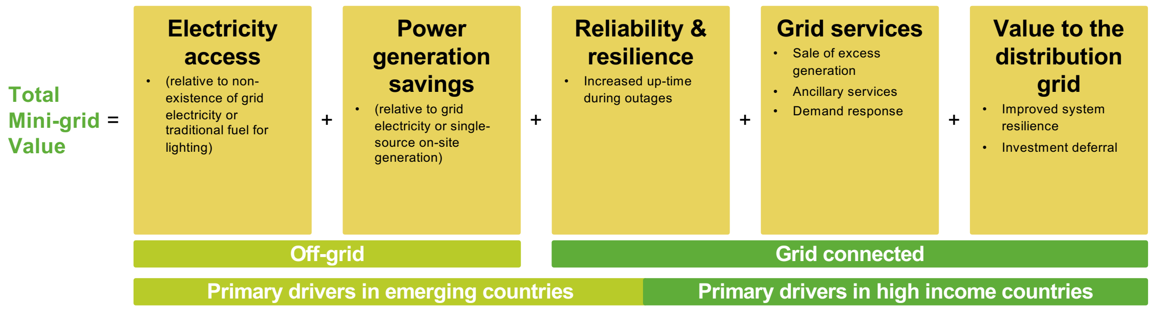
Other functions of grid-connected mini-grids (but not typical in emerging countries):

- Providing ancillary services to the main grid if regulations allow.
- Balancing the grid locally where significant intermittent renewable energy is installed.

Source: BloombergNEF.

Figure 16

Value streams of a mini-grid



Source: BloombergNEF.

Synonyms

Microgrid is probably the most commonly used alternative term for a mini-grid. Both mini-grids and microgrids allow for independent operation. While there is no single definition for mini-grids or microgrids, variation in their use typically comes down to the size of the generation system (Table 4). There are other synonyms such as nano-grid and pico-grid, which also relate to the size of the system. Microgrid is commonly used in some markets such as the US and Japan, regardless of size.

In this report, the authors only use *mini-grid* although some organizations and research may refer to mini-grids as microgrids. The authors do not apply any additional criteria to the definition such as size, number of DERs within a mini-grid or ability to interact with the main grid.

Box 1

First, second and third generation mini-grids

The World Bank Energy Assistance Management Program (ESMAP) identifies three generations of mini-grids. First generation mini-grids were built more than 100 years ago, isolated and scattered. They were later integrated into the larger grid system. Second generation mini-grids are small-scale and isolated systems, built by local communities or entrepreneurs to provide electricity to communities in remote areas outside the reach of the main grid. Diesel generators and small-hydro are the most dominant generation technologies used for such mini-grids and are typical in remote areas in emerging countries today. Third generation mini-grids are technically more complex than the first two types. These mini-grids normally incorporate new energy technologies such as PV and battery energy storage. They are not necessarily isolated; some of these mini-grids were built in grid-connected areas for the purpose of bridging outages and to reduce energy costs. Business models for these projects tend to be more diverse (e.g., rental model or energy-as-a-service).

ESMAP identified more than 19,000 installed mini-grids in its 2019 report, of which the vast majority are second generation according to the above definition (ESMAP, 2019). However, nearly all mini-grids it found under current development are third generation.

This report covers both second and the third generation mini-grids but focuses mainly on the latter as these have become more mainstream. Government policies, interventions by international organizations, financing and business models are all trending towards third generation mini-grids.

Table 4

Example of definition by size

Name	Size
Microgrid	1–10kW
Mini-grid	10kW–10MW

Source: EU Energy Initiative Partnership Dialogue Facility (EUEI PDF), BloombergNEF. **Note:** This is one example. Distinction by size can vary depending on organizations.

Customer segmentation

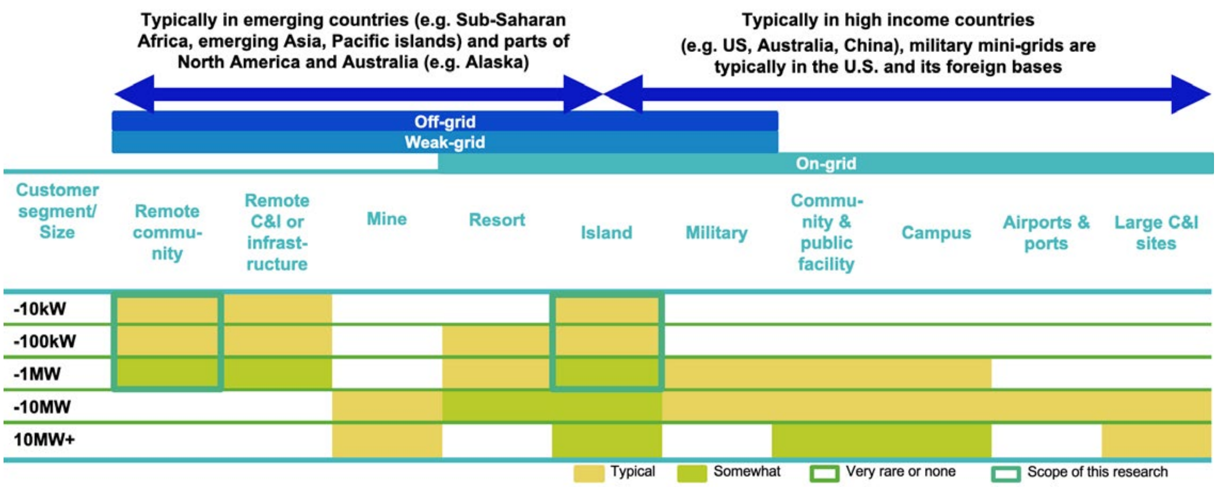
Different sites and customers use mini-grids for different purposes (Figure 17). As the technology has advanced and concerns over resilience have increased, more companies have become active in the mini-grid industry, and the range and types of customers have broadened.

In developing countries, typical customers of mini-grids are rural households, small C&I sites and those with remote infrastructure such as telecom tower sites in off-grid or weak grid areas. Island communities are another customer segment. They use mini-grids to integrate renewable energy and/or reduce dependence on imported fossil fuel for power generation (e.g., islands in Hawaii. Japan and Portugal), or for electricity access in emerging countries (e.g., Caribbean islands, Indonesia, Pacific islands and the Philippines).

In high-income countries such as the US, Australia and China, mini-grids tend to be large, often over 1MW. Large industrial or commercial facilities such as car manufacturing plants, petrochemical facilities, ports and airports typically install MW-scale mini-grids. The customer types are particularly diverse in the US, where, as resilience concerns have increased over the last several years, some communities, hospitals, university campuses and military bases use mini-grids to ensure uninterrupted power supply. Mini-grids have become popular for mining companies whose mining sites are located in remote areas in Western Australia and Sub-Saharan African countries. They traditionally use diesel, heavy-fuel oil and gas generators on-site for power supplies. Some miners have retrofitted their generation plants with renewables to save energy costs (e.g., B2Gold's 30MW solar hybrid mini-grid in Mali). These mini-grids are usually used in a different context from rural mini-grids in emerging countries. Customers in high-income countries tend to use the technology for a back-up of power supply, energy cost saving, an increasing share of renewable energy use and renewable energy integration.

Figure 17

Mini-grid customer segmentation and typical size



Source: BloombergNEF. **Note:** This research uses only the term 'mini-grid' regardless of the size of the system.

Section 3

Electricity access trends

By the end of 2018, the total estimated number of people who lacked access to electricity globally had fallen to about 900 million, from 1.4 billion in 2010.[4] Grid extension as well as rapid deployment of off-grid solar kits contributed to this remarkable progress, particularly in Asia. However, electrification is much more variable across Sub-Saharan African countries, with the number of people who do not have access remaining constant in recent years, at just over 600 million. Achieving universal electricity access by 2030 is unlikely without the deployment of new energy access technologies, such as mini-grids, at unprecedented speed.

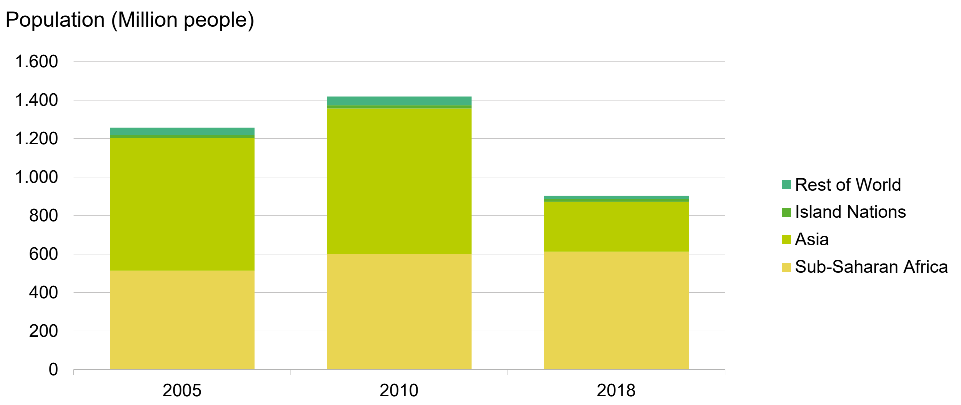
3.1 Electricity access gap

At the end of 2018, some 88 percent of the world's population of 7.6 billion had access to electricity, the highest number ever. The number of people without electricity access has declined by about 350 million since 2005 (Figure 18). Until less than a decade ago, the majority of those without energy access were in Asia, but there has been a dramatic improvement there in recent years. Asia's expansion of main grid infrastructure, particularly in India (IEA, 2019), and distribution of off-grid solar kits have been the primary reasons for the decline in the number of people without electricity.

In Sub-Saharan Africa, 57 percent of the total population did not have access to electricity at the end of 2018, an improvement from 69 percent in 2010 due to grid extension as well as deployment of off-grid solar kits. However, in absolute terms, the number of people without electricity access in the region increased to 612 million, due to the steady increase in total population.

Figure 18

Number of people who lack electricity access, by region[5]



Source: BloombergNEF, Climatescope 2019, World Bank.

4 Estimates of population without electricity access for 63 countries are based on Climatescope 2019. The authors used data from the World Bank for the remaining countries.

5 The authors estimate some 900 million people lacked electricity access at the end of 2018, larger than the IEA's 862 million and 789 million in the SDG7 Tracking Report. The difference is due to electrification rate assumptions. Some governments calculate electrification rates based on villages reached by the distribution grid, which does not necessarily mean all the households within the villages gained access.

Island nations, mostly in the Pacific and Caribbean, account for about 13.5 million people without electricity access or 1.5 percent of the global total. Overall, electrification rates have improved across these nations since 2005, particularly in the Pacific islands where there has been fast uptake of off-grid solar kits.

Progress is not uniformly distributed

Progress in electricity access varies significantly by country, even within the same region. These differences suggest that progress can be accelerated where governments pursue determined electrification programmes (Figure 19, Figure 20).

In Asia, the Philippines and Indonesia have seen steady progress in the last eight years and achieved electrification rates of 89 percent and 98 percent by the end of 2018 respectively. However, progress beyond this may be slower and require decentralized energy technologies on remote islands where grid extension is not economically viable. Bangladesh improved its electrification rate from 49 percent to

Figure 19

Historical electrification rates of select Asian countries

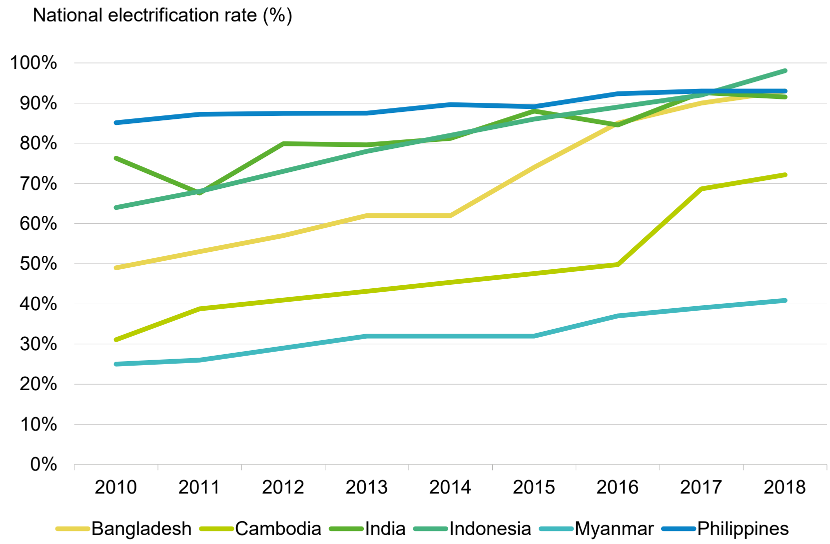
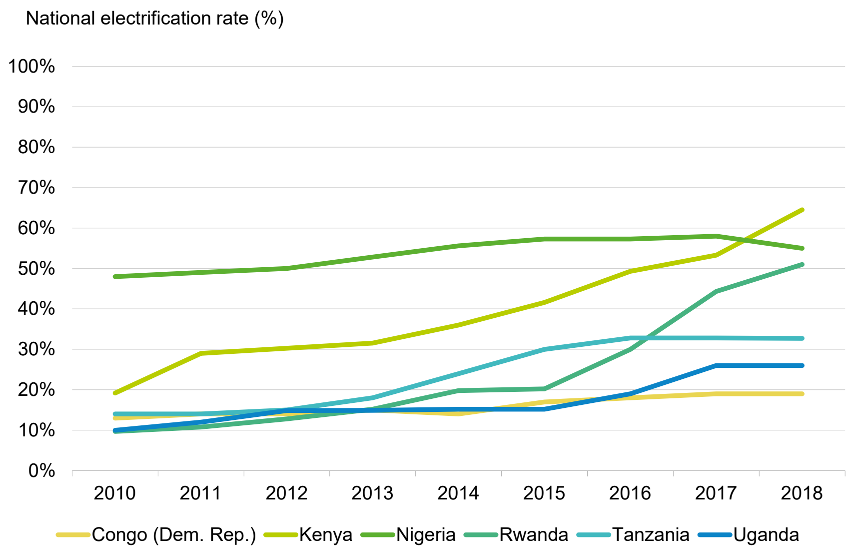


Figure 20

Historical electrification rates of select Sub-Saharan African countries



Source: BloombergNEF, Climatescope 2019, World Bank.

93 percent between 2010 and 2018 with a boom in the off-grid solar market, and concessional finance provided by the Infrastructure Development Company Limited (IDCOL).

In Sub-Saharan Africa, off-grid solar kits have underpinned development in East African countries. Rwanda's electrification rate jumped from 20 percent in 2015 to reach 51 percent by the end of 2018, approximately a third of which was due to off-grid solar kits (Rwanda Energy Group, 2019). Kenya's electrification rate improved from 18 percent to 65 percent from 2005 to 2018 thanks to both grid extension and off-grid solar.[6] Nigeria, however, saw a drop from 58 percent to 55 percent between 2017 and 2018 as population growth outpaced the number of people gaining access.

Papua New Guinea, the most populous country in the Pacific with about 8.6 million people, increased its electrification rate from 15 percent to 54 percent between 2005 and 2018. The nation has more than 10,000 ethnic clans spread across 600 islands. The complex topography of these islands makes it hard to extend the main grid. By 2017, 60 percent of households were using off-grid solar kits, up from 2 percent in 2012 (Lighting Pacific and IFC, 2018). Conversely, Haiti's electrification rate was only 25 percent, the lowest amongst the island nations, although recent funding from the government and the World Bank is likely to promote distribution of off-grid solar kits, which should raise the electrification rate in the next few years (PV magazine, 2019).

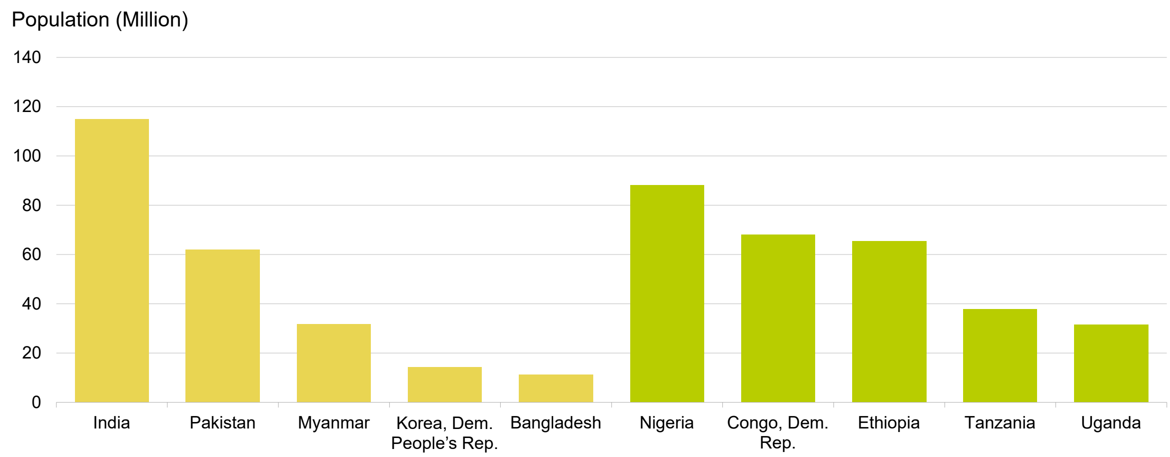
Figure 21 shows the countries with the largest number of people lacking electricity access in Asia and Sub-Saharan Africa in 2018. India was the largest Asian market, with 115 million people without electricity access. Nigeria was the largest Sub-Saharan African market with 88 million people lacking electricity, followed by 68 million in the Democratic Republic of Congo.

Reliability challenges

Even if a customer gains electricity access from the grid, the supply of electricity is not always reliable (i.e., electricity is supplied intermittently). For example, the Government of India claimed "*100% electricity access*" at household level in March 2019 (India Ministry of Power, 2019). However, a survey of 10,000 rural consumers and businesses in four states commissioned by Smart Power India Initiative of the Rockefeller Foundation found that even though most respondents were located within less than 50 metres of an electricity pole, many did not actually use electricity from the grid (Smart Power India, 2019). In the states of Uttar Pradesh and Bihar, some 32 percent and 36 percent of small businesses respectively exclusively used other sources such as solar, mini-grids, lead-acid batteries or diesel generators (Figure 22). An additional 18 percent

Figure 21

Countries with largest populations lacking electricity access in 2018



Source: BloombergNEF, Climatescope 2019, World Bank.

6 The Kenyan government claimed it had a 75 percent electrification rate in 2018, possibly higher than the actual rate according to an interview for this report with stakeholders in Climatescope 2019.

and 32 percent, respectively, used those technologies in conjunction with the grid, presumably to bridge the 9–12 hours per day when the grid does not supply electricity. Such usage patterns suggest that distributed energy options are not just viewed as a last resort for areas not reached by power lines, but can be seen to complement or displace the grid and provide additional services to the consumer.

3.2 Will universal access be achieved by 2030?

The short answer to this question is: no, not on current trends. According to Climatescope 2019, as many as 65 governments in Africa, Asia and Latin America have set medium or long-term targets for electricity access. Some of the more ambitious examples include Kenya's universal electricity access target of 2020, Ethiopia's by 2025 and by 2030 for Haiti and Myanmar. The targets are not on track to be met. Even if we take such announcements at face value, the financing gap facing the world is huge and not currently set to achieve the goal of universal electricity access by 2030 (Sustainable Energy for All and Climate Policy Initiative, 2019). Under the current pace of electricity access progress and planned policies, about 620 million people would still be deprived of electricity access in 2030. This would be about 8 percent of the world's population, with nine in 10 people lacking access living in Sub-Saharan Africa (IEA, 2019). This suggests an urgent need to accelerate electrification initiatives and financing to introduce and scale up least-cost technologies for electricity access.

Beyond electricity access

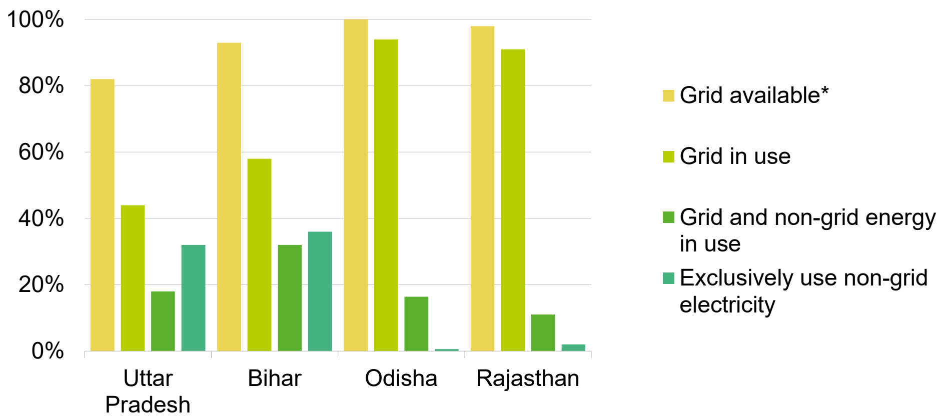
Achieving universal electricity access targets does not necessarily mean that all people will have access to reliable electricity at any time. Most governments in emerging countries measure electricity access simply based on whether consumers have any means to use electricity, regardless of its availability, reliability and quality. Since this approach does not give a complete picture of the quality of access, the World Bank Energy Sector Management Assistance Program (ESMAP) and Sustainable Energy for All (SEforALL) proposed Multi-Tier Frameworks (MTFs) in 2015. MTFs can help better capture the multidimensional aspects of energy access including both electricity and cooking, different technologies and sources that can provide energy access, while accounting for difference in people's experience (ESMAP, 2015).

Figure 23 shows metrics within the MTFs to assess household electricity supply. The frameworks, for example, allow us to measure whether households are using simple solar lanterns or grid electricity, or how many hours households can use grid electricity per day on average. Even if the grid electricity is available, households fall into Tier 3 or lower if availability is less than eight hours per day.

ESMAP has conducted studies on the status of energy access in 16 countries across Africa, Asia and

Figure 22

Available electricity options among small rural enterprises in India



Source: Smart Power India / Rockefeller Foundation. * Measured as having an electricity pole within 50 metres.

Figure 23

Multi-tier frameworks to measure access to household electricity supply

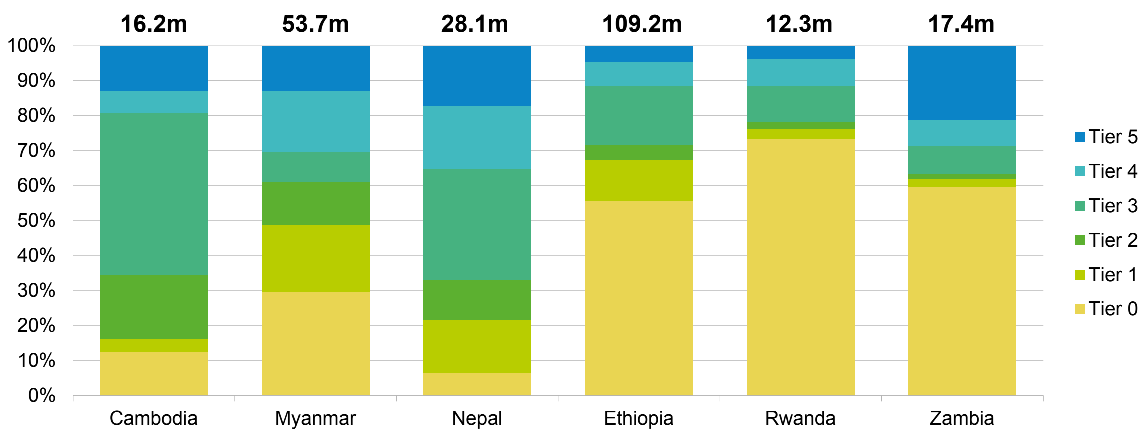
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Electricity supply	1.Peak capacity	<3W (<12Wh)	Min 3W (Min 12Wh)	Min 50W (Min 200Wh)	Min 200W (Min 1kWh)	Min 800W (Min 3.4kWh)	Min 2kW (Min 8.2kWh)
	2.Availability (hours per day/evening)	<4hrs/1hr	Min 4hrs/1hr	Min 4hrs/2hrs	Min 8hrs/3hrs	Min 16hrs/4hrs	Min 23hrs/4hrs
	3.Reliability	More than 14 disruptions per week			At most 14 disruptions per week, at most 3 disruptions per week with total duration of 2hrs+	Max 14 disruptions per week	Max 3 disruptions/week of total duration <2 hrs
	4.Quality	Household experiences voltage problems that damage appliances				Voltage problems do not affect the use of desired appliances	
	5.Affordability	Cost of a standard consumption package of 365 kWh/year is more than 5% of household income			Cost of a standard consumption package of 365 kWh/year < 5% of household income		
	6.Legality	No bill payments made for the use of electricity				Bill is paid to the utility, prepaid card seller, or authorized representative	
	7.Health & safety	Serious or fatal accidents due to electricity connection				Absence of past accidents and perception of high risk in the future	
Electricity services			Task lighting and phone charging	General lighting, phone charging, television and fan (if needed)	Tier 2 and any medium-power appliances	Tier 3 and any high-power appliances	Tier 4 and any very high-power appliances
Electricity consumption	Daily consumption	<12Wh	12Wh+	200Wh+	1,000Wh+	3,425Wh+	8,219Wh+

Source: Adapted from World Bank ESMAP, SEforALL.

Latin America using the MTF approach. Figure 24 shows the results for six of these. Households categorized as Tier 3 or above mainly use grid electricity. Those in Tier 2 or below typically use decentralized energy technologies such as off-grid solar and mini-grids, or have little or no access to electricity if they belong to Tier 0. The chart also indicates that the majority of households in Sub-Saharan Africa have no access to electricity or use basic tools for lighting, with for example more than 55 million people belonging to Tier 0 in Ethiopia. In Asia, more households have access to grid electricity in some form, but there is room for further improvements in reliability.

Figure 24

Household distribution by tier



Source: World Bank ESMAP, Scaling Up Renewable Energy Program, SEforALL, BloombergNEF. **Note:** The figures above the columns reflect population (million) in 2018. The distribution of population by tier is based on surveys conducted between 2017 and 2019. Tier 0 includes both those without electricity access and with very basic tools for electricity.

Section 4
Mini-grid market trends

The authors identified 5,544 mini-grids installed in Sub-Saharan Africa, Asia and small island nations with some in Latin America (see Appendix A for the data collection). The mini-grid industry has been consolidated with more participation from large corporates pursuing investments, mergers and acquisitions (M&A) and partnerships. No single form of business model has dominated as developers need to adapt their approaches to the regulatory environment.

4.1 Overview

As of February 2020, there were 5,544 installed mini-grids identified in the mini-grid asset database built in this research, of which 60 percent and 39 percent were in Asia and Sub-Saharan Africa respectively (Figure 25). Generation capacity totalled 2.37GW. Remote mini-grids are not a totally new phenomenon, but the technologies used for them changed substantially from 2012. Most of the earlier mini-grids use a single fuel source: fossil fuel, hydro or biomass (so-called 'second generation' mini-grids). About 31 percent of the existing installed mini-grids use diesel or hydro (Figure 26). The mini-grids installed in the last five years have tended to incorporate PV and battery storage with diesel generators as backup (i.e., solar hybrid mini-grids) as technology costs have fallen and as control technologies to integrate multiple distributed energy resources (DERs) and optimize their operation have advanced. PV is also modular and relatively easy to install in remote areas. Solar hybrid mini-grids are the most dominant form of modern mini-grids installed today, and many mini-grid programmes are led by governments that are eager to promote them. Hydro mini-grids continue to be common where resources are available (e.g., in parts of Tanzania and Nepal).

In Sub-Saharan Africa, Senegal and Tanzania have 227 and 209 mini-grids installed respectively. In Senegal, at least 63 projects were built under the Energising Development (EnDev) programme. In Tanzania, a robust regulatory framework resulted

Figure 25

Installed mini-grids by region

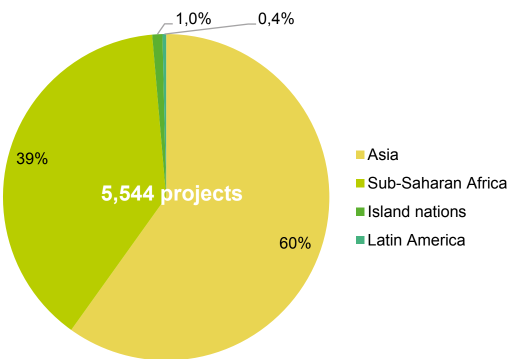
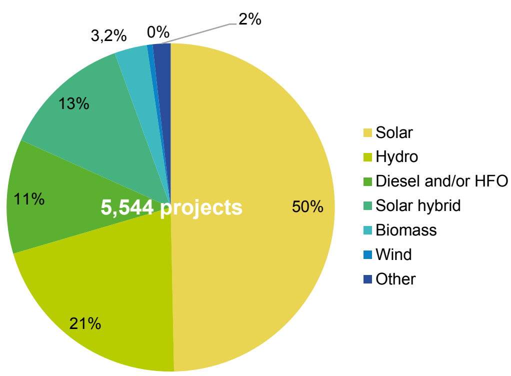


Figure 26

Installed mini-grids by technology



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, surveyed developers.

in a rural electrification programme that has attracted private developers and spurred the solar hybrid mini-grid market. In Asia, India leads with 1,792 mini-grids, followed by 1,061 in Indonesia and 326 in the Philippines. The latter two countries have thousands of islands that have no main grid connections and are either reliant on mini-grids or have no access to electricity. Figure 27 and Figure 28 show the cumulative number of installed mini-grids in the two regions. Both markets were developed in the early 2010s with the introduction of solar mini-grids. While more diverse geographies introduced mini-grids across Sub-Saharan Africa in the latter half of the decade, mini-grid installations in Asia were concentrated in only a few countries.

4.2 Mini-grid value chain

Figure 29 illustrates the mini-grid value chain in terms of technology. Companies shown here focus on developing and selling technologies, including both hardware and software used for mini-grid systems, with a limited number of equipment vendors offering battery energy storage systems, on-site generators and renewable energy equipment such as PV modules. The players that integrate these

Figure 27

Historical cumulatively installed mini-grids in Sub-Saharan Africa

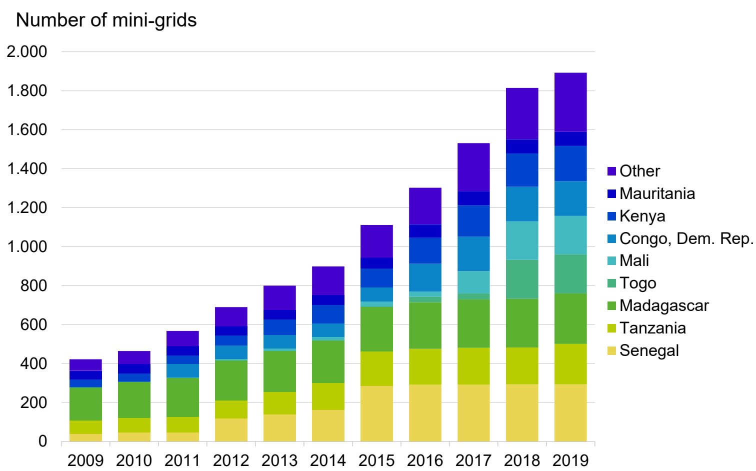
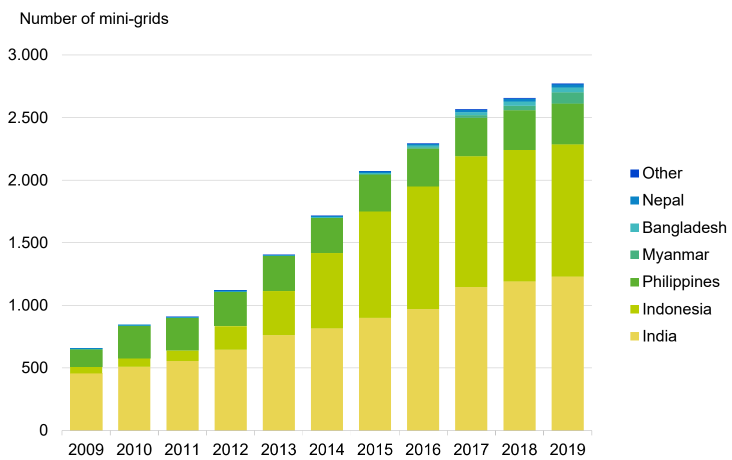


Figure 28

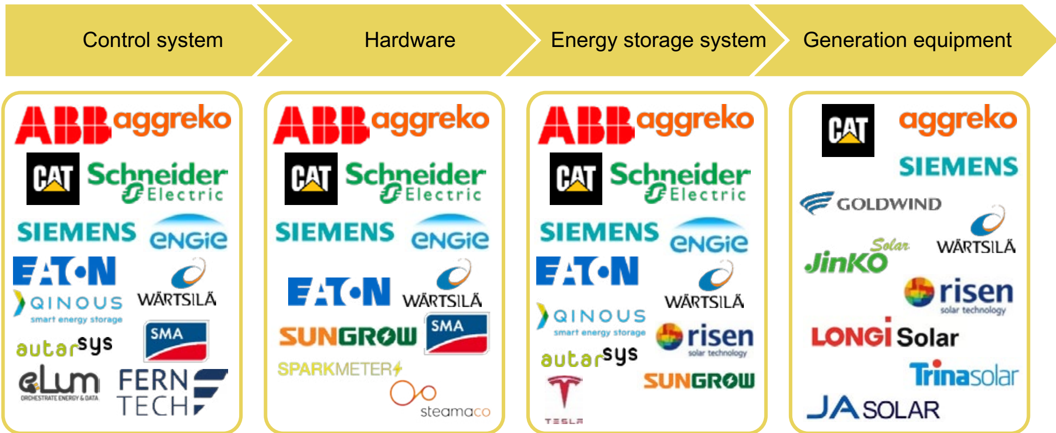
Historical cumulatively installed mini-grids in Asia



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, surveyed developers. **Note:** Projects without commercial operation dates are not included.

Figure 29

Value chain of mini-grids (technology)



Source: BloombergNEF, company websites. **Note:** The logos in each box only show examples of companies providing those technologies for mini-grid projects in general. The logos of parent companies are shown in the value chain if their subsidiaries are active in that area.

technologies and offer services tend to be more fragmented because the renewable hybrid mini-grid market is still relatively new.

Most vendors currently active in the mini-grid market originally came from other manufacturing sectors such as those for energy storage systems and generation equipment. They tend to focus on product sales although some vendors integrate all mini-grid components into an easily installable platform, reducing the costs and complexity of integration, installation and operation. The following are the physical components of mini-grid systems.

- **Control system**: The control system helps the mini-grid operate independently, reliably and optimally by managing multiple DERs and loads within a mini-grid. It is a combination of several components including a mini-grid management system (software), switches/routers and the user interface (hardware). The control system normally has remote monitoring and data capture capabilities.
- **Hardware**: This includes inverters, protection relays, switchgear, transformers and smart meters. A vendor in this category manufactures at least one of these.
- **Energy storage system**: These companies integrate energy storage components including batteries, battery packs, the power conversion system and balance-of-system equipment. They often add their own software.
- **Generation equipment**: This includes on-site generation and renewable energy equipment manufacturers, for example of PV module wind turbines. This is a well-established sector.

Some of the companies offering control systems and hardware are start-ups established in recent years.

Chinese technology providers are predominant in the hardware manufacturing part of the value chain, in particular, those manufacturing PV modules and lithium-ion battery cells. Figure 30 illustrates the mini-grid value chain in terms of players offering services, from development to installation to operation and maintenance (O&M). Many mini-grid developers cover the entire value chain of mini-grid service offerings. Some mini-grid control system vendors (usually multinational large companies) offer full turnkey project development or work closely with local installers who are in charge of project development, construction and installation and O&M.

Mini-grid systems also require the following:

- **Site identification**: Developers base decisions for site identification on criteria such as distance from the main grid, population density, average income and level of economic activities. Developers active in Sub-Saharan Africa tend to target communities that already have commercial and industrial (C&I) facilities, or customers with assets

Figure 30

Value chain of mini-grids (services)

Source: BloombergNEF, company websites. **Note:** The logos in the box are examples of companies providing mini-grid services in general, not just for rural electrification but also for utility-scale projects.

such as shops, machinery and agricultural pumps that ensure a predictable level of power demand. Unless governments disclose candidate sites, the site selection process can take a long time as it may involve analyzing GIS data of settlements that lack electricity, talking to local communities, and conducting detailed studies on power demand and sources of renewables. In Indonesia, the government identifies sites and private companies are in charge of the subsequent steps.

- **Project planning and development**: This includes the technical design of mini-grid systems, negotiating with relevant stakeholders including authorities and local communities for approvals, financing, administration works such as obtaining required licences, and capacity development.
- **Construction and installation**: After procuring the necessary equipment, developers and often local installers commit to civil and electrical works to build and commission a mini-grid sys-

Box 2

Case study: Husk Power installs ABB's MGS-100 in India

ABB offers mini-grid systems that address a wide range of customers, from below 100kW for rural electrification to double-digit MW-scale projects for utilities and off-grid mines. One of its solar division products, MGS100, targets rural communities and C&I customers in off-grid and unreliable grid areas in emerging countries. The product is an all-in-one mini-grid system, pre-wired and configured, and can be installed within a day once it is delivered to the site. The company had sold over 100 systems by the end of December 2019, with installations in eight countries located in Africa and Asia. While ABB offers full turn-key mini-grid development services including its control system for large-scale customers (e.g., off-grid mines), the business model for MGS100 is different. In India, ABB works with several local developers such as Husk Power, which is in charge of transporting, installing, operating and maintaining the MGS100. ABB's strategy is to focus on its product, with its partners concentrating on development, construction and O&M – all of which require knowledge and experience of both the local market and local regulations.

tem. Transporting equipment to the project site is also a part of this process.

- **O&M**: This involves emergency response, fuel management and delivery, revenue collection, equipment replacement, and quality control of customer connections and installed equipment. It may include customer education on electricity usage. Remote monitoring and control systems are typically deployed as mini-grids are installed in remote areas, which are difficult to access and costly for engineers to visit for maintenance. Developers usually provide technical training at the mini-grid site to local staff, who are in charge of some of those tasks.
- **Soft services**: Soft service providers support mini-grid developers at different stages of a mini-grid project through providing services including identification of optimal sites for mini-grids using satellite imagery, mini-grid system designs, equipment procurement, customer acquisition and management, and remote monitoring and operation of mini-grid systems. The services often involve data analytics. Use of these services is important to keep development cost (as part of capex) and opex low by managing soft costs efficiently.

Project ownership depends on whether the developer continues to own the asset directly or transfers it to a third party (e.g., government, state-owned utility or community). This depends on regulatory frameworks and the developer's preferred business model.

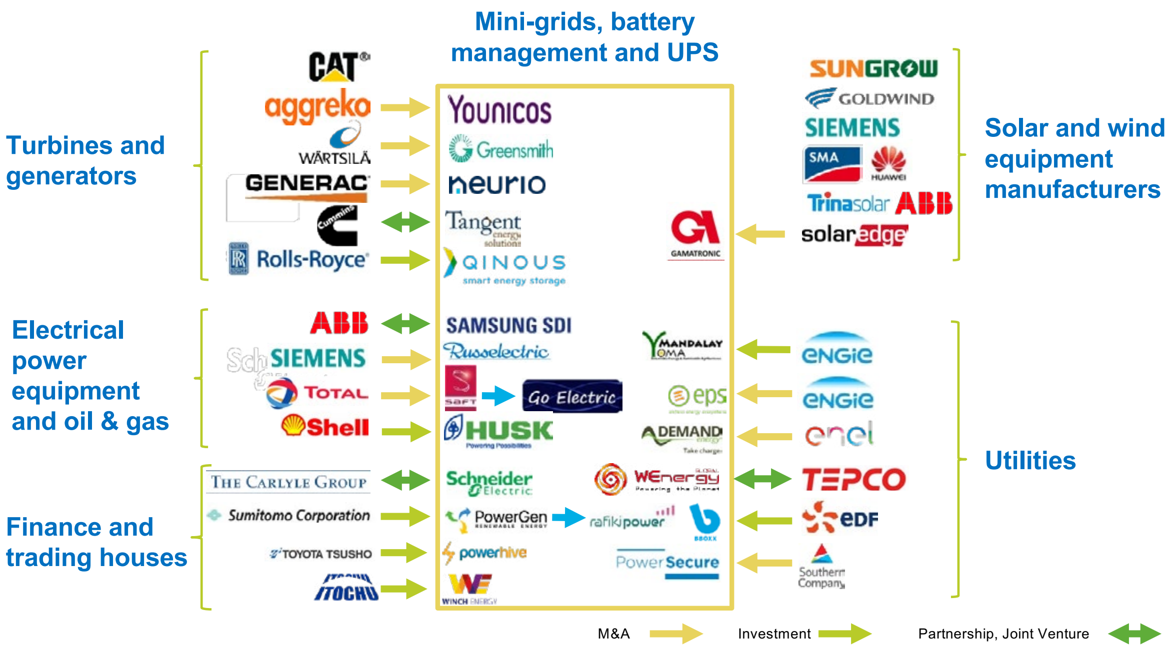
Convergence in the mini-grid industry

As the mini-grid market has grown, not just for rural electrification but also for utility-scale projects, large corporates have made an entry into the market in the last few years, either by acquiring companies that offer battery storage systems, uninterrupted power supply (UPS) and control software technologies, or by investing in or partnering with them (Figure 31).

These corporates aim to use their partners' technologies and combined sales networks to offer new products and services and to access new customers. Some primarily target MW-scale mini-grids, whereas others look at smaller-scale projects in emerging markets or cover both. Two utilities, ENGIE and RWE, used their internally developed start-

Figure 31

Select companies with mini-grid activities, partnerships or M&A since 2016



Source: BloombergNEF, company websites. **Note:** Companies without arrows are developing proprietary products related to micro-grids, battery management or uninterrupted power supply (UPS). The diagram includes companies that are active in MW-scale mini-grids and smaller mini-grids for rural electrification.

ups to develop rural mini-grids (PowerGen acquired RWE's Off-Grid Solutions operated under the Rafiki Power brand in August 2019).

For rural electrification, large corporates tend to work with experienced developers active in Sub-Saharan Africa or Asia through equity investments, selling their products through local partners or bringing their technologies to assist with mini-grid development. There are also a few cases of joint ventures for mini-grid development in particular countries.

Turbines and generators

Companies such as Aggreko, Caterpillar and Wärtsilä, with backgrounds in powering off-grid or backup power systems, have added mini-grids to their product portfolio in response to the rise of solar and battery storage. Their aim is to offer all of these technologies in an optimized package. These companies build on existing client relationships, including local distributors.

Electrical power equipment and automation controls

Electrical power equipment and automation control providers offer mini-grid control systems that address a wide range of customer segments. While the providers focus on product sales, they are actively supporting their customers in mini-grid development, particularly for MW-scale projects. For rural electrification, ABB and Schneider Electric offer containerized mini-grid systems in partnership with local installers. They both also offer full turnkey project development for utility-scale mini-grids. In April 2019, Carlyle Group and Schneider Electric entered a new phase in their partnership, launching a new joint venture (JV), called AlphaStruxure (The Carlyle Group, 2019). The JV will develop and operate new mini-grids in the US under a *microgrid-as-a-service* model, including a mini-grid project for New York's JFK Airport Terminal.

Oil and gas majors

Two established oil majors – Total and Shell – engage in the mini-grid sector quite differently. In 2019, Total's subsidiary and battery manufacturer Saft acquired Go Electric, a US-based mini-grid developer. While Total has been active in the US market, working closely with military bases and C&I facilities that need high resiliency, it is looking for opportunities outside the country. Shell has focused on investments in emerging markets. Its investment arm invested in Husk Power together with ENGIE's Rassembleurs d'Energies and Swedfund. On 4 November 2019, Shell, together with the Japanese trading house Sumitomo Corp, also bought a 15 percent stake in PowerGen, a Kenya-based mini-grid developer (Shell New Energies, 2019).

Finance and trading houses

In 2019 Sumitomo's rival, Toyota Tsusho, a trading company under the Toyota Group, signed a memorandum of understanding with Powerhive, a Kenya-based developer, as well as with five other organizations for mini-grid development in Kenya, Togo and Zambia (Toyota Tsusho, 2019). Japanese trading houses have been actively looking into off-grid solar, C&I solar and mini-grid sectors in Sub-Saharan Africa over the last two years.

Solar and wind energy equipment manufacturers

These manufacturers have extended their activities beyond just product sales to engage in mini-grid project development. Chinese companies such as Goldwind and Sungrow are primarily active in the Chinese market. While there have been no major announcements about international expansion so far, Trina Solar was reported to be looking into the Philippines market in January 2019 (Business World, 2019). Siemens manufactures both wind turbines and mini-grid control systems, and has developed some utility-scale mini-grids.

Utilities

Western European and Japanese utilities have entered the mini-grid market in emerging countries through acquisitions, investments or by launching joint ventures. Enel, Iberdrola, ENGIE and EDF have committed to SDG7 in some form according to their company filings. Three of them have set quantified targets of providing rural electricity access through their business, investment and philanthropic activities, and plan to reach 27 million people by 2020. Reaching this scale is not possible with social responsibility activities alone. Instead, they have addressed the goal as part of their business strategy in Sub-Saharan Africa, Southeast Asia, and Latin America.

Japanese utilities have taken a different approach from their European peers. In January 2019, Tokyo Electric Power Co. Power Grid (Tepco PowerGrid) formed a new investment entity called CleanGrid Partners, with an initial investment of USD 60 million (WEnergy Global, 2019). CleanGrid Partners plans to commit USD 100 million to electrification in South East Asia in the next three to four years and to replicate mini-grid projects in other parts of Indonesia, Myanmar and the Philippines. The other partners in the venture are Greenway Grid Global, ICMG Partners and WEnergy Global. Tepco is Japan's largest utility and has sought opportunities outside its home market for investments, use of its grid technologies and to understand those markets more broadly by working with partners. Tepco and other regional utilities in Japan are looking for new sources of revenue, as their core business is shrinking in the home retail market amid declining domestic power demand and rising competition after liberalization.

4.3 Business models

Business models for mini-grids for rural electrification vary, with different combinations and approaches to ownership and operation, technology, customers, service delivery and billing (Figure 32). There is no proven business model that works everywhere as developers need to adapt to the regulatory environment and other local contexts such as geography, topography, culture and demography, but some trends can be seen.

Operational models

Mini-grid operational models vary according to who owns and operates the mini-grid assets, including the generation and distribution assets. These are affected by the regulatory framework under which projects are developed, determining which types of operational models are most likely to flourish (EU Energy Initiative Partnership Dialogue Facility, 2014). Table 5 shows examples of mini-grid operator models.

Under a utility operator model, the national utility normally owns and operates the mini-grids. In Kenya, the Kenya Electricity Generating Company (KenGen) owns and operates two mini-grids. Cus-

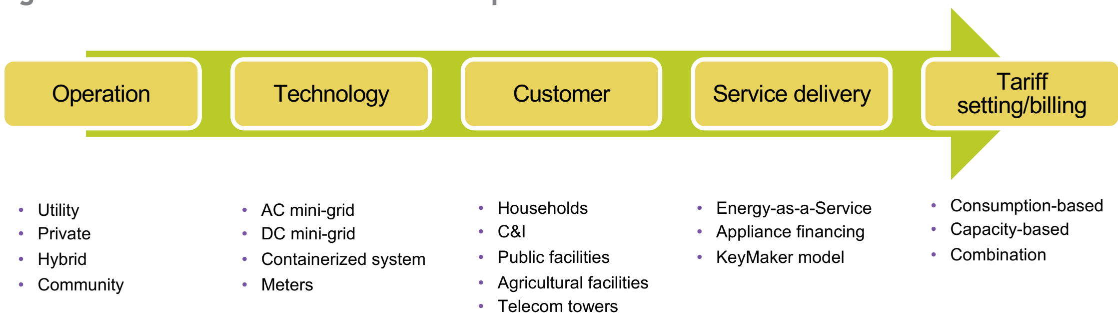
Box 3

Case study: ENGIE's mini-grid strategy

ENGIE is one of the most active major utility companies in the mini-grid sector. It launched ENGIE PowerCorner with the installation of its first mini-grid in 2016 and had expanded to 12 mini-grids with 2,500 connections in Tanzania and Zambia as of November 2019. In March 2019 it entered the Myanmar market by taking a minority stake in Mandalay Yoma, a Myanmar-based microgrid developer (PVTech, 2019). Over the next three to five years, the two companies aim to install solar hybrid mini-grids of 50–100kW in about 1,000 villages, out of a total of 30,000 that lack electricity access. Electro Power Systems (EPS) is a subsidiary of ENGIE, specializing in hybrid-storage solutions and looking into MW-scale mini-grids. EPS developed an off-grid mini-grid design, combining 1MW PV, 0.75MW wind, a 3.2MW diesel generator and 1MW/1.8MWh of lead-acid/lithium-ion battery storage to power a whole town with 60,000 inhabitants in Somalia. The utility has acquired decentralized energy companies and made strategic investments in them for business in emerging markets. ENGIE's Rassembleurs d'Energies impact fund has also provided funding to several energy access start-ups such as Husk Power. It is possible that the utility will make more strategic investments, as it initially provided impact investment to a pay-as-you-go solar company, Fenix International, and acquired it later.

Figure 32

Mini-grid business models – elements and options



Source: BloombergNEF.

Table 5

Examples of mini-grid operator models

Operator model	Owner	Operator	Examples
Utility	Utility	Utility	KenGen, NPC-SPUG in the Philippines, PLN in Indonesia
Hybrid	Government	Developer	Powerhive, GVE
	Government	Utility	REREC-Kenya Power
Private	Developer	Developer	Powerhive, PowerGen
Community	Community	Community	Cooperatives in Indonesia

Source: BloombergNEF, EUEI PDF.

tomers pay the same rates as they would for grid electricity, subsidized by charges collected from grid electricity customers. In the Philippines, the majority of known mini-grids were installed by the National Power Corporation Small Power Utilities Group (NPC-SPUG) and are owned and operated by local electric cooperatives. The cooperatives are in charge of electricity distribution and owned by local communities, although the latter's' involvement is limited; in reality this is close to a utility model.

In a hybrid model, different organizations are in charge of ownership, generation and distribution. Many projects developed under this model take the form of a public-private partnership; the government finances and owns the mini-grid, and a private company operates it. The Kenyan government's Rural Electrification and Renewable Energy Corporation (REREC) owns 19 mini-grids that are operated by a retail utility, Kenya Power.

In a private operator model, a private developer builds, owns and operates the mini-grids. If the mini-grids are connected to the main grid and if regulations allow, the developer may sell electricity to the grid operator. This is a similar structure to that of independent power producers (IPPs) that sell electricity from bulk generation power plants to the grid. For instance, Clean Power Indonesia sells electricity from its biomass mini-grids to the state-owned utility. Developers usually need a specific licence to operate. In the Philippines, private entities need to be licensed as a Qualified Third Party (QTP) to own and operate the mini-grid system in the designated area under the country's electrification programme.

The community operator model is where the local community owns and operates the mini-grid. This includes cases where the developer transfers assets to the community upon completion of the installation. Such a model exists in Indonesia where local communities both own and operate mini-grids. Some mini-grid assets are transferred to cooperatives in Indonesia although they do not have always have sufficient capacity to maintain the systems.

Technology models

While AC solar hybrid mini-grids have become the most common configuration in the last five years, developers may select different technologies depending on the type of customers served and the resources that are available near the project site.

Some developers such as Mesh Power and Devergy have deployed DC solar hybrid mini-grids, in Rwanda and Tanzania respectively. Capex and opex for DC solar hybrid mini-grids are lower than for AC, and it is easier for developers to train local people to become technicians to maintain the system. DC mini-grids can also reduce losses as electricity generated from PV does not need to be inverted into AC. However, this limits load to DC appliances only and the electricity cannot be integrated into larger networks. DC mini-grids can only cover a limited area due to higher voltage drops[7] and are best suited to small-sized communities whose power demand is very low. For example, in the Philippines, Okra Energy and InFunde Development have implemented a pilot project to install a DC mini-grid on a remote island, where household customers can trade electricity.

A separate option for developers is to avoid diesel generators and combine only PV and storage to reduce maintenance. To do this they would need to manage loads to avoid unnecessarily oversizing the battery storage.

Some developers install and operate containerized mini-grid systems, which are pre-engineered and standardized. This has become more widely available, with systems offered by vendors such as ABB, Schneider Electric and BoxPower. (See Section 5.4 for more details.)

Developers also need to select meters to measure energy consumed and track usage for billing purposes (see below for the discussion on pricing and billing).

7 Voltage can be increased to reduce voltage drop but this may increase the risk of safety hazard.

Customer targeting

An increasing number of developers are looking into opportunities to supply C&I customers or other business customers with large predictable loads (e.g., for irrigation pumps and cold storage) while also using the mini-grid to provide electricity to residential customers. This increases the utilization rate of the mini-grids and reduces risks, hence lowering the cost of electricity and increasing profits for the developer. DESI Power and OMC Power are pursuing this approach in India. Developers may limit mini-grid connections to high-demand customers in a small catchment area and offer solar home systems to low-demand customers further afield. (See also Section 11.)

Service delivery models

Customer engagement is a critical element for improving the average revenue per user (ARPU) of the mini-grids. Operators may provide education to customers on the use of appliances and electrical equipment for economic activities or offer to lease these products to the customer or provide finance. Such services could improve the profitability of the mini-grid projects.

Some operators combine mini-grid operation with product trading. This is called a KeyMaker model whereby the operators in rural areas buy local products such as fish, meat and agricultural products, process them using mini-grid electricity, and then transport them to sell to customers in urban areas (Figure 33) (Inensus et al., 2019). In this way, the operators can help local communities generate more income while increasing their revenues in the mid- to long-term. For example, Jumeme purchases tilapia from local fishermen in Tanzania for a fair price and then cleans and freezes the fish using electricity generated from its mini-grids. The company then delivers the fish to wholesalers in Dar es Salaam where it can sell it at a higher price.

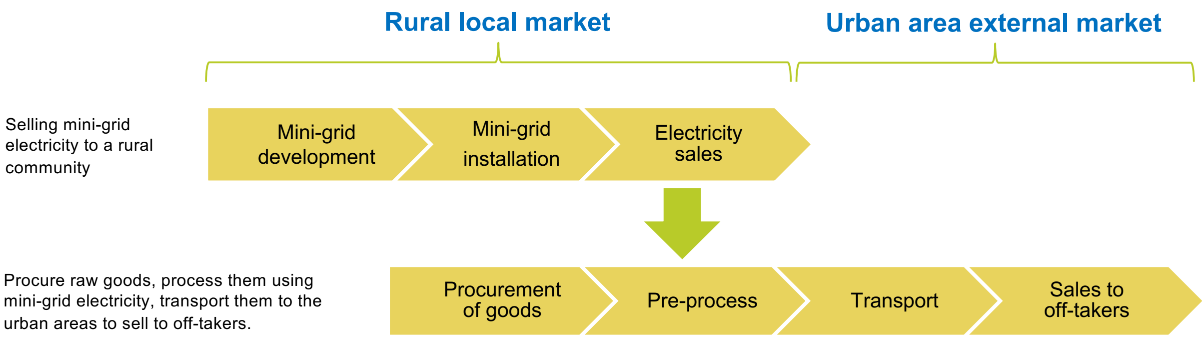
Pricing and billing approaches

Types of tariffs

In countries where developers have flexibility, mini-grid tariffs are structured in a variety of ways. Charges can be per kilowatt-hour (consump-

Figure 33

KeyMaker model



Source: Adapted from INENSUS, Energy4Impact, Sustainable Energy Fund Africa, SEforALL, African Development Bank.

tion-based), per-kilowatt (capacity-based), or a combination of the two (Table 6).

As many as 80 percent of the developers reported to the authors that they charge customers on a consumption basis. Of these, half stated that they used a time-of-use tariff, particularly as a way to align consumption with generation. One developer in Nigeria applies a consumption-based tariff structure and varies the tariff per unit of electricity depending on a customer's energy consumption level, ranging from USD 0.25–0.70 per kilowatt-hour.

Where tariffs are structured on a capacity-basis, mini-grid operators typically differentiate tariffs by customer types. The charges of one mini-grid operator in Tanzania vary from just above USD 4 per month to more than USD 60 per month depending on what appliances customers use. The tariff becomes higher if the customer uses, for example, a refrigerator. This model may be more suitable for operators whose customers have limited power demands (i.e. Tier 1 or 2 of the Multi-Tier Framework), which is also hard to forecast.

The above approaches may not be possible for operators where tariffs are regulated. In Uganda, the regulator approves tariffs for mini-grids in line with the grid electricity tariffs, limiting freedom to set cost reflective tariffs. Mini-grid operators in the Philippines collect fixed payments approved by the regulator (a so-called 'Subsidized Approved

Table 6

Tariff structures

Tariff type	Definition	Suitable operators & rationale
Consumption-based	Charge based on energy consumption (kWh).	National utilities and mini-grid developers as the revenue aligns with the amount of power consumed.
Capacity-based	Charge based on maximum power demand allocated to the customer (in kW).	Developers operating hydro-based mini-grids or other power-limited systems, where the marginal cost of energy is not relevant.
Combination	Charge based on a combination of energy consumed and maximum power allowed.	Utilities and developers operating within tight operating constraints, and able to apply demand-side management strategies.

Source: BloombergNEF, Energy 4 Impact & INENSUS 2019.

Generation Rate' (SAGR)) if they operate under the missionary electrification framework, the country's rural electrification mechanism. Where mobile money is established, it has become a popular method of billing for rural mini-grids and can significantly reduce billing costs. Many remote customers do not have bank accounts but do have mobile phones (US AID, Energy 4 Impacts, NREL, Power Africa, 2018).

Tariff structures can be further split into different types, each type with its advantages and disadvantages (Table 7).

Table 7

Comparison of tariff sub-types

	Description	Advantages	Disadvantages
Consumption-based			
Simple	Single rate based on the units of energy consumed.	• Incentivizes energy efficiency. • Facilitates PAYG.	• Customer education is required.
Energy use (block rate)	Tariff level varies with the overall consumption (i.e. increased consumption leads to lower/higher average per-kWh tariff).	• An increasing block rate favours lifeline and productive- use customers.	• Customer education is required. • Some disincentive for energy efficiency.
Time-of-use	Consumption at specific times of the day affects the amount (per kWh) charged (i.e. lower tariff during off-peak hours).	• Incentivizes energy efficiency. • Convenient for solar + storage projects.	• Customer education is required. • Discouraging use during peak hours may impact customer satisfaction (but this is typically addressed by having several time slots).
Seasonal	Tariff level changes with the time of year (i.e. higher tariff during rainy season).	• Incentivizes energy efficiency. • Matches generation costs with revenue.	• Operational cost per season is hard to determine. • Frequent tariff changes may impact customer satisfaction.
Capacity-based			
Simple	A rate is charged based on the maximum power demand.	• No bill calculation. • Easy to understand.	• Demand prediction difficult. • Does not encourage energy efficiency.
Per-device	The number of devices (within a power rating limit) affects the charge per unit of energy.	• Suitable for low income households.	• Demand prediction difficult. • Discourages productive use. • Hard to calculate per-kWh cost.
Combination			
Energy-as-a-service	Customers pay for energy services or devices they use during a certain period of time.	• Precise calculation of prices. • Low level of complexity.	• Customers are unable to monitor their own consumption.
Time-bound	Customers pay (per kWh) to consume energy within a specified block of time e.g. 09:00–12:00.	• Stimulates regular payments.	• Does not encourage efficiency. • Customers may be unaware that they still need to pay even if they do not consume electricity during the allocated time.

Source: Adapted from Energy 4 Impact & INENSUS 2019, Electric Capital Management, BloombergNEF.

Metering technologies determine the tariff structures that developers can deploy. In the absence of meters, a load or time limiter can be used that involves capping daily energy consumption or the period in which electricity is available. Conventional meters must be manually read by a technician, and are separated into post-paid or pre-paid, whereby consumers pay after or before consuming electricity, respectively. However, smart meters that can also be configured in either pre- or post-pay mode are becoming increasingly common; 75 percent of interviewed developers stated that they use the technology, particularly in conjunction with solar hybrid mini-grids. This eliminates the need to manually read meter data. Instead household consumption is sent to a central database. This automatic meter reading and billing means that personnel are no longer needed to collect data from households, lowering opex.[8] It also unlocks more complex tariff structures and insights into actual operations.

While conventional meters are only compatible with a limited number of tariff structures, smart meters allow operators to have more options to set the tariffs to align with their business models (Table 9).

With smart meters, operators can easily change the tariff level depending on the level of electricity consumption, timing of the day, or seasons, thanks to the advantages of the technology discussed earlier. There is a trade-off between costs for smart meters and the services they enable (e.g., utilities in Sub-Saharan Africa do not install smart meters due to the lower costs of conventional metering).

Billing options

Consumers pay for their energy consumption either in cash or using mobile money. In some instances, developers offer both payment methods. Cash payments are made to a local reliable agent that transfers the collected revenue to the mini-grid operator, either in cash or via mobile money. Alternatively, the operator can collect revenue directly from consumers via mobile money. This revenue collection method eliminates the cost of intermediaries, mitigates issues around handling cash, and provides a log of transaction history. Research conducted by the World Bank's International Finance Corporation (IFC) found that revenue collection choices vary by region. Figure 34 shows that mobile money is used by the majority of operators in east Africa, whereas cash payments are

Table 8

Comparison of conventional and smart meters

	Conventional (pre-/post-paid) meter	Smart meter
Consumption monitoring	Periodic (e.g. total monthly).	Real-time.
Reading	Manual (read by technician).	Automated (sent to cloud/local server).
Communication	None.	Bi-directional (household to operator and vice versa).
Benefits for consumer	• Some pre-paid meters show the amount of consumption left before payment is required.	• Electricity charges can be better adapted to each consumer's situation. • Better customer service from real-time alerts and remotely available data. • Lower opex reflected in cost to consumer.
Benefits for operator	• Lower upfront cost.	• Automated billing. • Opportunity to analyze granular data and identify consumption trends. • Adjust the tariff type/level remotely. • Connect/disconnect remotely.

Source: BloombergNEF.

8 The extent to which, or even whether opex is reduced depends on how much a developer has scaled up operations. For a developer with few sites, the software licence fees and meter costs may outweigh the cost savings associated with hiring fewer revenue-collection personnel.

Table 9

Meter compatibility based on tariff structure

		Load limiter	Load & time limiter	Post-paid meter	Pre-paid meter	Smart meter
Consumption-based	Simple					
	Energy use (block rate)					
	Time-of-use			Some meters can be programmed, but control & visualization are not possible.		
	Seasonal			Seasonal changes to unit price/ invoice calculation.		
Capacity-based	Simple				Additional cost or marginal benefit.	
	Per-device					
Combination	Energy-as-a-service					
	Time-bound					

Source: Adapted from Energy 4 Impact & INENSUS 2019, BloombergNEF. **Note:** Green = Recommended. Orange = Possible, but not recommended. Grey = Not applicable.

more popular in Asia. By the end of 2017, there were approximately 396 million mobile money customers registered in Sub-Saharan Africa, totalling 44 percent of all accounts globally and 66 percent of all transactions by value globally (GSMA, 2019).

Pay-as-you-go (PAYG)

Pay-as-you-go (PAYG) encompasses a range of payment models that charge customers when they use a service, instead of charging fixed amounts on a regular basis. Mini-grid operators have adopted a range of payment plans to provide low- or variable-income households with electricity by lowering upfront costs and offering more flexibility. Households are equipped with smart meters, enabling central tracking of consumption. If a household runs out of credit, the electricity supply can be cut off. At the discretion of the operator, consumers can add credit to their account by:

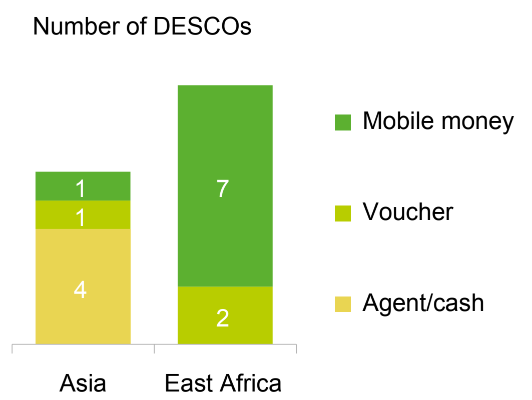
- Making a cash payment to a local agent
- Purchasing scratch cards from a local kiosk
- Using mobile money.

In addition to selling electricity, PAYG has been used to sell complementary appliances to stimulate demand. Similar to electricity, consumers may not be able to use appliances without a flexible payment method. Developers often integrate these appliances within their payment plans using three main bundling strategies:

- Selling an appliance as a stand-alone in parallel with electricity
- Bundling an appliance with electricity
- Bundling several appliances and electricity.

Figure 34

Revenue collection preferences by region



Source: BloombergNEF, IFC.

Section 5
Technology trends

Most modern mini-grids installed in recent years incorporate PV and battery energy storage, often combined with a diesel generator, providing communities with clean and reliable electricity for less cost than a diesel mini-grid. This is particularly thanks to the sharp decline in the price of PV modules. Technology innovations in system integration, control and data analytics assist with site identification, development, construction, and operations and maintenance.

5.1 Generation technologies

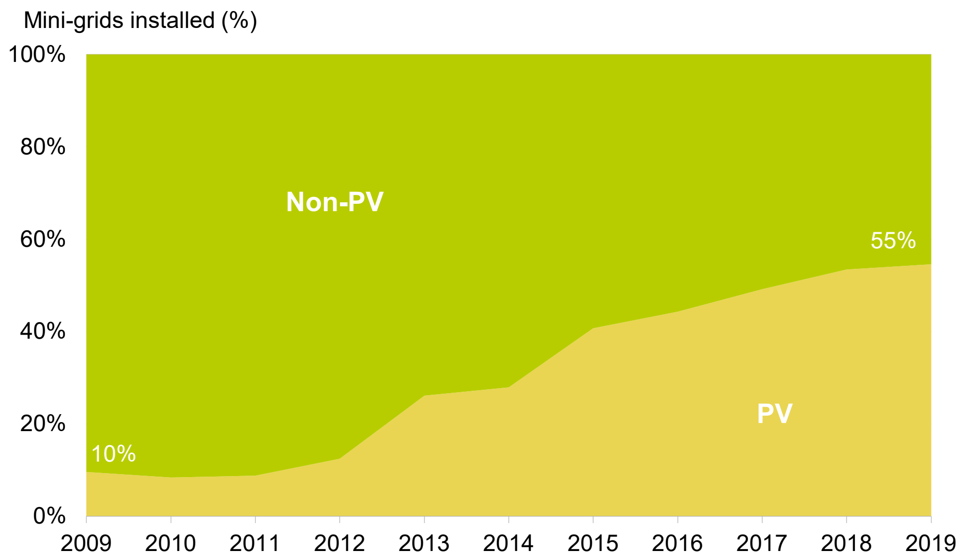
Amid various types of renewable energy generation technologies that have been used for mini-grids, there is a strong mandate to hybridize diesel mini-grids with the use of solar. Given PV's modular capabilities, its low cost of generation and potential for further cost reduction, solar-based systems look promising. There is also a strong economic rationale for biomass and hydro projects in some locations, although this depends on the availability of natural resources.

Solar

PV is the most predominant technology used for mini-grids installed today. In 2019, 55 percent of operating mini-grids incorporated PV – a more than five-fold increase on 2009 installations (Figure 35). It is expected that this trend will continue. PV is relatively easy to install in remote areas and is the most cost-competitive technology today, unless low-cost resources such as biomass and small-hydro are available.

Figure 35

Rapid uptake of PV in the mini-grid sector, 2009-2019



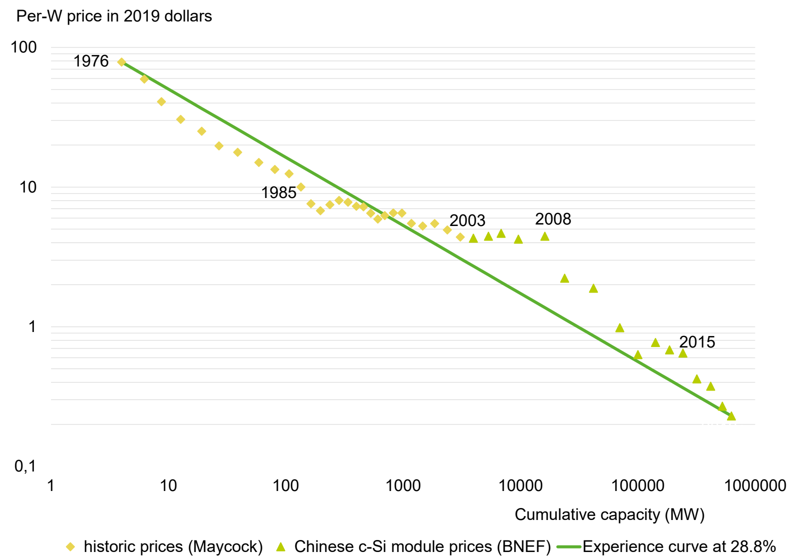
Source: BloombergNEF, Carbon Trust, CLUB-ER, GIZ, surveyed companies.

PV module costs trends

The price of crystalline silicon PV modules fell steadily, from USD 80/W to USD 0.27/W between 1976 and 2018 (Figure 36). Prices fell further in 2019, and the authors of this report expect them to average about USD 0.25/W for the year with more efficient monocrystalline silicon becoming the dominant module technology in 2020. The price and volume data illustrate PV's very high learning rate — the cost reduction for each doubling of deployed capacity — of about 28.5 percent. This steep learning curve is the result of technology innovation, economies of scale and manufacturing experience.[9] The learning curve uses price as a proxy for cost, because average price data for solar modules are more readily available than cost data, and margins are usually slim. In the short term, price does fluctuate relative to cost with temporary fluctuations in demand and supply, but this does not affect the inexorable long-term downward trend.

Figure 36

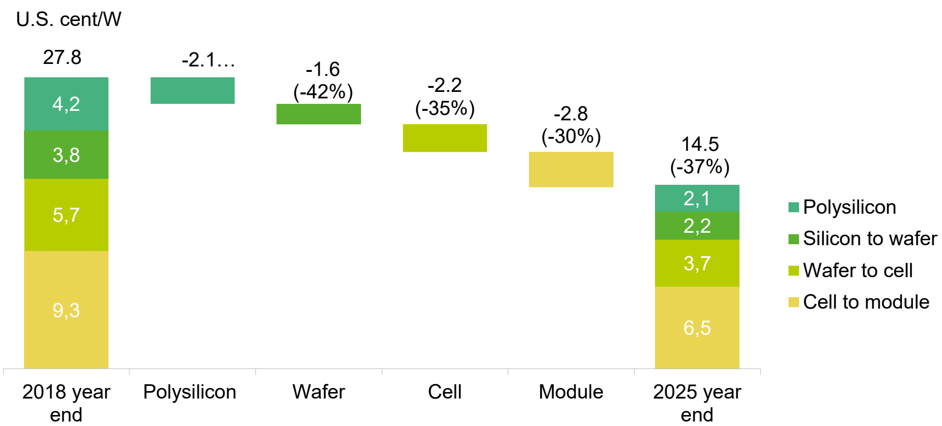
PV module experience curve (logarithmic)



Source: Paul Maycock, BloombergNEF.

Figure 37

Forecast of best-case integrated production cost for c-Si module



Source: BloombergNEF.

9 An example of technology innovation in the past three years is the switch from multi- to monocrystalline silicon, enabled by the wide adoption of diamond wire saws.

Assuming that best-in-class module production cost was USD 0.23/W at the end of 2018, it is possible to corroborate the top-down PV experience curve by looking bottom-up at manufacturing innovation. This illustrates how a further 37 percent reduction in c-Si module prices can be achieved by 2025 (Figure 37). The expected cost reduction is driven by further material savings, improvement in module performance and efficiency, and further incremental innovations to module design.

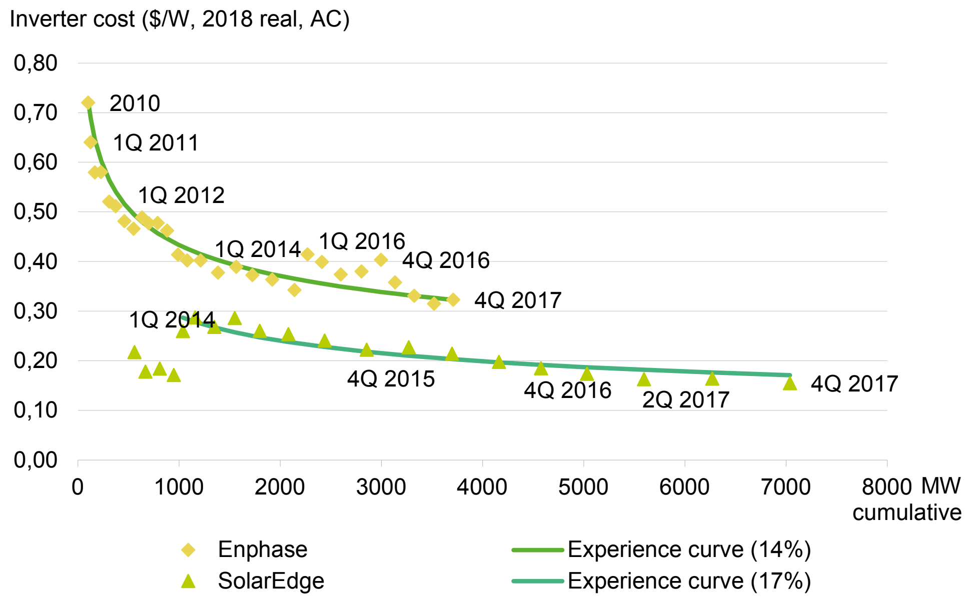
Inverters

The learning rates of inverters are difficult to estimate as they are a more heterogeneous type of product, with many different specifications and product categories. The authors also expect inverters to become more sophisticated, with additional abilities to detect faults, control system output and manage storage charging and discharging.

As a proxy, pricing data for the module-level power electronics produced by SolarEdge and Enphase appear to follow a form of experience curve, with learning rates of 18 percent for Enphase and 13 percent for SolarEdge (Figure 38). Unlike most inverter makers, these two companies supply a device for every module, so their costs per watt tend to go down in parallel with modules as both become larger or more efficient. However, there are complications; Enphase's costs per watt (DC) have come down partly because it supplies many of its microinverter units integrated with modules, and as module capacity goes up, the wattage covered by one unit automatically goes up. SolarEdge's costs have gone up slightly due to changes in product mix and the effects of a global shortage of power components used in inverters and automotive control systems. The component shortage is expected to be solved with increased production in the next two years, and inverter prices are likely to come down as a result. A learning rate for inverters of 20 percent is assumed, driven by competition between manufacturers.

Figure 38

Enphase and SolarEdge experience curve – cost of goods sold (COGS) by cumulative shipped MW[10]



Source: BloombergNEF, Enphase, SolarEdge company filings. **Note:** The selling prices shown are for distributed inverters with module-level control. Enphase reports in MW (DC) as most of its inverters are sold integrated with modules; SolarEdge reports in MW (AC).

10 Although it is not common for mini-grids to be installed with micro-inverters, they are a more standardized product compared to central or string inverters. Due to the challenges of developing an experience curve for a product that is not commoditized, this figure focuses on micro-inverters instead.

Other forms of renewable energy

Some installed mini-grids incorporate non-solar renewable energy technologies such as hydro and biomass. Recently, these technologies have been less commonly used for mini-grids than for solar, partly because their use is limited to locations where resources for power generation are available, and partly due to the sharp relative cost declines of PV and batteries. While these technologies lack modularity to scale up (or down) depending on demand, they have a part to play as a viable solution for off-grid access where resource is abundant.

Hydro

A quarter of installed mini-grids use hydro power. Run-of-river has been used as the most common hydro technology. This depends on river flow for power generation without requiring a reservoir, as opposed to other types of hydro technology. Therefore, power output fluctuates on a seasonal basis.

Hydro projects need to be designed for each specific site, hence there is a wide range in development costs. For hydro projects less than 10MW, the cost of equipment can represent more than half of the total capex (IRENA, 2018).

Biomass

Some mini-grids convert solid biomass fuels to produce biogas, which is a mixture of methane, carbon dioxide and other gases produced from sources such as rice husks, nut shells, sugarcane bagasse or wood chips.

However, with these technologies there are risks of operators being unable to source enough feedstock throughout the project lifetime and of increasing feedstock costs if the technology becomes more popular. Also, the cost associated with waste management is not included in the generation cost. For instance, rice husk gasifiers produce a large amount of tar through the pyrolysis process. There is typically a lack of regulation to manage the waste in emerging countries.

When Husk Power began operations in India in 2008, it initially used biomass gasifiers with rice husks as the main feedstock and provided customers with six to eight hours of power. However, as customers today demand 24/7 electricity access and PV costs have declined, Husk's business model has shifted toward developing solar-biomass hybrid mini-grids with battery storage.

Small-scale wind

Small-scale wind is much less common for mini-grids although some combine it with diesel or solar. Wind power is intermittent and its generation curve does not match the daytime load profile of communities. A reduction in the cost of small-scale wind turbines at the same level as that seen with solar is not expected.

5.2 Storage technologies

Energy storage technologies can help plug the gap originating from the intermittent nature of renewable energy used in mini-grids. There are several technology options. Lead-acid batteries have been the cheapest and most commonly used for rural mini-grids. Falling costs of lithium-ion batteries have piqued the interest of developers, but the higher capex versus lead-acid batteries as the incumbent is a barrier. According to research by USAID, lithium-ion's longer lifetime leads to a lower life-cycle cost and a lower LCOE. This suggests that governments can design a financing mechanism to incentivize the procurement of favourable technologies if consumers' affordability of mini-grid electricity is a concern. In theory, the private sector can then charge a lower tariff to its consumers. Hydrogen can be used to store energy but currently lacks market maturity, and it is likely that battery technologies will continue to dominate as the storage technology of choice for the mini-grid market.

Battery energy storage

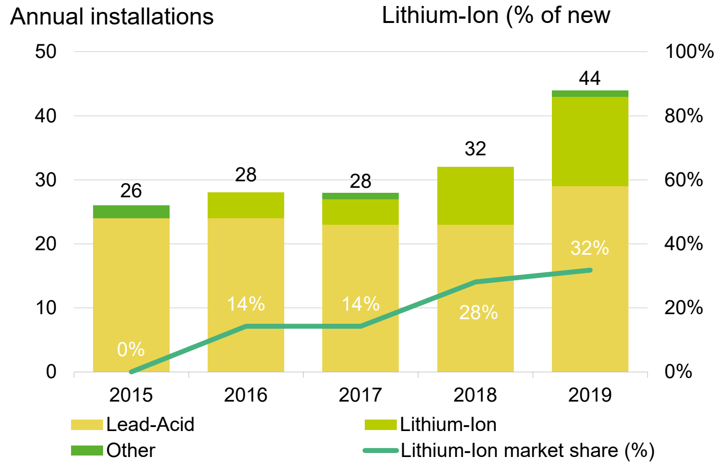
Typical modern mini-grids installed today incorporate battery energy storage together with PV, which can be charged when the PV produces excess electricity, and discharged in evening hours. This cuts the running time and cost of diesel generators. Battery storage can also bridge outages if the mini-grids are connected to the main grid. Some developers do not integrate diesel generators, to reduce their operating costs and avoid potential diesel theft. Instead, they use just solar and battery storage, and manage loads to avoid oversizing the storage unit. However, this is only possible if power demand and the cost of electricity are both low.

Mini-grids use various storage technologies, including lithium-ion, lead-acid and flow batteries. Overall, developers in emerging markets favour lead-acid batteries because they are more readily available and have a lower upfront cost than other available types of battery, typically costing around USD 70–80/kWh (BloombergNEF, 2017). The supply chain of lead-acid batteries has also matured in emerging markets, easing procurement and installation. However, as technology costs have declined, developers in Asia and Sub-Saharan Africa are beginning to use lithium-ion batteries more frequently (Figure 39, Figure 40).

Some developers use both lead-acid and lithium-ion batteries for their projects. It is expected that the uptake of lithium-ion batteries will continue in this decade. The choice of battery technology will depend on developers' experience and familiarity with new technologies.

Figure 39

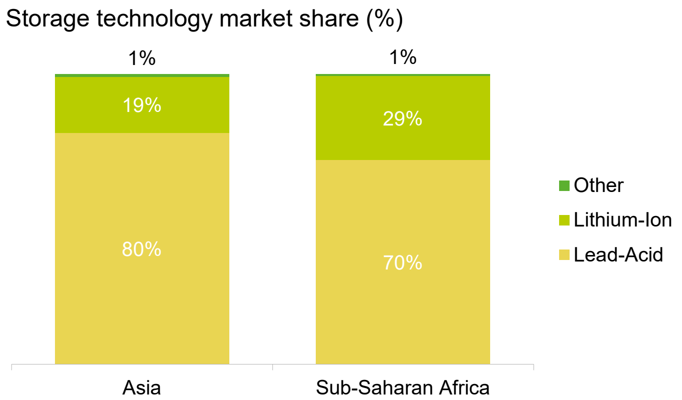
Battery technologies used for installed mini-grids



Source: BloombergNEF, Carbon Trust, GIZ. **Note:** Only includes project data where information regarding installed battery technology is available.

Figure 40

Share of battery technologies used for installed mini-grids by region



Source: BloombergNEF, Carbon Trust, GIZ. **Note:** 44 and 114 installed mini-grids with energy storage were identified in Asia and Sub-Saharan Africa, respectively.

Lithium-ion batteries cost reductions and technology advancement

Figure 41 shows historical prices of lithium-ion battery packs. Prices have fallen to USD 176/kWh, down by 85 percent from 2010 to 2018. The authors anticipate that prices will fall further at a learning rate of 18 percent, to reach USD 94/kWh in 2024 and USD 62/kWh in 2030. These anticipated price reductions will come from the use of new materials, cell designs, and manufacturing equipment and techniques. The use of new materials can reduce reliance on expensive metals, such as cobalt, and reduce overall costs by increasing energy density.

Thanks to the introduction of new chemistries and cell and pack designs, battery-pack energy density has already increased by 67 percent since 2011, and is estimated to reach 224Wh/kg by 2030 (Figure 42).

Lead-acid batteries are easier to recycle than lithium-ion

Lead-acid batteries typically don't last as long as mini-grid projects (Table 10) and they may need to be replaced more than twice throughout the duration of a project. As a result, it is important for developers to consider the battery end-of-life challenges that they may face.

Figure 41

Volume-weighted average lithium-ion battery prices, historical and forecast

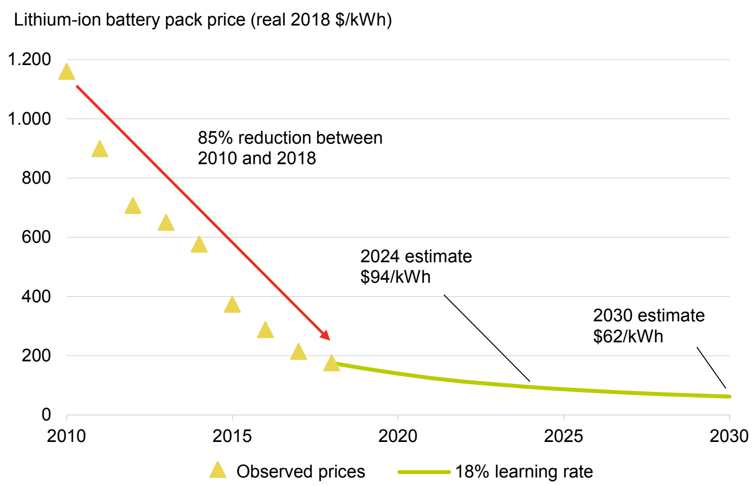
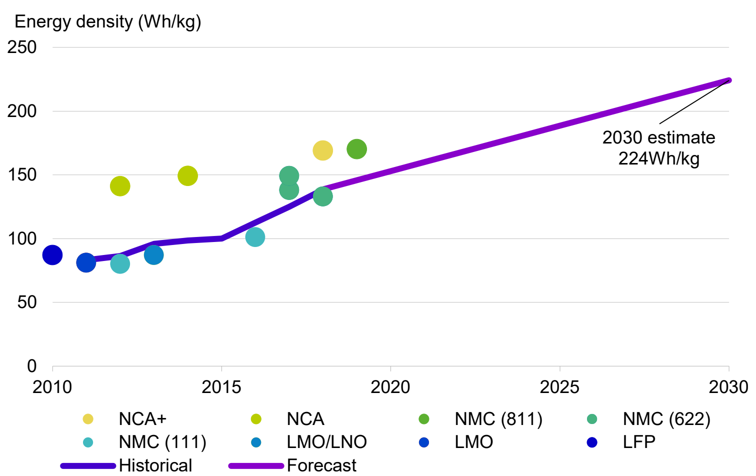


Figure 42

Battery pack energy density, historical and forecast



Source: BloombergNEF.

Battery recycling is well-established for small-format batteries used in consumer appliances. The successful business of recycling lead-acid batteries is often held up as an example of how battery recycling should work. 70 percent of the battery weight is lead and it is easily recoverable as a pure product that can be sold on; about 50 percent of global lead supply comes from recycled batteries. Lead-acid batteries have a standard format, simple design, one form of chemistry and a simple recycling process.

Recycling of lithium-ion batteries is not as well-established. The authors estimate demand for electric vehicles and stationary storage will create 2 million metric tons of lithium-ion battery scrap available for recycling per year by 2030 (BloombergNEF, 2019). Large-format batteries used in EVs and utility-scale stationary storage will account for nearly 90 percent of the recycled battery market by 2030, up from only 3 percent today.

Cost comparison

The upfront cost is a useful metric to compare technologies but fails to tell the whole picture. Lead-acid batteries have a lower initial cost, but this factor

Table 10

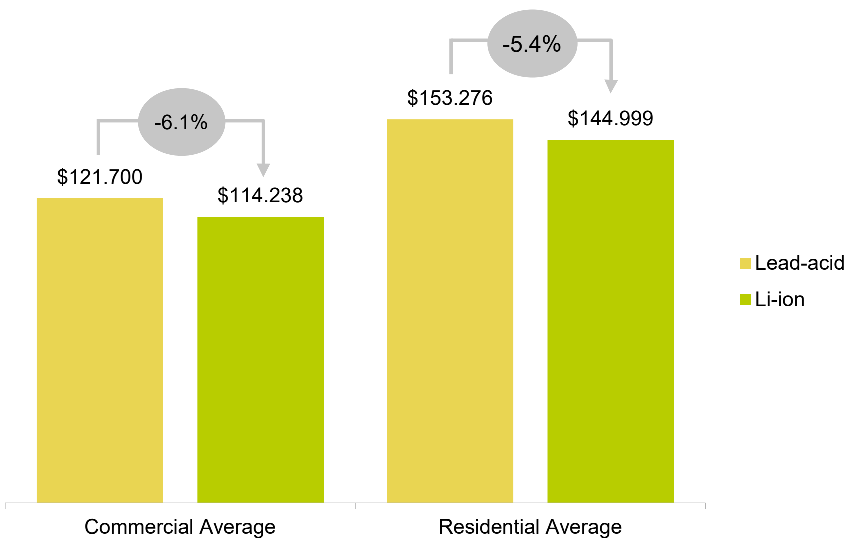
Comparison of battery characteristics relevant to end-of-life management strategies

Battery types	Lead-acid		Lithium-ion	
	Automotive	Deep-cycle	Lithium manganese oxide (LMO)	Lithium iron phosphate (LFP)
Purchasing price	Very low	Low	Medium-high	High
Lifetime	Very low	Medium	High	High-very high
Safety	Low	Low	Medium	Medium
Toxicity	Very high	Very high	Medium	Medium
Recyclability	Very high	Very high	Very low	Very low

Source: GIZ, 2018.

Figure 43

Cost comparison of battery system life cycles



Source: BloombergNEF, NREL. **Note:** Average calculated from data in Table 5 of NREL report. The average system size is 41.1kWh for lead-acid and 32.7kWh for lithium-ion (commercial) and 69.7kWh for lead-acid and 54.1kWh for lithium-ion (residential). The study assumed a lifetime of 7 years for lead-acid ion and 10 years for lithium-ion.

alone fails to take lifetime and efficiency into account. Instead, looking at the life-cycle cost gives a much clearer indication. The National Renewable Energy Laboratory (NREL) undertook a comparative technology and economic study. It evaluated the life-cycle cost (LCC) of mini-grids incorporating either lithium-ion or lead-acid. This configuration was modelled in five locations (Ghana, Niger, Zambia and two locations in Kenya), and found that the LCC system integrating lithium-ion was consistently lower. Taking an average of the LCCs, lithium-ion mini-grids were cheaper by 6.1 percent when serving commercial customers and 5.4 percent when serving residential customers (National Renewable Energy Laboratory, 2019).

Other battery technologies

In addition to lead-acid and lithium-ion, other flow battery technologies are being deployed.

Absolute Energy used a 60kW/520kWh vanadium flow battery for a mini-grid on Kitobo Island, Uganda. Flow batteries use chemicals held in tanks that can in effect be charged, allowing capacity to be increased by increasing the volume of the tank. They may be better suited to longer-duration applications, but most providers do not yet have the capacity to scale up the technology and experience the same cost reductions observed for lithium-ion. Advocates of alternative technologies highlight their advantages and their competitiveness once at scale, although the ability to achieve necessary scale is not clear.

5.3 AC versus DC mini-grids

Solar hybrid mini-grids can be DC, AC, or a combination of the two. While the majority of mini-grids installed are AC, rural communities with low power demands may be suited to DC mini-grids. DC systems are more commonly used in certain countries such as Rwanda and tend to have a lower capex per watt as they require fewer components and are directly compatible with energy-efficient DC appliances. Eliminating the need for inverters also reduces the overall cost and allows mini-grid operators to set lower tariffs unless they are regulated. Conversely, AC mini-grids are more expensive, but allow the use of higher-voltage machinery and are able to connect to the main grid if and when it arrives.

Table 11

Comparison of battery types

	Lead-acid	Lithium-ion	Flow
Applicable capacity (MW)	0-40	0-100	0.5-100
Round-trip efficiency	80%	90%	75%
Specific energy (Wh/kg)	33-42	128-256	10-20
Lifetime (years)	2-5	5-15	40
Life cycle	1,650 @ 50%DOD 1,050 @ 80%DOD	1,900-3,000 @ 80%DOD	3,750 @ 80%DOD
Advantages	Mature technology Low cost	High energy density Long lifetime Low maintenance	Fast response time Long lifetime
Disadvantages	Short life cycle Slow charging Maintenance Toxicity	High cost Safety Self-discharging	High operating cost

Source: BloombergNEF, Bushveld Minerals, GIZ, Kocer et al., Port of Long Beach, USAID.

Figure 44

Typical AC mini-grid configuration

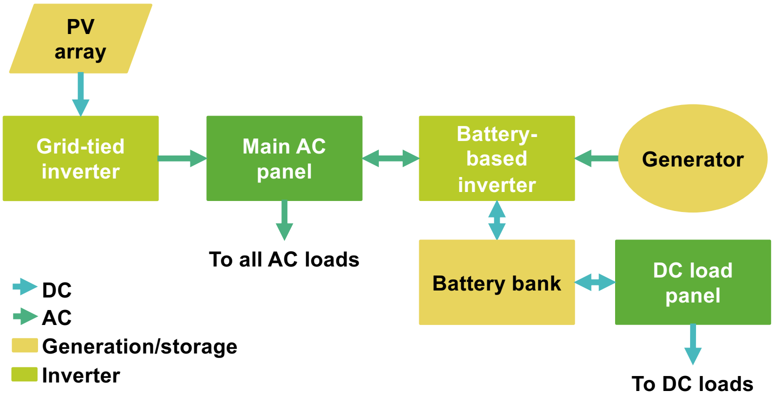
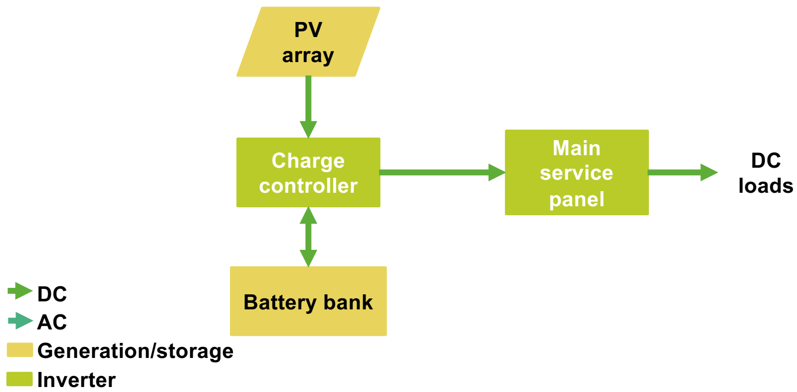


Figure 45

Typical DC mini-grid configuration



Source: BloombergNEF, Clean Energy Reviews, Sikiru 2018.

5.4 Development and operations solutions

System integration, control systems and remote monitoring

In developing a mini-grid system, one of the key challenges is how to build the system and integrate the various components including generators, batteries, controllers, power electronics and the physical site itself. The remoteness and lack of skilled labour near project sites also pose challenges in operating mini-grids. Developers usually provide local personnel training to maintain the mini-grid, but they still need to oversee the project, troubleshoot, and send technicians to the site if necessary. Control systems and remote monitoring technologies can help automate mini-grid operations in a synchronized and optimized manner, as well as reduce the mini-grid opex.

Figure 46

BoxPower's container-based microgrid system

Source: BoxPower

System integration

Some companies are working on the problem of physically integrating mini-grids through pre-wired or containerized systems. In 2017, GE launched a containerized hybrid power system, including PV, diesel generators and a controller, for communities and businesses in remote areas (GE Power, 2017). Power ratings range from 15kW to 250kW. Excellerate, a manufacturer of electrical components and assemblies has partnered with Schneider Electric to launch 'Xcape,' a containerized system that it claims can be launched in two days, in contrast with the many months that are typically needed to install a custom mini-grid. Schneider Electric also supplies containerized systems directly – for example its 'Villaya Emergency' product for rapid deployment of emergency power (Schneider Electric, 2018). Everything needed is shipped in 10- to 20-foot pre-configured containers with built-in recyclable sodium battery storage, inverters and charge controllers, and pre-mounted retractable PV modules that two people can put up in minutes.

Smaller companies are also entering this market. BoxPower has developed a turnkey containerized solar hybrid mini-grid system, which allows solar panels to be mounted either on the container or on a separate roof (Figure 46). PV capacity is from 6-24 kW, although smaller 'miniboxes' are available at 3.5kW. The company is targeting off-grid or poorly served residential, commercial and agricultural sectors, as well as disaster recovery and emergency backup. It has particular experience of operating in Alaska, with 15 installations achieving an average cost per watt of USD 8.82, but believes that for larger system sizes approaching 50kW, the costs could fall to USD 4.7-5.7 per watt.

The benefits of these approaches are largely due to standardization, economies of scale and simplified logistics. Containers can be built, pre-configured and tested in a factory environment as opposed to assembling a series of individual components on site. This lowers the costs of manufacturing and logistics and reduces technical risks. Once the containers have been delivered, installation is almost immediate and can be redeployed to another location should that in future be necessary (for instance, for temporary but emergency power). However, this flexibility also depends on location — some remote locations are very difficult to access where the road infrastructure is not developed — and even containerized systems are hard to transport. In this case, developers may need to deliver components separately to the site.

Control system and remote monitoring

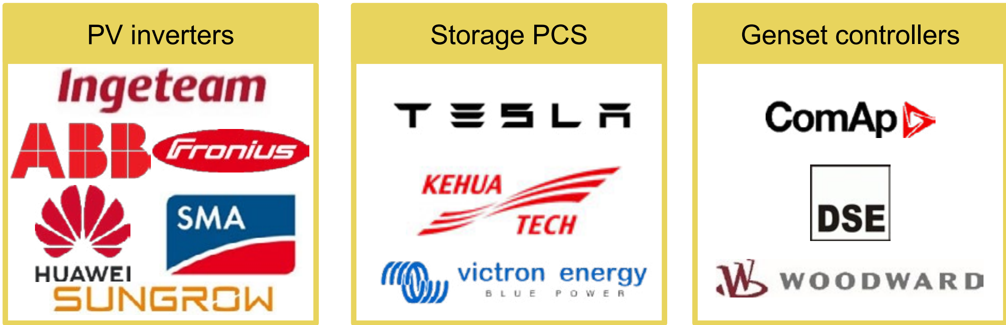
There are many different potential suppliers, often with proprietary interfaces that make it more difficult for these pieces of equipment to work with one another. This suggests that more standardization and interoperability are needed. A number of companies, both large and small, are addressing this problem. For example, Elum Energy has launched a set of compatible products that aim to facilitate integration of third-party equipment from an IT/control perspective Elum Energy, n.d.). This includes:

- ePowerControl, a mini-grid controller that offers plug-and-play integration of PV, diesel and batteries within a system. The company has developed a comprehensive library of software drivers that interface with the products of major equipment providers (Figure 47), including their communications interfaces. The controller includes machine-learning algorithms to optimize control and dispatch, as well as cybersecurity measures and local encryption.
- ePowerMonitor, a cloud-based platform, that allows the performance of a portfolio of assets to be monitored centrally, with automated reporting and remote management of some elements of the mini-grid, to reduce site visits and operating costs.
- ePowerControl, another mini-grid controller allowing high levels of PV integration in diesel hybrid systems.

Remote monitoring technology allows each component of a series of mini-grids at different sites to be monitored in real time and generates alerts as well as reports for system behaviour through analytics. Some technology vendors offer technologies specifically designed for off-grid mini-grids (Figure 48). According to AMMP, in the absence of remote monitoring, an operation engineer spends 50 percent of their time in identifying issues, 22 percent in planning site trips as well as execution, and 5 percent on

Figure 47

Compatibility of Elum Energy ePowerControl with other equipment brands



Source: BloombergNEF, company websites.

Figure 48

Select remote monitoring and control technology providers

Source: BloombergNEF, company websites.

reporting (AMMP, 2018). Remote management also helps to maximize battery storage lifetime by reducing the depth of discharge and through proactive load-shedding and improved planning of generation. It can also reduce the frequency of battery replacements, and hence capex. Such technologies will be more important when the mini-grid market scales, as mini-grids are often scattered across different remote sites.

Data analytics

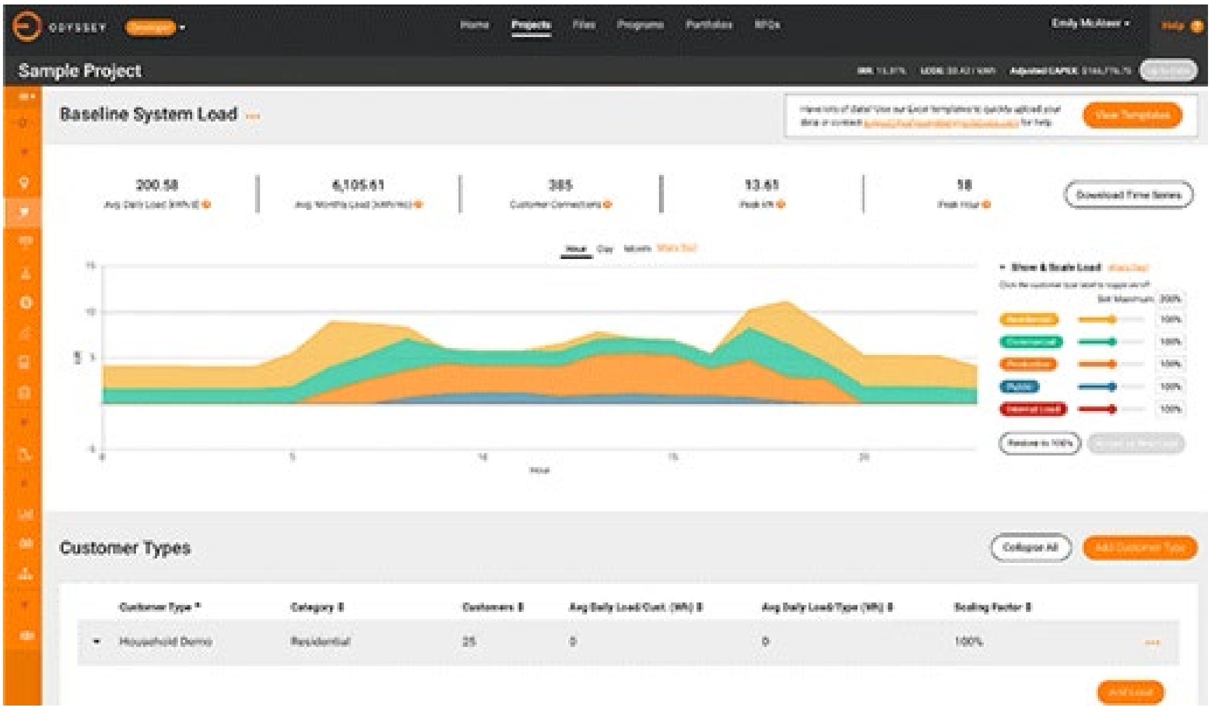
Analytic tools, combined with new forms of data, are increasingly important when targeting, designing and operating mini-grids. HOMER Energy, founded in 2009 based on technology originally developed at NREL and recently acquired by UL, is a leading provider of modelling software for mini-grids and distributed generation. It has powerful modelling tools that allow different combinations of mini-grid components to be simulated, evaluated and optimized so that developers can select the most economic type of mini-grid for a given situation and pattern of demand. Odyssey Energy Solutions, a company based in Boulder Colorado, has developed a web-based platform, partly powered by HOMER's software, which helps to manage the workflow of planning and developing a mini-grid – from the initial survey, to technical and financial evaluation, to management of a portfolio of mini-grids once they are developed (Figure 49).

Data are being used to identify geographies and communities that are promising targets for mini-grid technologies. TFE Energy developed the Village Data Analytics (VIDA) tool with support from the European Space Agency (Figure 50). It uses a combination of satellite data and machine learning algorithms to identify and rank commercially viable sites for mini-grid developments. The algorithms look for settlements and then determine certain features such as size, access to roads, grid and water as well as agricultural activity. This information is fed into an energy access model and used to predict socioeconomic characteristics of the village, such as ability to pay for power and expected energy demand. Taken together, the information and analysis layers predict a site's viability for a mini-grid and give it an overall score relative to other potential sites.

Facebook has also developed a predictive model for mapping existing power grids. In many developing countries, information about the grid is inaccurate, outdated or incomplete. To address this, the company, with a number of partners, used publicly available datasets to predict the layout of the medium-voltage grid. The approach included nighttime radiance measurements via satellite in order to detect settlements with significant electricity supplies and a *shortest pat* algorithm to infer the most likely layout of the grid. Facebook believes that the model is accurate to within a kilometre of known grid

Figure 49

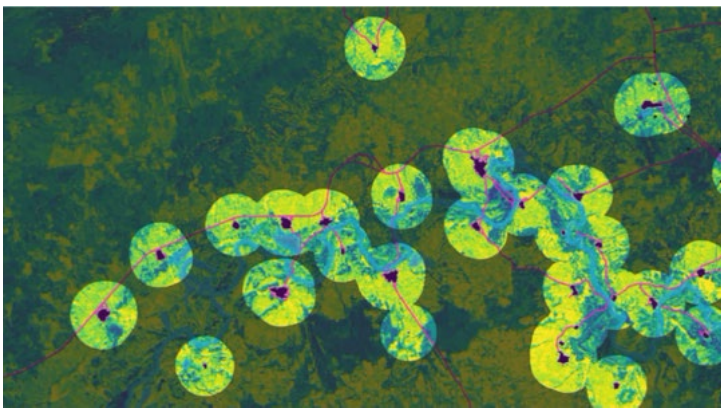
Odyssey Energy Solutions' web platform



Source: Odyssey Energy Solutions.

Figure 50

TFE Energy's satellite-based identification and analysis of settlements, using VIDA tool



Source: TFE. **Note:** The bright circles represent candidate sites for mini-grid development.

connections about 70 percent of the time and that more data would improve that rate. The output of the model is available for six countries, with a guide on how to replicate it.

Other analytical technologies will, in the future, be increasingly important in mini-grids. In particular, machine learning is already being used in some mini-grid controllers, to optimize the balance between supply, storage and demand. These technologies can also be used to reduce the costs of maintenance and operations, for example by identifying patterns of data that suggest a component may fail, allowing it to be fixed before a major fault occurs.

Part 3

Analysis

Section 6
Policy and regulations

National, state and local policymaking are all central in determining opportunities for mini-grid development, with regulations and support schemes often necessary for projects to be viable. Underlying policy is the question of centralization: when determining administrative responsibilities, setting licensing procedures or launching subsidy schemes, policymakers must decide between a bottom-up approach or maintaining a more centralized oversight. There are trade-offs between these approaches in terms of cost, speed and efficiency.

This tension is by no means always clear-cut. While some governments might afford considerable freedom to developers when it comes to siting, they might still introduce onerous criteria regarding asset performance or permitted technology types. Certain regional trends stand out. Francophone western African administrations tend to enforce more burdensome licensing procedures than those in the continent's east, where developers are typically less subject to regulatory constraints when developing projects. Other trends are universal. When governments set clear, pragmatic and consistent regulations, they are best placed to attract developers. Among the most impactful policies for mini-grid development are those relating to licensing, tenders, subsidies, tariff setting and grid arrival.

6.1 Policy frameworks

As mini-grids proliferate and knowledge of relevant technologies spreads, policymakers are becoming more adept at designing high-level electrification *roadmaps*. These blueprints are increasingly comprehensive, providing greater visibility on how mini-grids can play a role in expanding energy access. That said, while a select few countries are at the vanguard of roadmap design, there remains a long way to go. Not coincidentally, countries most in need of sustained investment have seen the slowest progress toward comprehensive policy frameworks.

Successful roadmaps typically require policymakers to be committed to one goal and to one principle. The goal: to dramatically *expand energy access* to as many citizens as possible. The principle: *flexibility* about the tools that can be used to meet the goal. That includes an openness to private investment, as well as the de-centralized production and delivery of electricity.

Pledges to widen access to energy have been around for decades in countries with low electricity rates. In recent years however more governments have sought to ratify universal targets. Many of these governmnents are now striving to meet these targets by 2030.

At their best, electrification objectives are accompanied by clear roadmaps. National electrification plans typically combine access targets with details as to how they are to be achieved. Some targets are listed within more general energy plans, while others are tagged on to specific legislation relating to electrification.

From the mini-grid developer's perspective, the best plans clearly outline what regions are to be electrified and by which electrification technologies, shedding light on the role envisioned for mini-grids, solar home systems and the build-out of transmission infrastructure. The most credible are based on a lowest-cost-of-electricity model, identifying the most economically viable technology for each region.

Plans vary in their level of detail and may not reflect shifting policy priorities, but those that explicitly mention mini-grids show that the sector is prioritized by the government – a strong investment signal to potential market entrants. Such roadmaps should be put into context; policymakers might, for instance, be under pressure to overpromise in view of the prevailing political climate.

Success or failure often rides on the entity tasked with steering the national electrification strategy. In some cases, governments hand state-owned utilities the reins. In others, they establish new rural electrification agencies (REA). Such REAs typically oversee electrification programmes but may also coordinate the disbursal of subsidy payments and licences. Of the countries that the authors surveyed, governments had set up a REA in just under half as of 2018 (Figure 51).

REAs are often tasked with spending rural electrification funds, which can be raised via domestic subsidy programmes, from government coffers or donors. In countries such as Kenya and the Philippines, funds to support REAs have been raised via levies on retail electricity bills. In Tanzania, Uganda, and elsewhere, governments have made direct transfers to support initiatives.

REAs can vary widely in their independence from other public bodies. Key decisions concerning electrification initiatives may at times ultimately lie with regulators or ministries of energy and finance, confusing developers as to who they should be turning to. In other cases, REAs enjoy a high level of autonomy, setting strategic agendas while coordinating *one-stop shops,* which serve as primary points of contact for developers over the course of the implementaion of a mini-grid project. Mini-grid stakeholders need clarity on these REAs' responsibilities and a well-defined sense of future developments and work against which they can plan.

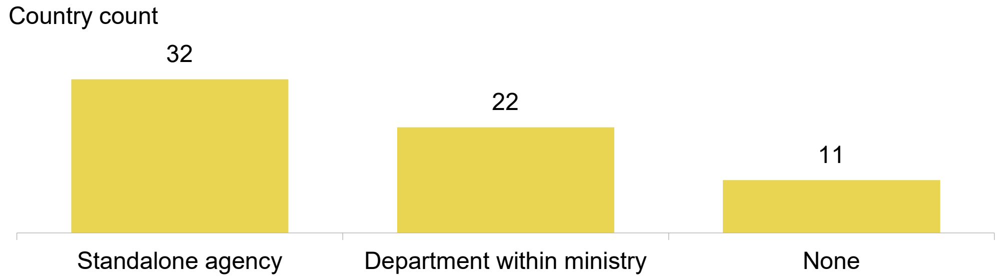
Some governments specifically parcel out regulatory responsibilities among multiple public agencies, including REAs, state-owned utilities and local administrative bodies. While this can lighten the administrative burden for any one regulatory authority and empower local actors, it also poses challenges in terms of collaboration and information for government officials. For developers, it can result in a lack of clarity on who to turn to for answers. Kenya for example has three government agencies involved in providing licences with no mini-grid focal point. In Mali on the other hand, the REA has full oversight over mini-grid development.

Many countries, particularly in Sub-Saharan Africa, have yet to phase out subsidies that artificially reduce the price of diesel fuel in power generation (Figure 53). Such subsidies fundamentally undermine the development of new mini-grids employing cleaner technologies. Customers in specific areas designated by the regulator pay tariffs so low, which do not cover the underlying costs being incurred by generators burning diesel.

Regulations pertaining to mini-grid development are prone to instability. Generous subsidy schemes can be suddenly dialled back when market pene-

Figure 51

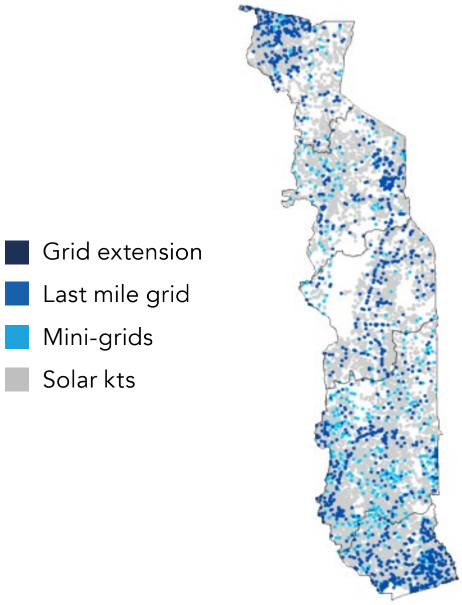
Countries with rural electrification agencies or departments tasked with improving energy access



Source: Climatescope 2019, BloombergNEF. **Note:** 38 Sub-Saharan African, 15 Asian, 10 Latin American and Caribbean, 2 Middle Eastern and North African countries were surveyed.

Figure 52

Togo's electrification strategy per locality



Source: AT2ER. **Note:** Last mile = electrification of households in localities connected to the grid.

Figure 53

Fossil fuel subsidies across surveyed countries, 2018

Source: Climatescope 2019, BloombergNEF.

tration rates have accelerated faster than policymakers anticipated. Similarly, relatively hands-off approaches to issuing licences to build mini-grids can suddenly be tightened with little forewarning. Legislation or regulatory decisions can be subject to inconsistent enforcement, fuelling uncertainty and deterring investment. However clear or permissive regulations may seem, their ability to attract investment relies on the stability of the underlying political environment and the government's attitude toward private investment. Policy and regulatory instability is consistently listed as one of the top reasons why investors do not pursue long-term investments in rural areas.

Box 4

Case study: Togo's electrification strategy

The Government of Togo published its electrification strategy in late 2018, setting a target of universal access by 2030. Basing its conclusions on electrification models and case studies, the plan outlines clear roles for grid connections, solar home systems and mini-grids. Lowest-cost technology choices were detailed for over 3,000 communities across the length of the country. The document foresees that solar home systems and grid extensions will predominate, but also envisions the installation of over 300 mini-grids.

The strategy outlines clear timelines to achieve interim electricity access targets, backed by cost estimates for each relevant technology. For instance, mini-grids are identified as requiring XOF 12 billion (USD 20.2 million) per year, or XOF 147 billion (USD 247.5 million) in total. The plan estimates the costs of providing tax incentives, technical assistance, credit lines and results-based subsidies. In its entirety, it details the government's strategy for the mini-grid sector, alongside how deployment will be incentivized.

What the plan lacks currently is specificity: how specific communities will be electrified other than on a country-level map (Figure 52). This limits the information that is immediately available to developers, but it does show that the government has a clear vision for how it hopes to electrify the country.

6.2 Licensing

Mini-grid development is also contingent on the receptivity of existing regulatory frameworks. While a small number of countries (e.g., India) allow mini-grids to operate in a largely deregulated manner, many others require licences to build and distribute power locally.

Countries such as Sierra Leone that take a relaxed approach issue single licences allowing developers to generate, distribute and sell power. Others, such as Tanzania, allow developers to obtain a single licence for multiple specified sites. This is critical, given that the need per country is for hundreds, and in many cases, thousands of mini-grids over the next few years. Licences vary in scope, subjecting projects to a range of criteria ranging from operating conditions to performance requirements. Licences are typically good for 15–25 years, allowing enough time for developers to amortize project assets.

The speed at which licences are issued can vary significantly and investors can be deterred from doing business in countries where the process takes years. The time required for licences to be issued is also often unpredictable, and companies generally have no avenues to complain, nor other recourse in the case of unreasonable or illegitimate delays. Of relevance are the priority the government ascribes to mini-grid deployment, how many licences are required, and the efficiency of local administrations. Developers benefit from schemes that are swift, clear and pragmatic, with relevant procedures and legislation easily available. In this regard, Tanzania has long been praised for the clarity of its mini-grid regulations. Conversely, the Philippines has no defined process for licensing mini-grids, making the process as long and as complex as that for utility-scale projects.

Some countries set capacity thresholds below which licences are not required for new mini-grids. A growing number of countries exempt smaller projects from being certified, but still require larger projects to obtain certification. Capacity limits can vary considerably, from 20kW to 2MW in Sub-Saharan Africa alone (Figure 54).

Some countries require mini-grids to be located in proximity to the national grid to be exempt from licensing. Others exempt mini-grids from licensing where all power will be used by the same entity that owns the project, but require those that sell to customers to secure licences. Regulations in some countries are even more relaxed: India for example does not require licences to develop and operate projects. While this kind of deregulation can be problematic, such measures simplify project development considerably.

Beyond the types of carve-outs and exemption rules described above, more nuanced licensing regulations are emerging as the sector matures. These include tweaking documentation requirements for mini-grid projects based on whether they deliver AC or DC, the technology they deploy, or their specific location. Often this means simplified licensing for smaller or *greener* projects, but it can also mean setting different conditions regarding tariffs, access to subsidies and rules for the arrival of the main grid.

The development of decentralized resources can also be incentivized through the issue of provisional licences. In some cases, these confer temporary exclusivity for developers to build in specific geographic zones for periods of one to five years. Such provisional licences can provide useful windows for developers to carry out assessments, structure project financing and secure land. Provisional licences allow the private sector to play a more proactive role, providing developers with de-risking frameworks within which to investigate the most promising sites.

6.3 Concessions

Markets that have seen the highest levels of mini-grid penetration have also often allowed developers the highest degree of autonomy. That said, regulators have also tried to attract private sector participation through more centralized approaches such as organizing concessions.

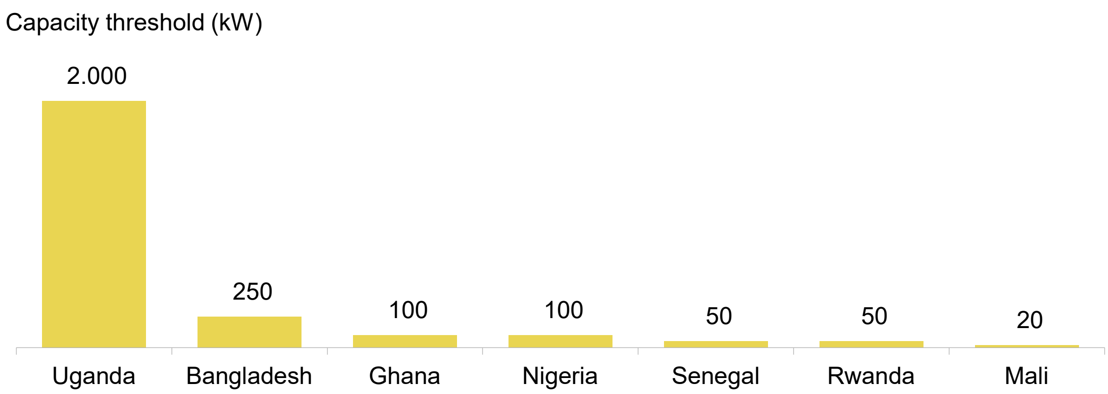
Concessions can give developers exclusive rights to operate and maintain distribution and generation assets within specific geographic areas for defined periods of time. Mini-grids constructed through such frameworks are often transferred to public ownership upon completion. This retains public sector oversight over projects, but can dis-incentivize investment by the operator towards the end of the concession period.

Concessions can encompass large expanses of territory (as has been the case in Senegal) or cover smaller village clusters (Uganda). Such frameworks are typically established by a REA, which provides a subsidy to shoulder part of the initial capital costs facing developers. Concessions can explicitly prioritize mini-grids or allow developers to pursue projects that improve electrification rates as they see fit.

Concessions allow public authorities to decide where mini-grids are constructed, and when projects are clustered, costs can be reduced. Through

Figure 54

Mini-grid capacity thresholds for licence exemptions, select markets



Source: BloombergNEF. **Note:** Figure shows levels below which developers are not required to secure a licence. Uganda requires projects 2MW or smaller to secure specific certificates granting exemptions from licences but obtaining such certificates can take up to a year, according to local market participants. Tanzania's legislation sets a 100kW threshold, but developers have indicated that in practice this is not respected and they must still obtain licences in the country. In Nigeria, mini-grids of 100kW to 1MW benefit from a simplified licensing procedure.

Box 5

Case study: Senegal's concessionary system

Senegal was one of the first countries to pursue electrification through concessions on a significant scale. The government divided the country's rural regions into 10 vast areas for concessions in 1998. Over 25-year mandates, concessionaires have been granted the right to provide electrification services to local populations using a variety of technologies, including mini-grids. Tariffs are capped below cost-reflective levels and vary across concessions.

Despite the government's offer to cover up to 70 percent of capex through subsidies, private participation has been stymied by the tariff caps. Bureaucracy has also slowed progress: it took five years to award the first concession and another five for the first household to get connected. Four concessions have yet to be allocated. Developers have claimed that the vast sizes of the concessions awarded should have been broken up into smaller ones, making electrification projects more effective to carry out.

Parallel to the concessionary system, Local Rural Electrification Initiatives (ERIL) allow smaller actors to provide electricity to communities, the only conditions being that they lie outside the 10 larger regional concessions or that there be no announced plans to electrify the communities over the next three years.

Very few mini-grids have been developed as part of the concession or ERIL schemes. However, reforms to clarify the complex framework are under consideration and legislation passed in December 2018 subsidizes concessionaires, allowing them to bring rates down to the state-owned utility Senelec's grid retail tariffs. This should potentially substantially expand the share of rural population able to pay mini-grid tariffs.

aggregation, concessions can have a much larger impact on local communities than isolated mini-grid projects. The added benefit is that they can also boost buy-in from public authorities that might otherwise regard individual mini-grid developments as lower priority.

Unfortunately, not all concessions are executed in a regimented manner and at times, they result in the greenlighting of projects that have been submitted on an unsolicited basis. More rigorous frameworks see would-be concessionaires competing according to a variety of criteria, such as providing the highest number of connections within a given period or meeting electrification targets at the lowest subsidy rate. Such schemes can also prioritize a particular technology type.

Introducing concessions can be complex, but once up and running, they can serve as effective vehicles for standardizing contracts and licences, reducing transaction costs, and providing positive signals to investors seeking to reduce risk. Concessions are however an imperfect response to the challenge of right-sizing mini-grids to the targeted community, as governments may not be best positioned to commission the accurate demand assessments required for their introduction.

6.4 Subsidies

Implementation

As for most rural electrification efforts, mini-grids remain reliant on public support schemes of various sorts, including those not explicitly aimed at mini-grid development. For instance, renewable hybrid mini-grid developers can benefit from incentives to reduce the cost of equipment for renewables or from diesel fuel that has been subsidized. Tariff setting is also relevant; operators that can charge cost-reflective rates would be less likely to require public support, assuming their customers can pay the tariffs.

Subsidies have two main sources of funding — governments and donors — including multilaterals such as the World Bank. The degree to which external funding matters largely rests on the government's ability to mobilize funding from its own budget. Truly private financiers can be hard to attract, being put off by an absence of subsidies, difficulties in estimating demand growth and a lack of experience financing mini-grid projects. They can also be reluctant to invest due to risks related to future power demand growth, lack of regulations, currency fluctuations and instability. All of this boosts the potential need for subsidies.

Timetables for phasing out subsidies following their introduction can vary. In some cases, governments communicate a phase-out plan, with support tapered off as the sector achieves greater maturity. Such reductions can be calibrated according to variables such as the number of registered mini-grids or their overall capacity.

Support schemes for renewables in markets such as Germany saw available feed-in tariffs sink due to automatic adjustments. In 2009, Germany introduced an automatic adjustment mechanism for tariffs paid to PV plant operators due to increasing uptake. Subsequent reforms had a monthly degression rate increase should yearly deployment volumes exceed a cap. Although a transition to auctions later meant that only small-scale PV continued to benefit from such support, the mechanism provided a transparent tool to reduce subsidy payments.

Whatever the policy instruments through which subsidies are applied, governments that consider how subsidies will eventually be removed are more likely to propose sustainable support schemes, diminishing the risk of investor-deterring backtracking. While the mini-grid sector requires subsidies until the market takes off on a commercial-financing basis, how support mechanisms should be structured and used is open to debate.

Although a wide range of subsidies have been implemented across mini-grid markets, two main types of support have driven project development: upfront capex subsidies and results-based financing (RBF).

Upfront capex subsidies

One way to subsidize mini-grids is to provide developers with financial support to cover some portion of the total capex of their projects before they build, a form of support known as an upfront capex subsidy. This typically involves issuing grants or concessional loans to cover upfront capital costs. Grants can be distributed on an in-kind basis and involve providing technical assistance or distribution, generation and metering equipment.

In terms of distribution, upfront subsidies can be made available at a fixed rate on a first-come, first-served basis. They may also be disbursed through minimum subsidy tenders. Developers complain that they must devote substantial resources to engage in such programmes, which tend to be administratively complex. Bidders can win subsidies, but then apply elsewhere for licences to operate. Since 2019, eight African countries have launched tenders to introduce mini-grids (Figure 55).

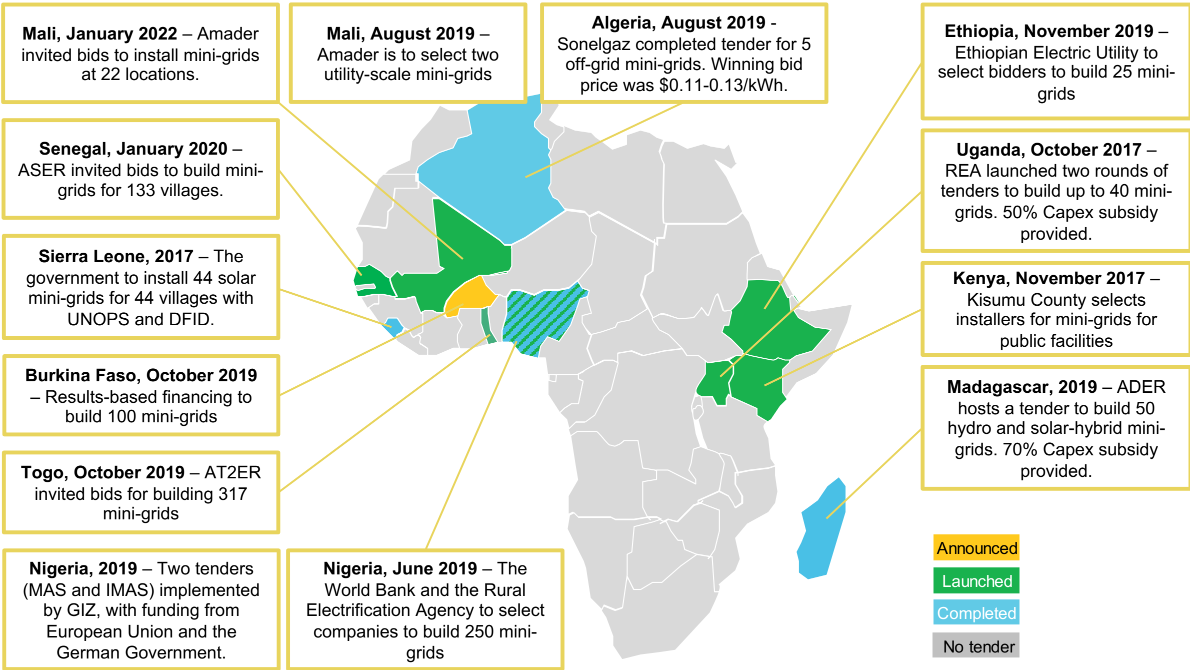
Results-based financing

Upfront capex-based subsidies are generally not contingent on how successful a project proves to be. This has led donors, private investors and developers to call for schemes that grant rewards based on the results achieved. RBF involves payment of specified sums when projects achieve certain criteria or surpass milestones. Those considering making payments have typically focused on providing a specified sum for each completed connection, although the specified subsidy criteria could include a wide range of variables. The level of support, meanwhile, is usually capped at a specific point – a contract might specify an end goal of 1,000 connections, beyond which no further subsidy is paid out.

Implementing RBF can come with challenges, but its introduction is usually simpler and faster than up-front proposals based on capex subsidies. Risk of delivery is also shifted to the private sector while maintaining regulatory certainty about what financial support will be provided. Because the payments are back-loaded however, developers might still require financing support to achieve early milestones. RBF entails higher risk for developers should they fail to advance a project as fast as expected.

Figure 55

Africa tender map



Source: BloombergNEF.

Box 6

Case study: Uganda's upfront subsidy model

Developers in Uganda have the potential to have substantially large portions of initial capital expenditure for their projects taken off their hands by the government. The country's REA covers 50 percent of capex and notably takes on the cost of low-voltage lines, financing the distribution network. This might involve directly constructing the distribution infrastructure or simply reimbursing the developer for the cost.

As distribution assets typically represent at least 12 percent of capex (M.Moner-Girona, 2018), the subsidy removes a large chunk of total project outlays through the Renewable Energy Fund (REF). This is in turn funded by the government's annual budget, a levy on transmission of bulk purchases of electricity, surplus revenue from the regulatory authority and support from development finance institutions (DFIs).

Concessions are issued to developers for 10-year periods on a build-own-operate-transfer basis through which the mini-grid's distribution network is ultimately transferred to the government. The REA takes on the additional tasks of identifying and securing sites, removing much of the pre-application work facing developers. The government is generally comfortable issuing such generous incentives because the concessions on offer are for a relatively short duration and the it knows it will ultimately take direct control of the mini-grids.

RBF programmes lend themselves to less centralized frameworks, where regulators grant developers more autonomy. Given the number of new RBF schemes currently in operation, much will be learnt regarding their effectiveness in the coming years.

Box 7

Case study: Nigeria's performance-based grants

A number of mini-grid subsidy schemes are being deployed in Nigeria. One is a performance-based grant programme, which provides grants of USD 350 per new connection. The scheme is open on a first-come, first-served basis. A minimum total grant request of USD 10,000 has been set per mini-grid, with eligible projects restricted to solar hybrid mini-grids in off-grid regions.

The onus to carry out the studies, energy audits and community surveys required to select sites is on developers. Supported by both the AfDB and the World Bank, NIgeria's programme has seen the development of a pipeline of projects. Progress has been swift: the first mini-grid was commissioned in December 2019, just one year after World Bank financing was secured.

Tax incentives

The economics of renewable hybrid mini-grids improve when governments waive taxes levied on certain classes of equipment for renewables. Such indirect subsidies are typically designed with utility-scale projects in mind and therefore do not always apply to components used in mini-grids.

From the government's perspective, tax incentives can be comparatively simpler to implement than other subsidies. However, when foregone tax revenues are taken into account, the costs associated with such incentives can skyrocket when adoption rates rise faster than anticipated. This has already occurred in a number of countries around the world. Such incentives can be structured so that they are reviewed annually and can be changed. This can complicate matters for developers looking to construct projects with multiyear lead times.

6.5 Cost-reflective tariffs

Developer requirements for subsidies to support mini-grids are often directly related to the tariffs they can ask of customers. Certain countries place limits on power prices to protect poorer rural consumers, either by enforcing price caps or by pegging them to retail rates charged for electricity from the main grid.

Box 8

Case study: Eastern African Community's renewables tariff exemptions

A number of African countries have implemented fiscal policies favouring equipment for renewables such as PV modules. The authors found that 23 Sub-Saharan African countries had implemented fiscal policies ranging from waivers on import duties to exemptions on value-added taxes. One of the first blocs to adopt a coordinated approach, the Eastern African Community (consisting of Burundi, Kenya, Rwanda, South Sudan, Tanzania and Uganda) adopted an import duty exemption in 2004 to be introduced across member states. But tax waivers on a range of project components were removed in 2016, leaving only modules and batteries exempt.

Inconsistency in how standards are applied can be an issue. For instance, while import duties are not imposed on batteries entering Uganda when packaged alongside other solar equipment, batteries for renewables projects that are imported separately are subject to import duties.

In many cases, the tariffs that would be needed to fully recover costs of a rural mini-grid are significantly higher than subsidized retail rates for power from the main grid. The ability to set cost-reflective tariffs also depends on what customers can afford to pay. When operators cannot recoup capital and operating costs through tariffs that are cost-reflective, they typically need subsidies.

Fine-tuning tariffs also depends on understanding consumers' price sensitivity and the potential demand that can be unlocked by making electricity available at a certain price point. Initial results from a research initiative launched by investment firm CrossBoundary show that rural mini-grid customers are often budget-constrained and quite price elastic; consumption increased significantly when tariffs were lowered. For every dollar saved on the tariff, the average customer spent another USD 0.93 on raising electricity consumption. This suggests that developers might be able to lower tariffs by more than initially expected while maintaining their revenue stream.

In practice, regulators tend to have political difficulties in accepting cost-reflective tariffs. Even in markets where developers can impose such tariffs, they may still require subsidies due to high capex, limited overall demand for power or customers' low willingness or ability to pay. In such cases, regulators can be involved in ensuring that cost-reflective rates are kept in check. Such oversight can involve conducting yearly tariff reviews against a reference internal rate of return or be based on an assessment of how much replacing the asset being used would cost, a method known as the cost-plus approach.

In some countries, regulators allow cost-reflective tariffs to be charged but only for mini-grids below certain capacity thresholds. Countries such as Cambodia have disbursed top-up payments to operators to make their project revenues more cost-reflective because of tariff caps that they can charge customers. Regulators can calculate reasonable levels through avoided-cost tariffs, where rates are set to reflect what consumers would otherwise have spent on pre-existing power sources such as diesel or kerosene.

Domestic power prices exert considerable influence over what developers can charge. For those connected to the main grid, the prices they pay are often maintained low through subsidies. As a result, customers on mini-grids often face higher bills than those on the national grid. Not surprisingly, this can give rise to discontent, with some communities opposing plans to develop mini-grids and instead calling for grid extensions. However, customers in markets such as India have been willing to pay a premium for the superior quality of service offered by a mini-grid compared to the main grid.

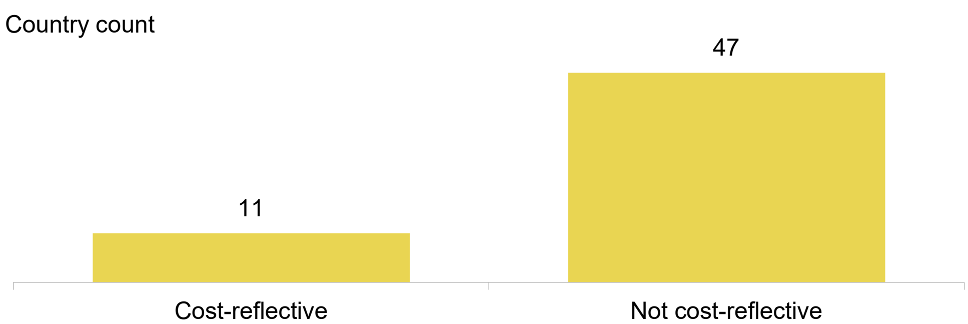
6.6 Grid arrival

Why does it matter?

Developers typically strive to site isolated mini-grids in areas unlikely to be electrified over the coming decade or so, as connecting a mini-grid to the extended network can threaten a project's revenue stream. Once attached to the grid, in the absence

Figure 56

Mini-grid tariff regulations across surveyed countries, 2018



Source: BloombergNEF, Climatescope 2019. **Note:** Of the countries surveyed, 39 are in Sub-Saharan Africa, 12 in Asia and 7 in Latin America and the Caribbean.

of regulation, the state might simply expropriate a mini-grid's distribution and generation assets with minimal compensation, or the operator may find the mini-grid coexisting and competing with the national grid. This may leave the operator with no choice but to abandon, resell and relocate assets.

To date, grid arrival to mini-grids in far-flung locations has been largely a non-existent problem. Very few isolated mini-grids have been integrated into national grids. Clarifying rules on what occurs when a grid is extended to a mini-grid is important yet less than half of the countries surveyed for this research have set up clear rules governing grid arrival (Figure 57).

Electrification master plans, discussed earlier, sometimes detail how the transmission grid is to be built out. They are a start, although forthcoming transmission extensions are usually clarified

Figure 57

Clear rules on the arrival of the main grid across surveyed countries, 2018

Source: Climatescope 2019, BloombergNEF.

Box 9

Case study: Zambia's PSP programme

Despite the low incidence of grid arrival leading to expropriation, the spread of a national grid can render mini-grid projects redundant before they even get off the ground.

Planning for Zambia's Private Sector Participation in Micro-Hydro Power Development (PSP) project kicked off in 2006, laying the foundation for attracting private actors to develop six hydro mini-grids of 0.1–2.2MW.

Yet as the project progressed, so too did Zambia's national grid extensions. A national Electricity Access Rollback Project was launched in 2010, entrusting the utility with an obligation to connect private power producers within 10km of the national grid. Combined with the faster-than-expected transmission build, the duty to connect meant that none of the PSP plants were equipped with mini-grids. Poor communication of grid extension plans meant that developers had little visibility of grid expansion.

However, new rules setting remedial provisions for grid encroachment were developed by the regulator in partnership with the EU and passed in late 2019. This should help provide the certainty investors and developers require for the sector to grow.

by stand-alone documents. Master plans, if made public, can help developers gauge the risk of grid arrival facing a particular site.

Yet even when such plans are at hand, estimating when transmission infrastructure will reach a project site can be fraught with uncertainty. Changes in political priorities and evolving grid development plans often alter construction timeframes. Lack of communication between operators and public authorities, moreover, can lead to mini-grids being connected to the transmission network earlier than initially predicted.

Compensation

Rules concerning grid arrival can be written into national regulatory frameworks, or transposed into licences that support different approaches. Expropriation, for instance, might be accompanied by some form of compensation. One approach is for it to include unrecovered costs from operations, including those that would have been recovered through electricity sales or subsidies. Initial capex, such as that of generation, might also be included once accumulated depreciation is removed. Governments may also choose to pay developers for taking over assets linked to distribution, but not generation. In some cases, only larger generation units may be deemed worthy of compensation.

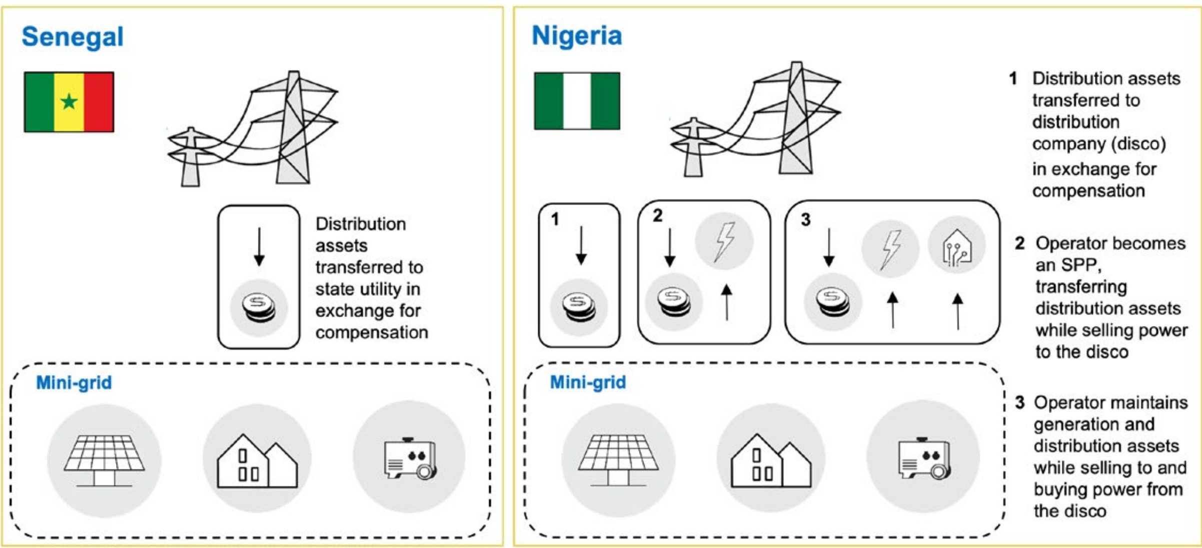
Conversion to a small power producer or distributor

One potential solution to the issue of grid arrival and the problems it poses is to allow the operator to continue running and deriving revenue from the mini-grid. This might occur through the conversion of the operator to a small power producer (SPP). Electricity is no longer sold to retail customers but provided instead to an entity such as the regional distribution system operator. The ease with which that can be achieved depends on whether a framework already exists for private generation actors. Barriers to establishing an SPP model are likely to be lower in countries where independent power producers (IPPs) are active across the energy sector.

An alternative arrangement can be arrived at if the mini-grid operators become a small power distributor (SPD). Just as with an SPP, the mini-grid would no longer sell power directly to customers. Instead of feeding its power back into the main grid, however, it purchases electricity from the local utility

Figure 58

Examples of options available to mini-grid operators upon grid arrival



Source: BloombergNEF. **Note:** In Nigeria, should the mini-grid's distribution assets be transferred to the disco, the mini-grid operator is free to relocate generation assets. Senegal lacks detailed regulations regarding grid arrival, but in practice, compensation-backed expropriation has been carried out across the board.

and sells it on to its local client base. The distinction between an SPP and an SPD is sometimes blurred – there may be some overlap when an SPD maintains a supply source to the main grid, such as reserve diesel generators.

Allowing for conversion to SPPs or SPDs requires the establishment of specific licensing procedures. The viability of operating as either, moreover, ultimately hinges on project economics and the amount of remuneration provided to the operator. SPPs rely on the tariff provided for power flowing into the main grid. Rates can be set via a power purchase agreement (PPA) or possibly a feed-in tariff, and compensation for distribution assets transferred to government ownership must also be accounted for. Similarly, PPA tariffs and appropriate levels of compensation for the project's generation assets must be set when a mini-grid converts to an SPD. In Tanzania, some hydro mini-grids have been connected to the main grid, and the operators sell electricity to state-owned utility Tanesco . However, developers have complained that Tanesco enforces the rules inconsistently in an attempt to lower tariffs as much as possible. (See also Section 12.4).

Operating alongside the grid

In some cases, a mini-grid operator might operate alongside the main grid, in effect competing with it. In such cases, tariffs to mini-grid customers are likely to be significantly higher than grid rates subsidized by the government. Despite the tariff differential, however, customers may opt to remain with the mini-grid provided it has provided superior service. They might place a premium on the quality of mini-grid power, which can be far higher than that offered by national, outage-prone grid networks.

Whatever the desired solution, the options on the table should be outlined by the licences awarded to operators. Markets without clear grid arrival rules, such as the Indian state of Bihar, have seen the lack of clarity hurting investment. That said, it may be beneficial to maintain a degree of flexibility, as some mini-grid operators might prefer paid-out expropriation to adapting to the grid's arrival. Transmission lines are often built at a glacial pace. But given that project lifetimes range from 15–25 years, clarity regarding what procedures are available is central to attracting finance.

Box 10

Case study: Bihar's lack of rules governing grid arrival

The Indian state of Bihar has no regulations governing grid encroachment. In practice, however, this has led to operators engaging with distribution companies (discos) through a number of configurations. Possibilities range from continuing to run the mini-grid without engaging with the local disco, to seeing operators sell surplus power to the disco at a fixed rate per kilowatt-hour.

Developers in Bihar are notably able to continue charging higher tariffs than the main grid on the basis of their superior quality of service. While the current system affords flexibility to developers, those interviewed for this research expressed concerns that future regulation could constrain the range of available options. Some stated that they would hold off from connecting their mini-grids to the main grid until rules had been passed.

Section 7
Financing

Development finance institutions (DFIs), donor agencies, foundations and governments have so far been the main providers of funding to the mini-grid sector. Their involvement is also critical in encouraging commercial financiers to participate in the market and to help them overcome perceived risks due to lack of scale, developer track record, regulatory uncertainties and the limited power demands of rural communities. To mitigate these risks and attract construction financing, governments have introduced results-based financing (RBF), where they agree to pay per-connection grants to developers once they can prove a mini-grid is operational and providing reliable power to end-users.

7.1 Financing of mini-grids to date

Most renewable hybrid mini-grid projects in emerging markets to date have relied on some form of non-commercial grant or equity investment. The sector is generally too nascent to take off with pure commercial financing, requiring the participation of DFIs, donor agencies, foundations and governments.

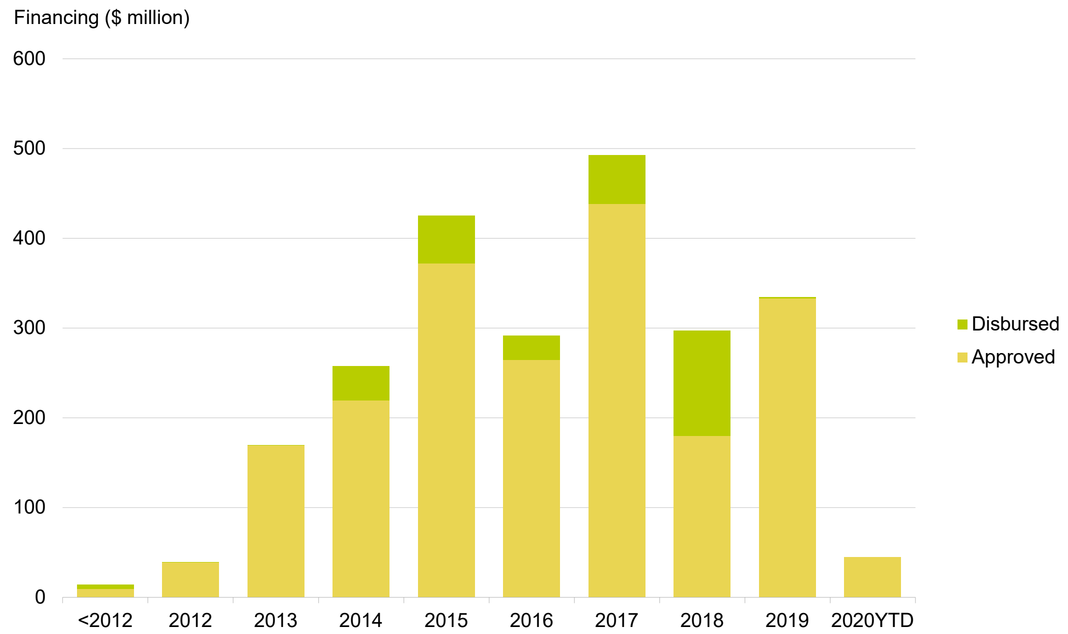
At the moment, the risks perceived to be associated with mini-grid projects are not aligned with the risk/return expectations of commercial financiers. This differs from the off-grid solar sector where, in the last five years, commercial debt has started to become available after technology testing, verification of business models, and the exposure of commercial financiers to the sector. Although the technologies used in mini-grids are proven and the costs of solar hybrid mini-grids have become increasingly competitive, most developers rely on their own balance sheets and struggle to raise external finance. Without additional mechanisms, supports or guarantees from public organizations, commercial financiers have shied from funding mini-grids due to concerns over ambiguous electrification strategies, a lack of regulations to protect mini-grid assets, a lack of developer track records and the limited power demand of rural consumers. However, commercial finance is possible when governments take strong initiatives by providing a form of grant — in particular a RBF grant — and a robust regulatory framework that supports the development of mini-grids.

Figure 59 shows financing approved and disbursed by financiers belonging to the Mini-grids Funders Group through March 2020. The 23-organization group consists of the World Bank, regional DFIs, public funds, donor agencies, impact investors and foundations. As of March 2020, 14 funders in the group had approved a cumulative total of USD 2.07 billion since 2007. The majority of this funding is aimed at assisting private mini-grid developers and providing technical assistance to governments to form policies and regulations. The approved financing started to increase in 2012 as the solar hybrid mini-grid market started maturing in emerging countries. It then peaked in 2017.

Just USD 297 million or 14 percent of approved financing has been disbursed to date. While the picture on the ground is likely to be better than the data suggest — funders often find it more difficult to track and report disbursements than commitments — there have clearly been significant delays in getting funding out the door. There are some possible reasons for the slow deployment of the funding according to the mini-grid stakeholders interviewed for this research.

Figure 59

Approved and disbursed financing in the mini-grid sector



Source: Mini-grids Funders Group, Carbon Trust, BloombergNEF. **Note:** YTD = March 20 2020. The World Bank's USD 150 million for Nigeria's results-based subsidies in 2019 is not counted as 'disbursed'. 'Approved' refers to the funds approved by the Mini-grids Funders Group for use by the specific mini-grid programmes.

- **The market remains immature.** The mini-grid industry is still learning across multiple vectors including policy/regulation, financing and business models. This immaturity has also meant there is a lack of competition among developers striving to offer the best projects to finance. That said, this is certainly changing as more players enter the picture, including large companies with strong development track records. Funding should accelerate as mini-grids with proven business models are built in line with customers' specific needs. Estimating future electricity demand in rural communities that lack grid access has long been a challenge for developers. This has resulted in oversized mini-grids that fail to generate positive returns for investors. As more data on how existing mini-grids are operating become available, developers can conduct more accurate demand assessments, potentially increasing the number of quality projects being planned. This in turn should enable greater financing.
- **Financiers have established demanding criteria for *bankable* projects.** Despite allocating substantial funds, DFIs have also established high criteria for new projects seeking capital. The result is a dearth of projects qualified to take on project-level debt in Sub-Saharan Africa. Getting a project to a stage where it can take on project-level debt typically requires a lot of sweat equity[11] and high-risk capital investment beforehand to ensure quality in approach. Due to the immaturity of the sector, there are only a limited number of players who can take ownership of this. As a result, this makes it difficult for investors to deploy their capital.
- **Projects get stuck in long and complex procurement and tariff negotiation processes.** Governments tend to have limited capacities to agree procurement terms. Negotiations between governments and developers over tariff terms are often challenging with customer protections and investor returns perceived to be at odds. The result is that such discussions can takes months or, in the worst cases, years to complete.
- **Policy reform and funding timelines do not sync.** Funding programmes and government mini-grid policies as well as regulations are of-

11 Refers to a company's contribution toward a project or a business. Sweat equity is generally not monetary and, in most cases, comes in the form of physical labour, mental effort, and time according to Investopedia.

ten misaligned. For example, when changes to a country's regulatory environment to welcome mini-grids take considerably longer than anticipated, funding and deployment get delayed.

Figure 60 shows annual funds committed by key funders over the past 10 years. The World Bank has approved USD 705 million, followed by USD 253 million from the German Agency for International Cooperation (GIZ) and USD 227 million from the French Development Agency (AFD). The Government of the UK, which channels funds through the Renewable Energy Performance Platform (REPP), the Department for International Development (DFID) and InfraCo Africa, is also a large funding provider with a total of USD 383 million approved.

About 79 percent of approved funding in the last ten years has been for Sub-Saharan Africa while 14 percent and 4 percent have been for Asia and Latin America respectively. While recipient countries are diverse, 66 percent of the total funding approved has concentrated on only 10 countries. Nigeria received the largest amount totaling USD 374 mil-

Figure 60

Approved financing by funder

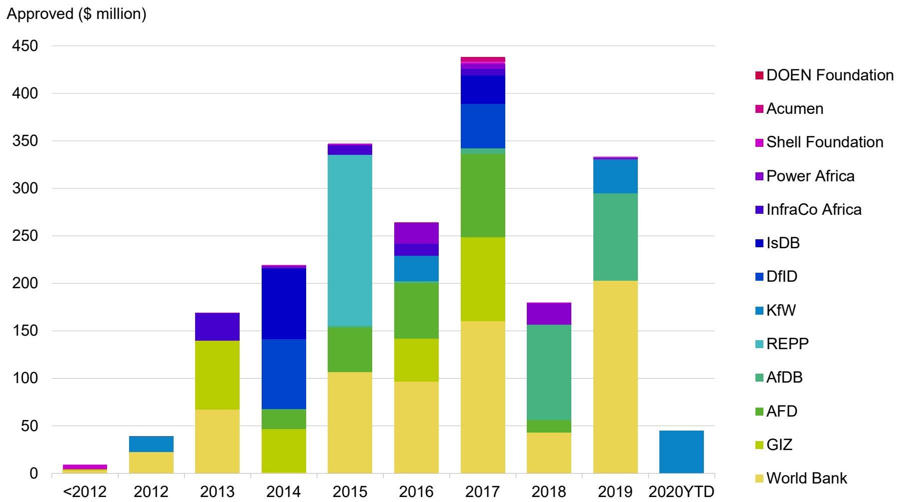
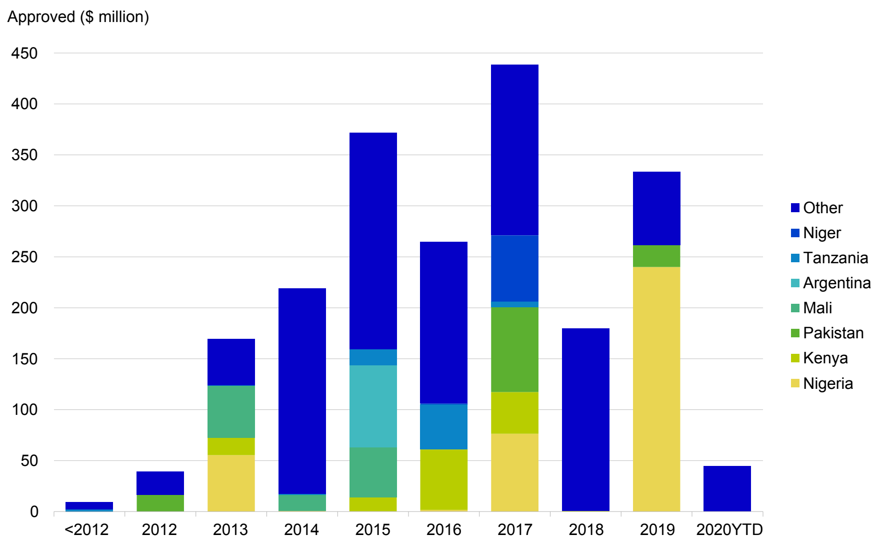


Figure 61

Approved financing by recipient country



Source: Mini-grids Funders Group, Carbon Trust, BloombergNEF.

lion, of which USD 150 million was provided by the World Bank in 2019 for the Nigeria Electrification Project (NEP). Kenya received the second largest at USD 132 million, including USD 50 million from the World Bank. Figure 64 shows selected financiers active in the mini-grid sector by category.

The year-to-year trend in funds actually disbursed in support of mini-grid efforts is more erratic than that for financing simply approved to be spent (Figure 62, Figure 63). The African Development Bank disbursed a total of USD 100 million in technical assistance funding to support educational efforts for policymakers across Africa in 2018 (categorized as 'Other' in Figure 63). The UK government disbursed USD 102 million across Africa through DFID and REPP, including USD 37 million for Sierra Leone in 2017.

Figure 64 shows select financiers active in the mini-grid sector. These include governments and DFIs that provide debt to recipient governments.

Figure 62

Disbursed financing by funder

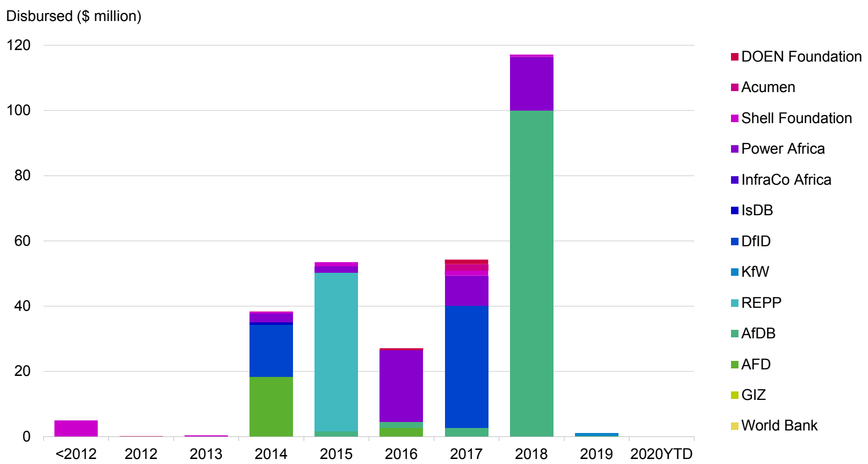
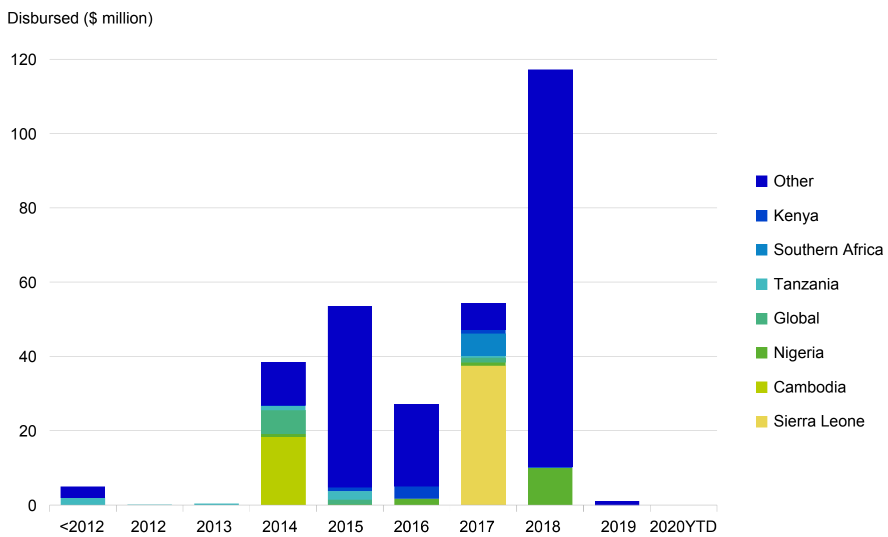


Figure 63

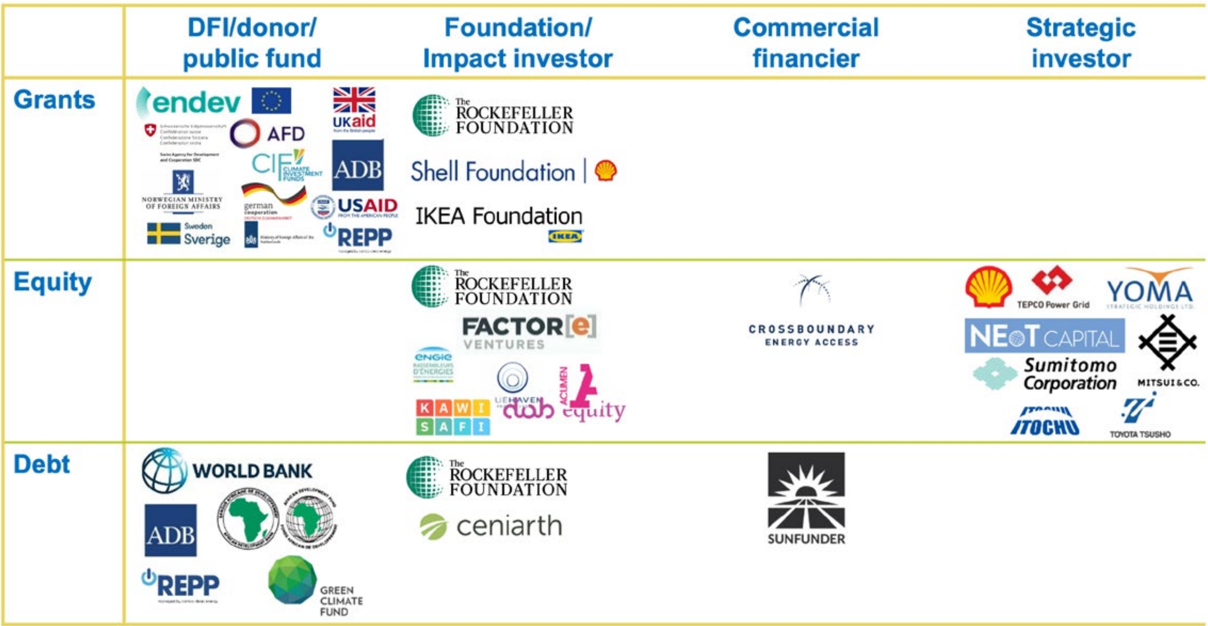
Disbursed financing by recipient country



Source: Mini-grids Funders Group, Carbon Trust, BloombergNEF. 'Other' includes, for example, Ghana, India, Madagascar, Niger, Rwanda, Senegal, Uganda and Zambia.

Figure 64

Select mini-grid financiers



Source: BloombergNEF, company websites. **Note:** The organizations here are limited to those that have financed the mini-grid sector. Often governments provide grants with loans directly from DFIs.

DFIs, donor agencies and public funds

The World Bank, regional DFIs and donor agencies have been active in providing funding on behalf of their government clients, primarily in the format of grants and concessional loans. Objectives include mini-grid project development, household connections and technical assistance. Funding for projects can be provided in the form of up-front subsidies or RBF (see the Policy and Regulation Sections for more details).

In 2016, the World Bank and Climate Investment Funds provided a USD 200 million loan and a USD 9 million grant to the Tanzanian government to provide electricity access to 2.5 million people through grid extension and installations of mini-grids as well as off-grid solar kits.

In 2017, the UK's DFID provided the Government of Sierra Leone with a USD 44 million grant to install 50 solar mini-grids to electrify community health centres and build distribution networks for an additional 40 villages through the Rural Renewable Electrification Project (RREP) (Ministry of Energy, Government of Sierra Leone, 2018). Another example of DFID's funding is GBP 20 million (USD 24.8 million) for the Energy Security and Resource Efficiency in Somaliland Programme (ESRES). In the first phase of the programme six solar hybrid mini-grids were built from September 2015 to August 2018. (Energy Security and Resource Efficiency in Somaliland, 2020).

In 2018, the World Bank provided a loan of USD 350 million to Nigeria's Federal Ministry of Finance to fund the Rural Electrification Agency (REA) Nigeria Electrification Project (NEP). Combining this with the recent African Development Bank's commitment of USD 200 million, the total fund amounts to USD 550 million. USD 220 million of this is dedicated to providing a results-based subsidy for developers to build solar hybrid mini-grids. The subsidy consists of two components: a USD 80 million performance-based grant (PBG) programme and a USD 140 million minimum subsidy tender scheme. In the PBG programme, developers are invited to submit proposals of mini-grids they would like to develop and should the project satisfy the NEP criteria, the developer will receive USD 350 per new connection. For example, if a mini-grid has 200 connections, the developer will receive a grant of USD 70,000 once they can prove to the NEP that the customers (newly connected households or businesses) receive reliable electricity. In the minimum subsidy tender programme, the REA has pre-defined some 250 sites.

Developers bid to develop mini-grids at these sites and five or six of them will be selected to develop all 250 sites. As with the PBG, grants will only be paid out once the NEP can confirm that the customers are connected to the developer's mini-grid network.

In 2018, the Asian Development Bank (ADB) announced support for over USD 1 billion in energy investment in Pacific nations between 2018 and 2021 (ADB, 2018). ADB set up an umbrella facility of up to USD 100 million to provide financing support including loans, guarantees, and letters of credit, to overcome constraints to private sector investment in renewable power projects. Thereafter, the bank approved several grants and loans for island nations such as Nauru, Solomon Islands, Tonga and Tuvalu.

FACTOR[e] VENTURES is an early stage impact investor and venture builder. It supports technology-enabled, early-stage ventures in emerging countries as it believes that the investor can bring positive disruptive changes to the energy, agriculture, mobility, and waste markets in these countries. Companies that have received investments include

Ferntech, a remote control and monitoring technology vendor, and Odyssey, a web platform developer that offers support for mini-grids, from development to operations, using data analytics.

Foundations and impact investors

This group is actively financing the mini-grid sector and offers grants, debt and equity. Foundations can offer loans at single-digit interest rates, with flexibility on tenors which can go up to 10 years. In 2019, the Rockefeller Foundation, Shell Foundation and Ceniarth invested in the CrossBoundary Energy Access Fund (CBEA), which aims to finance portfolios of mini-grids and attract more private capital. In November 2019, the Rockefeller Foundation founded TP Renewable Microgrid with Tata Power to build 10,000 mini-grids across India by 2026 . Acumen has provided equity financing to several mini-grid developers, who mostly aim to build solar hybrid mini-grids.

Commercial financiers

This group is mostly absent today in the mini-grid sector, but in 2019 a few companies closed deals. SunFunder for example provided USD 1.2 million of debt financing to PowerGen Renewables in 2019 to develop 20 mini-grids to supply reliable electricity to 2,400 households on a tea estate in Kenya, totaling 242kW of installed solar capacity and 1.25MWh of battery storage.

Strategic financiers

This category has broadened since 2018, and includes oil majors, trading houses and venture capital firms based across East Asia, Europe and the US. Major Japanese trading houses have actively invested in the sector. Their investments include, for example, Mitsui & Co's USD 9 million into OMC Power in India and Toyota Tsusho's USD 9.3 million into Powerhive in Kenya . In January 2019, Tokyo Electric Power Co. Power Grid (Tepco PowerGrid) formed a new investment entity called CleanGrid Partners, with a total investment of USD 60 million. CleanGrid Partners plans to commit USD 100 million to electrification in South East Asia by 2021 or 2022 and to build mini-grids in Indonesia, Myanmar and the Philippines.

It is important to note that commercial financiers and strategic investors do not usually engage in the mini-grid sector completely independently. Funding and support from DFIs, donors and foundations that have the effect of lowering risk are needed. Mini-grid developers that receive financing from private companies have normally already secured separate financing such as grants. This is known as a blended finance structure, which combines a mixture of private and public financing, helping developers close the project viability gap.

7.2 Financing structures

Financing types

There are three basic types of financing: grants, equity and debt (Table 12). Grants are not expected to be repaid and are provided to fund capex for mini-grids under rural electrification programmes. Some developers also raise equity from either foundations and/or commercial funders, which require them to show returns from their business opera-

Table 12

Types of financing in the mini-grid market

Types	Financing structures	Pros	Cons	Authors' Take
Grants	• Results-based financing (paid post- COD). • Upfront from host government through DFIs/ donors (paid pre-COD).	• 'Free' capital i.e., no repayment requirement. • Quick way to recoup capex.	• Stiff competition with other developers. • Usually small compared to capex.	The most common form of funding for the mini-grid sector, blended with equity. Developers and investors often claim mini-grid projects are not economically viable without grants.
Equity	• Developer balance sheet. • Private equity. • Venture capital.	• Easier to raise than debt or grants, particularly if using developer's own balance sheet.	• Selling part of the company or locking up existing cash. • Investors need to see returns (i.e., dividends). • Investors may have a say on business operation.	Majority of projects are financed with equity. Lenders either use their own balance sheet or run equity financing rounds to attract investors. Equity financing from major corporates have focused on developers with good track records.
Debt	• Project finance. • Asset finance. • Bank guarantees. • Convertible notes.	• Developer still fully legally owns asset. • Developer makes all decisions and keeps all profits. • Once paid back, owns the asset outright.	• Developer must always repay loan regardless of performance. • Debt repayments have precedence over equity.	Still largely absent in the mini-grid market except for concessional loans from DFIs, foundations and impact investors. Lenders prefer to finance developers with existing operating assets or those with a proven track record.

Source: BloombergNEF. **Note:** COD = Commercial operation date.

tions. In debt financing, lenders look for returns on money lent in the form of interest payments and seek to minimize risks, while developers aim for profits to maintain their autonomy.

Grants

Grants are free funds provided with no requirement of repayment that are typically used for capex and technical assistance in the mini-grid sector. DFIs and donor agencies are the primary grant providers. Figure 65 shows financing that 19 of the 26 mini-grid developers belonging to the African Mini-grid Developers Association (AMDA) received between 2013 and 2019. The total amount of the financing was only USD 50.9 million, disbursed by donor agencies, governments, private companies, and others, such as NGOs. Of this, about 80 percent was in the form of grants, which have been a predominant form of financing for mini-grids and used to support the building of projects and central operations (e.g., legal works, central staff, training and non-site travel). Those disbursing grants do not generally provide grants/loans directly to developers, but rather work with local government electrification agencies. The actual funding that mini-grid developers receive may only be a small fraction of the funding disbursed to governments.

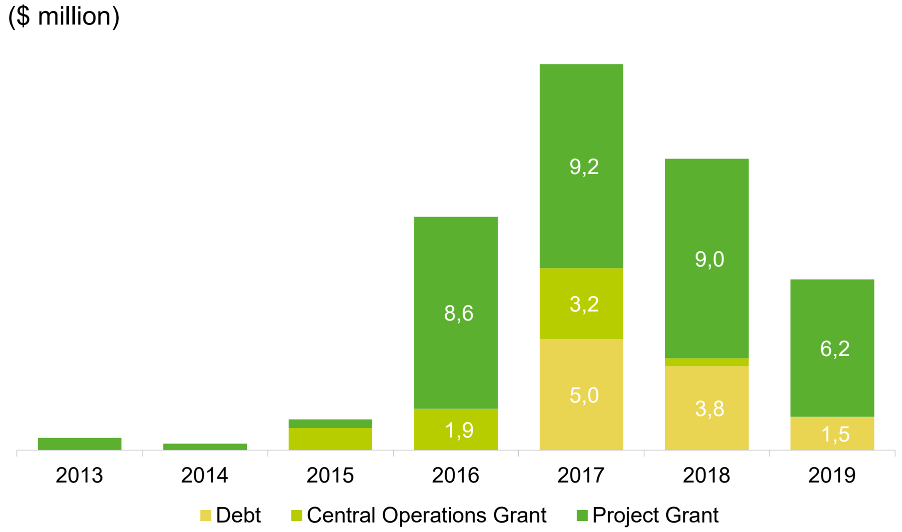
Grant funds are typically limited and tend to attract huge competition amongst developers. Some restrict the countries in which grants can be used, or require developers to spend a portion of the grant on equipment or services from the donor countries. Grants sometimes have significant reporting and other administrative requirements, which increase costs in the form of added staff time and transactional costs.

Equity

Many developers sell part of their project or company as equity in exchange for cash or where possible,

Figure 65

Financing received by mini-grid developers in Sub-Saharan Africa



Source: Africa Minigrid Developer Association (AMDA), ECA. **Note:** Equity is not included. Note that this uses a different dataset from the above figures sourced from the Mini-grids Funders Group. Some of the grant funds in the chart have been contractually committed, but will not be received by developers until the mini-grids are built.

invest their own capital from their corporate balance sheet. In infrastructure projects including mini-grids, private investor equity comes in two forms:

- Corporate equity – directly investing in a mini-grid developer's company
- Project equity – directly investing in an individual mini-grid or mini-grid special purpose vehicle (SPV).

Given the small size of individual mini-grids, equity lenders tend to invest directly in the developer's company (corporate equity). The developer may have multiple mini-grids in operation or in the pipeline, with projects varying significantly in size. Project equity is more common in financing for utility-scale generation assets, unless the developer creates an SPV with multiple mini-grids. Table 13 illustrates four different types of equity investor.

Table 13

Types of equity investor

Type of equity investor	Notes	Active in mini-grid sector?
Development finance institution	Invests equity either directly or through third-party funds. Aims for development impact and some evidence of potential commercial viability, linked to RBF (for example, AfDB, World Bank, ADB).	Somewhat
Impact investor	Aims for social impacts together with financial return on investment (Acumen).	Yes
Venture capitalist	Targets early-stage development of start-ups with strong potential for growth.	No
Private equity investors	Target private companies or public companies that plan to go private. Tend to have large balance sheets and usually aim to turn around a 'struggling' business.	No

Source: BloombergNEF.

Debt

Concessional debt generally includes interest rates lower than normally available (often single digit), and longer tenors as well as loan grace periods, where the loan recipients are not required to make interest repayments for several years. Commercial debt providers are more risk-averse and carefully assess the market opportunities and risks in the mini-grid sector. Commercial loans generally offer double-digit interest rates, with very short tenors (typically 6–24 months).

International lenders, which provide hard currency (usually US dollar) loans, are typically concerned about the risks and volatility of currency exchange rates, since mini-grid projects almost always receive revenue in the local currency. Local debt financiers, usually banks, typically require developers to provide a physical asset as collateral, known as asset financing. For example, in Nigeria, lenders tend not to accept renewable energy equipment as collateral and require borrowers to own some sort of real estate as collateral in order to draw down debt.

Lenders may require collateral such as real estate to disperse a loan to a developer, according to a representative at the Bank of Industry (BOI), a development bank in Nigeria. Developers who are unable to offer collateral may try to get a bank guarantee from a commercial bank with which they typically do business. However, bank guarantees are often difficult to obtain since the developer is essentially handing over most of the risks to the third-party bank providing the guarantee, so the bank will also require a 100 percent cash security before providing a guarantee. Partial (or political) risk guarantees (PRGs) can be provided by DFIs like the World Bank and used to satisfy commercial lenders such that, should the host government fail to honour its promise by providing a grant, the lender will still be paid back in full by the World Bank through the PRG. PRGs are best suited for commercial lenders who are comfortable taking on the credit risk of the mini-grid asset but not the political risk of the host government. According to the BOI, which provides concessional loans to mini-grid and commercial and industrial (C&I) developers in Nigeria, they accept either real estate or a bank guarantee as collateral.

Known mini-grid financing structures

Table 14 summarizes five known financing structures, which combine these forms of finance in different ways. These are discussed in more detail in the subsequent sections.

Up-front grants

Most mini-grid projects require some form of grant to be economically viable. Up-front grants have historically been the most common financing structure for mini-grids. Governments disburse payment to developers before developers install the mini-grids. Developers usually finance their projects with their own or other shareholders' equity.

Results-based financing (RBF)[12]

This is a grant mechanism that developers receive only once they prove to the host government that their mini-grid is successfully providing electricity to the customers connected to their network. Grants are issued on a per-connection basis, upon verification. Developers and commercial financiers believe that this is the best way to close the viability gap for mini-grid assets. There has been a limited number of RBF programmes for mini-grids to date, but they have become increasingly important for both developers and private investors. Though RBF is not a new financing structure, it is relatively novel to the mini-grid sector and ensures results are achieved before developers are paid. Prior to RBF a small number of mini-grids received upfront grants, but often these projects stall since developers have already been paid.

Developers typically combine financing from RBF with their (or their shareholders') equity and commercial debt (Figure 66). For example, according to the commercial lender, SunFunder, which is capitalized with blended finance (a mix of private and

12 RBF is defined as a form of grant that is linked more directly with outputs and outcomes than with inputs and processes. RBF has been used in development sectors that aim to have social (e.g., healthcare and education) or environmental impacts (e.g., water sanitation and pro-poor clean energy projects). RBF ensures that the allocated development fund is linked to pre-agreed and verified results, and that funding is provided only when the results are achieved (e.g., once a mini-grid is operating). Through a range of mechanisms, RBF helps deliver development outcomes, improves accountability, and drives both innovation and efficiency (OECD, "Results-based Funding", accessed on 12 November 2019).

Table 14

Financing structures in the mini-grid market

Financing structures	Pros	Cons	Authors' take
Upfront grant + Developer's equity	• Quick to deploy. • Developer owns all profit.	• Not scalable since developer is cash-locked. • Often difficult to obtain.	Most common financing structure to date. Developers typically use either their own equity or other shareholder equity to finance.
Results-based financing (RBF) grant + commercial debt + developer's equity	• Closes viability gap of mini-grids, making it easier to secure financing. • Developers have an incentive to deliver a good service.	• Still early stage.	This is the preferred financial structure for commercial lenders as it closes the viability gap of mini-grid projects. It's a type of public-private partnership (PPP) structure. Typically, financing combines an RBF grant, commercial debt and equity of the developer (or its shareholder).
Public funded (public-private partnership)	• Quick return on investment. • Good for building experience.	• Government owns mini-grid. • Often not well-maintained if developer capital is not involved.	Government fully pays capex, private company installs mini-grids. In many cases, mini-grids are often under-utilized after operation starts.
Project financing	• Financing multiple mini-grids. • Debt issued on value of predictable future cash flows.	• Cannot be applied to individual mini-grids as they are usually too small, so need to finance a portfolio of projects. • Predictable PPAs needed for all projects in mini-grid portfolio to satisfy lender.	It treats a portfolio of mini-grids as an infrastructure project with predictable cash flows. It can attract significant level of debt financing. This requires certain conditions such as developers' track records, a project pipeline and a robust regulatory environment where projects are to be built.
Convertible notes + developer's equity	• Simple terms, can close within weeks. • Founder retains majority of voting stock.	• Investor (or note holder) has no voting rights, unlike common shareholders. • Unpredictable valuation of business, so difficult to know true value of note.	There are few cases of convertible note deals in the mini-grid sector. Developers and financiers see this as a temporary solution that is less effective and scalable than alternatives.

Source: BloombergNEF.

public capital), it was able to provide a USD 1.2 million loan for a Kenyan tea plantation because PowerGen was already in an RBF programme, which would grant 30 percent of capex to PowerGen once the relevant mini-grids were successfully commissioned and operating. PowerGen could use this capital to close the viability gap and boost the project's overall internal rate of return (IRR), making it a safer investment for SunFunder, and increasing confidence that PowerGen would be able repay the construction loan.

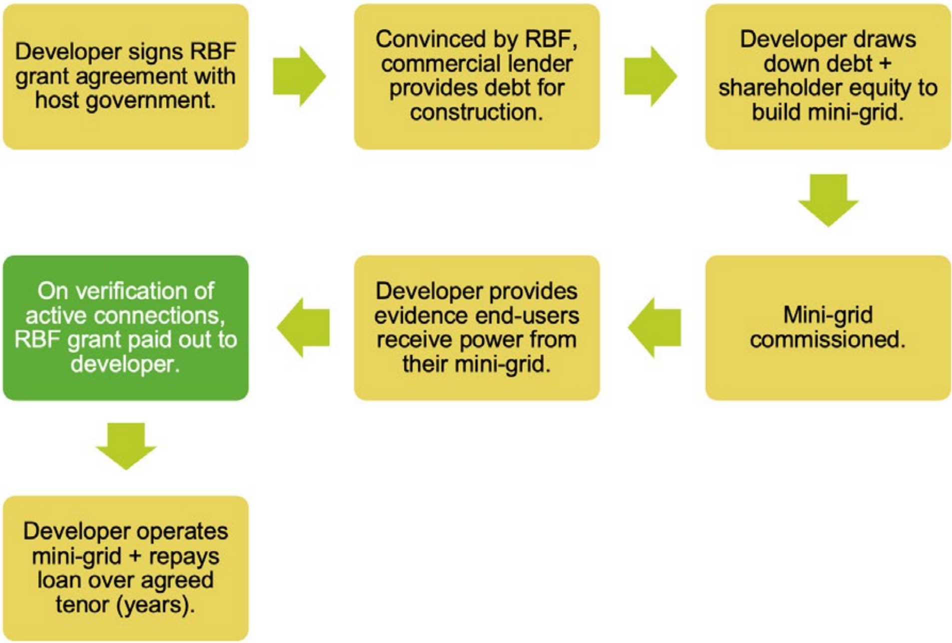
In general, even if developers have a slow start in revenue collection, the RBF grant, typically paid out within six months of commissioning upon verification, will boost operational revenues and enable the developer to repay a significant part of its commercial loan, depending on the agreement with the lender.

Public-funded (public-private partnership)

Developers collaborate with a government to build (or even operate) mini-grids in the form of a pub-

Figure 66

Example of a results-based financing structure



Source: BloombergNEF.

lic-private partnership (PPP) (Table 15). The government pays for all the capex and owns the mini-grids after installation. Risks for the developer include cost overruns, technical defects, and an inability to meet quality standards. The government takes the risk that end-customers may underutilize the mini-grid. A number of developers informed the authors of this report that while these deals allow them to build up track record, they do not enable them to build their mini-grid portfolios since they do not own the assets.

One example of a government-subsidized PPP is a pilot RBF mini-grid programme in Kenya that was supported by the German Agency for International Cooperation (GIZ) in 2019. The donor agency transferred funds to the Kenyan government to implement the programme under which four mini-grid developers developed 14 mini-grids. With GIZ's assistance, the Kenyan government identified sites, assessed consumers' ability and willingness to pay, carried out feasibility studies and sent out a public tender request. The government and GIZ also conducted due diligence on the private companies (developers) that participated in the programme to ensure they could cover 100 percent of the upfront capex for their mini-grids as the RBF would cover up to 50 percent of capex only, and the developers still had to recover another 50 percent from sales of electricity (Quinn, 2019).

Project financing

Project financing is a form of debt financing in which the bank (or lender) is willing to lend on a predictable stream of cash flows based on a long-term electricity off-take price agreed upon in the form of a power purchase agreement (PPA). Figure 67 shows a simplified project financing structure. Lenders agree to issue a long-term loan to a mini-grid SPV that produces a predictable stream of cash flows from a number of PPAs signed with numerous long-term off-takers. Where RBF is also involved, the government issues grants once the SPV can prove the end-users are receiving a reliable electricity service.

Mini-grids are typically small in size, ranging from below 10kW to hundreds of kilowatts, suggesting that a portfolio approach would be beneficial to make financing attractive for commercial project finance investors. Some financiers could also avoid cumbersome pre-construction processes and risks by buying mini-grids in a secondary market once these are fully operational.

Table 15

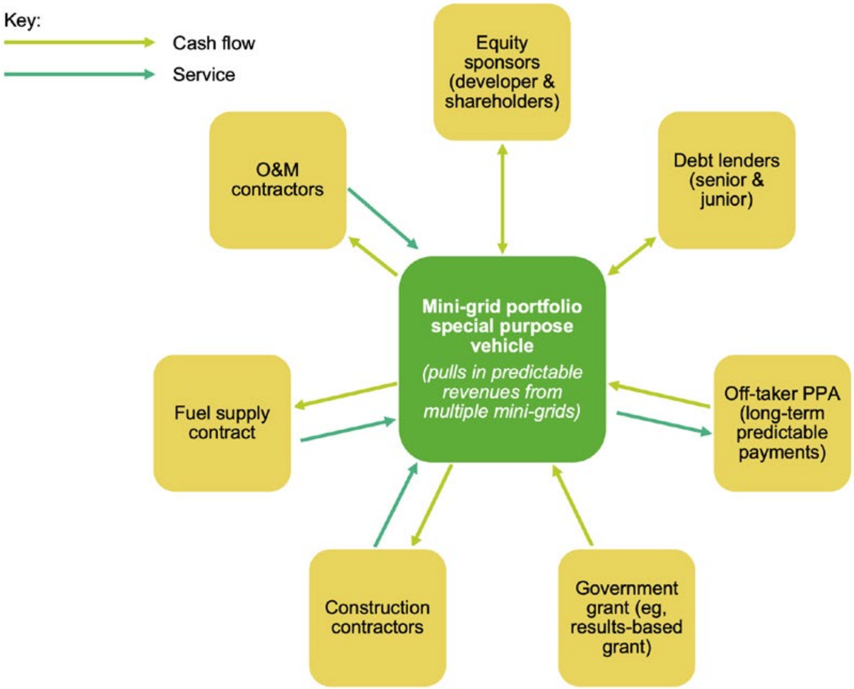
Types of public-private partnership contracts

PPP contract type	Design-build-finance-operate	Build-transfer-operate	Build-operate-transfer	Build-own-operate-transfer	Built-own-operate
Acronym	(DBFO)	(BTO)	(BOT)	(BOOT)	(BOO)
Description	Developer paid by government to design, build, maintain and finance mini-grid (i.e., carry out the EPC).	Developer finances and builds mini-grid, transfers to government agency then leases back and gets paid by users.	Developer builds and operates for a concession period and pays fee to receive mini-grid revenues.	Same as BOT but developer owns mini-grid and receives all revenues for concession period.	Mini-grid is fully privatized and owned by the developer. No transfer to government.
Construction	Private sector	Private sector	Private sector	Private sector	Private sector
Operation	Private sector	Private sector	Private sector	Private sector	Private sector
Ownership	Public sector	Private during construction, then public sector	Private during contract, then public sector	Private during contract, then public sector	Private sector
Who pays?	Off-taker or end-users	Off-taker or end-users	Off-taker or end-users	Off-taker or end-users	Off-taker or end-users
Who is paid?	Private sector	Private sector	Private sector	Private sector	Private sector

Source: BloombergNEF.

Figure 67

Simplified mini-grid project financing structure



Source: BloombergNEF.

For the purpose of illustration, Figure 68 shows a cash flow scenario for a portfolio of 30 solar hybrid mini-grids with some generic assumptions of capex and opex. The chart demonstrates how such a portfolio of projects might behave over the next 20 years. It shows future cash flows from the portfolio, which achieves an overall post-tax equity IRR of 10 percent with an average PPA (end-user tariff) of USD 0.60/kWh; without the RBF grant, the IRR drops by 20 percent. Note that the chart does not take into account the uncertainty in power demand of rural customers, which can vary depending on their income level, economic activities, the existence of productive-power users and mini-grid operators' business models.

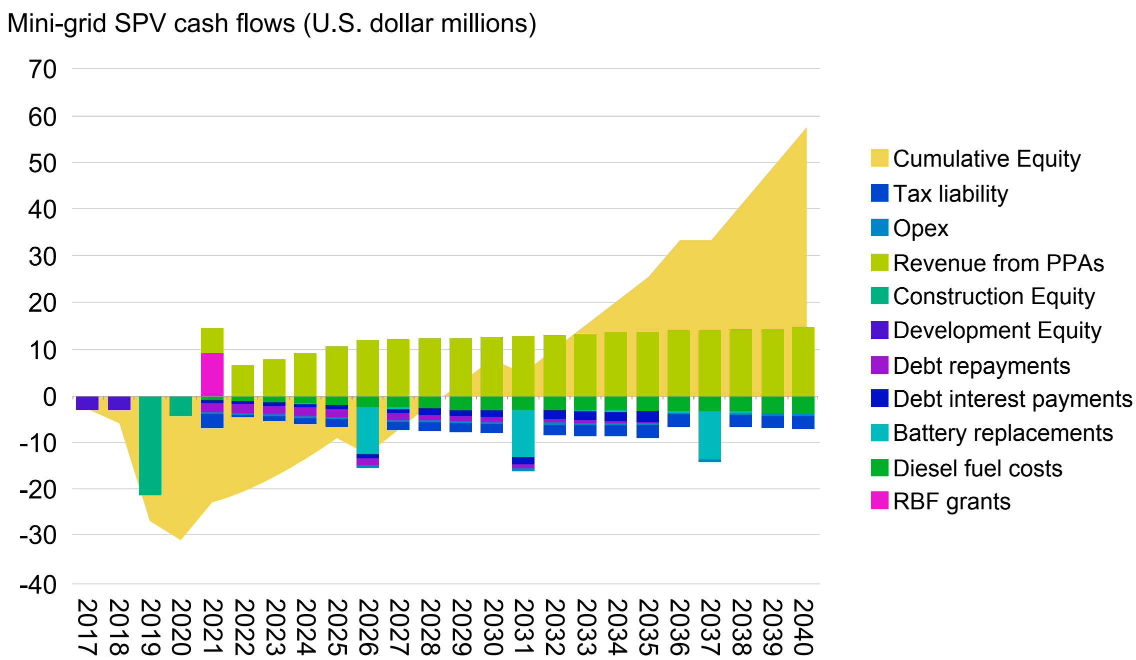
On 17 July 2019, CBEA announced its first project finance transaction to finance 60 mini-grids with a total capacity of 1MW in Tanzania, in partnership with PowerGen (Rockefeller Foundation, 2019). This is the first-ever project finance deal for rural mini-grids (see grey box, below). The deal involves some public funding, through the REPP fund. This type of framework is possible when the funding recipient has good financial status, experience and track records, and the regulatory environment is relatively well-established and able to minimize the risks of the mini-grid projects.

Convertible notes

Convertible notes are short-term loans issued as debt that convert into equity at a later date after a trigger event – a venture capital seed round, for example (Figure 70). This is a relatively uncommon financing structure for the mini-grid sector. An investor loans money to a start-up and is paid interest only without principal repayments. After the trigger event, such as an equity round, the debt converts to equity at a discounted price (typically 20 percent). Since the investor is lending money to a developer that may not yet be generating operating revenue, convertible notes can be an attractive option for an early-stage borrower. The investor benefits from receiving an enhanced proportion of future equity in a future equity financing round as compensation for taking an early-stage risk.

Figure 68

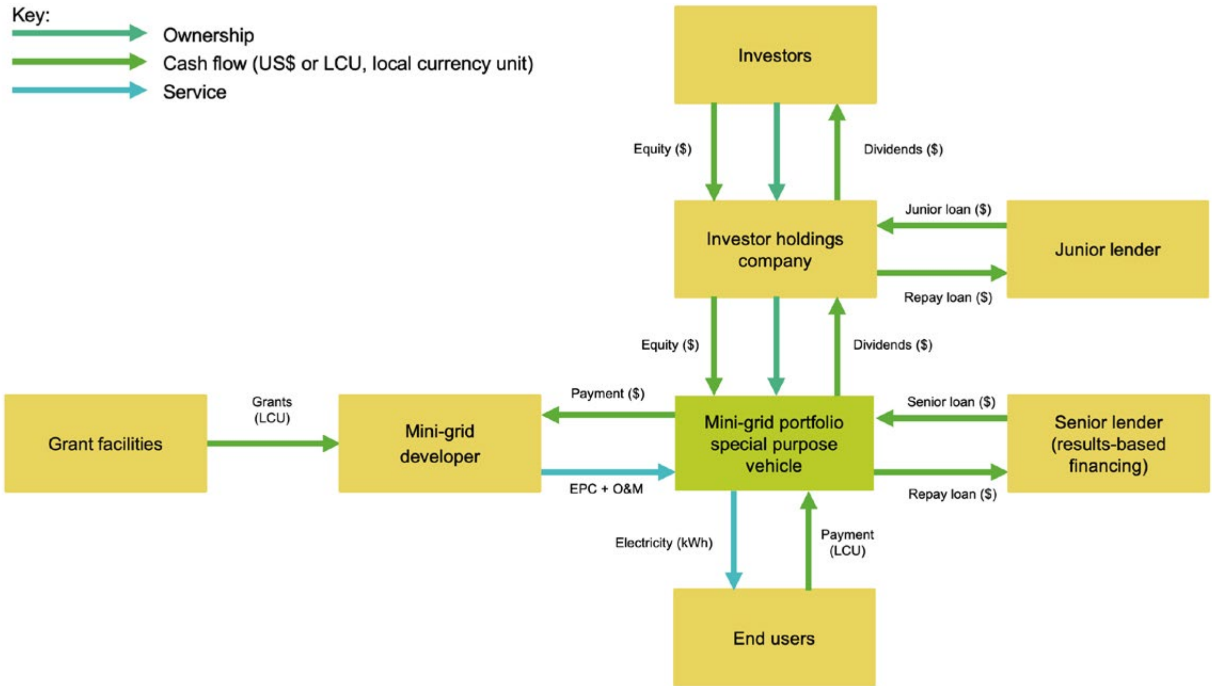
Example of mini-grid portfolio cash flows



Source: BloombergNEF, **Note:** Figure 68 contains example mini-grid data, representing 30 mini-grids (10MW generation capacity, 20MWh battery storage), with a total capex of USD 48m, 40 percent commercial project finance debt, 10 percent debt interest rate, 60 percent developer/shareholder equity, RBF grant (50 percent of capex), battery replacements every six years and 30 percent tax. The information in Figure 68 is not linked to any specific deals.

Figure 69

CrossBoundary mini-grid portfolio project financing



Source: BloombergNEF, CAMCO Clean Energy. **Note:** End-users pay the mini-grid portfolio in local currency (in this case TZS = Tanzanian Shilling).

Box 11

CBEA-PowerGen project financing deal

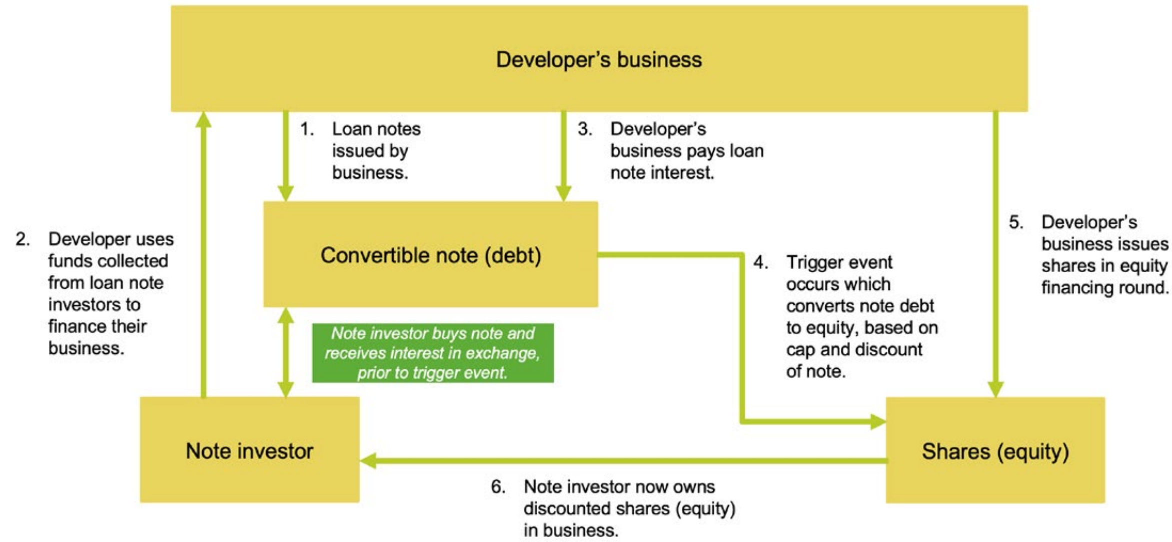
Once the mini-grid developer (PowerGen) builds the mini-grids, CBEA Tanzania, a local holding company 100 percent owned by Cross-Boundary, will acquire and own the assets for a total investment of USD 5.5 million. Power-Gen will build and operate the mini-grids on behalf of CBEA Tanzania. This allows CBEA Tanzania to remove the pre-construction risks. CBEA Tanzania sets up a SPV, which pools revenues from all 60 individual mini-grids into a single revenue stream. This treats the portfolio of mini-grids as a large infrastructure project, but where the risks are reduced through a portfolio effect. As part of this agreement, Cross-Boundary signed a loan agreement with REPP, a UK government-backed funding platform managed by CAMCO Clean Energy, which agreed to supply CBEA Tanzania with 58 percent debt financing of the total USD 5.5 million capital cost. The fund aims to help renewable energy projects access private and institutional investment.

By November 2019, PowerGen had 21 of the 60 mini-grids operating and ready to sell to CBEA Tanzania. Lenders do not have to wait until construction of all the projects is finished to start receiving returns on their investment. Cross-Boundary aims to replicate a similar business model in southern and western Africa.

With different values, the cash flows for this portfolio project finance deal are expected to fit the profile of the example presented in Figure 68, where the revenue slowly increases as more mini-grids are commissioned.

Figure 70

Convertible note-financing process



Source: BloombergNEF.

Box 12

Convertible note financing for Nuru, DRC-based developer

Nuru, formerly called Kivu Green Energy (KGE), is a developer based in the Democratic Republic of the Congo (DRC). On 4 February 2020, Nuru commissioned a 1.3MW solar hybrid mini-grid in Goma's Ndosho community, where only 3 percent of the 12,000 households have access to electricity. This 1.3MW project is the largest isolated mini-grid in Sub-Saharan Africa. On 13 March 2019, the project received USD 1 million of Series A equity funding, then later received convertible notes of USD 2.45 million and USD 0.35 million on 3 May 2019 and 2 September 2019, respectively. Energy Access Ventures and Electrification Financing Initiative provided both of the convertible notes.

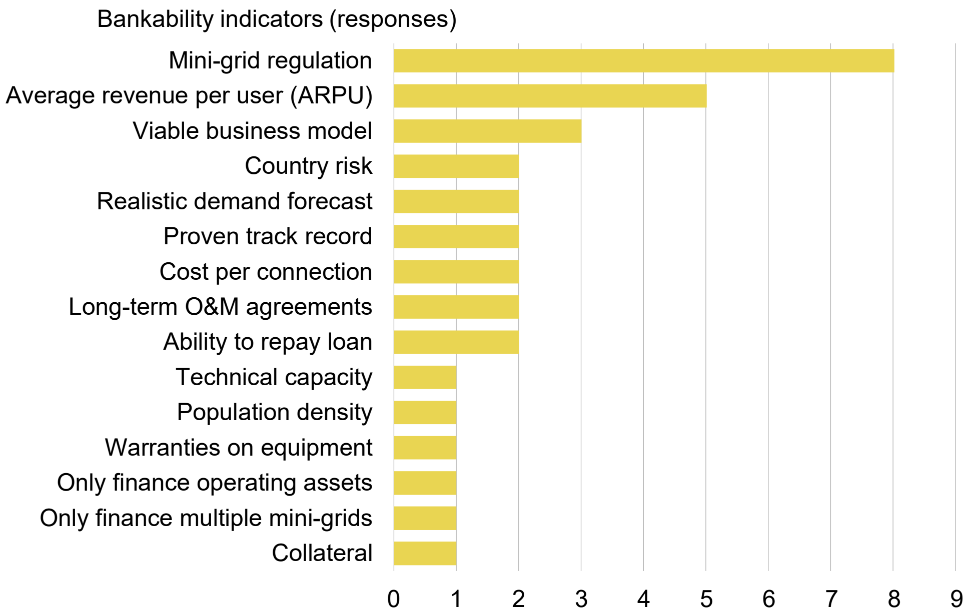
In January 2020, All On, an independent Nigerian-based NGO, partnered with the United States African Development Foundation (USADF) to launch *The Off-Grid Energy Challenge*. The challenge aims to increase electricity access in off-grid areas in Nigeria with sustainable business models. Winning proposals will receive USD 50,000 – USD 100,000 each in convertible notes and a USD 50,000 grant – along with extensive local technical assistance. The programme accepts proposals from Nigerian-registered companies planning to develop mini-grids, C&I solar projects, solar home systems and innovation projects (innovative smart metering, payment systems or other enabling technologies). Winners are to be announced in October 2020.

7.3 Mini-grid bankability assessment

For this research the authors spoke with 12 financiers including DFIs, impact investors and commercial lenders. Some have already invested in the mini-grid sector, and others are considering doing so. All the financiers interviewed claimed that having dedicated mini-grid regulations in force is the most important criterion in their bankability assessments. This includes whether mini-grids explicitly form part of a government's rural electrification strategy, with simple licensing and clear rules to determine what will happen to mini-grids if and when

Figure 71

Key indicators to assess mini-grid bankability



Source: BloombergNEF **Note:** Based on interviews with 12 financiers. There were multiple answers from one financier.

the main grid arrives. One financier mentioned that Nigeria has a better regulatory framework than others, with clear government support and hundreds of millions of dollars of financing from DFIs. Half of the financiers responded that they assess average revenue per user (ARPU) of the mini-grids carefully, which is a key indicator of the effectiveness of revenue collection from mini-grid customers. Financiers generally require projects to be able to achieve an average revenue per user (ARPU) of USD 4 or higher, depending on the nature of the mini-grid customers and whether they are using electricity in a productive process.

7.4 Risk management

Risks for mini-grid projects fit into two categories: exogenous in nature (i.e., systematic/external) and project specific (i.e., unsystematic/avoidable). Exogenous risk is inherent to a specific market or country (high interest rates, recession, sudden regulation changes, commodity prices and war) and is often uncontrollable. Project risk is inherent only in a mini-grid project itself (non-payment by mini-grid customers and technical issues or a sudden strike by employees). Table 16 summarizes risks in the operational phase. Financiers can lower project-specific risk by pursuing diversification – for example, investment into multiple mini-grid projects as a portfolio, distributed over multiple locations. Investment diversification can also address some exogenous risks if the projects are spread across different countries. These risks greatly affect the chances of a mini-grid developer obtaining commercial financing; lenders must be convinced that developers have minimized these risks where possible.

Exogenous risks

Resource price volatility risk

Diesel prices in each of the six countries studied in this report varied significantly over the past 10 years (see the Economics Section). They are linked to Brent crude. Where a mini-grid relies on diesel generation, its economics vary according to the price of diesel.

Currency convertibility risk

Most mini-grid customers in emerging countries pay their bills in local currency. The operator needs to convert the revenue in local currency to US dol-

Table 16

Typical risks in mini-grid projects

Risk type	Details	How developers can manage the risk
Resource price volatility risks	For diesel, the mini-grid is exposed to potentially volatile diesel fuel prices. Grid-connected mini-grids are exposed to the retail power price. Commodity prices are affected by politics, seasonal changes, technology and current market conditions, which are market dependent, cannot be controlled and hence represent systematic risk.	• Hybridize the mini-grid asset by integrating renewables and battery storage, and substitute for diesel where possible. Dispatch the cheapest available source to meet demand when possible.
Currency convertibility risks	Revenue for mini-grid projects is always paid in local currency by end-users. International and even local developers need to convert this to hard currency. Central banks often allocate US dollars to local banks with which developers deal. In Nigeria, the central bank applies restrictions on converting Nigerian naira into US dollars. This is a huge risk, particularly if a company holds US dollar debt.	• Developers are typically free to convert any amount of local currency they hold. However, in some cases the country may apply a restriction (i.e., exchange transfer blockage). The longer the local currency is held, the more a developer is exposed to this risk and hence, to potential currency depreciation against the US dollar. • It is advisable to quickly convert as much as possible, or to obtain political risk insurance (PRI) if available, to shift this risk to a third-party.
Currency volatility risks	Currencies in emerging countries often fluctuate against the USw dollar. A stable currency makes it easier to predict future cash flows and estimate potential returns more accurately.	• Developers rarely hedge currency variation risks. The available hedging instruments are currently considered to be too costly, potentially making the business case for mini-grid projects unviable. This favours local players whose business is denominated in local currency. • Developers may buy a premium currency hedging instrument to minimize this risk, operate in various markets (across international borders) or charge higher electricity prices (at least on new sites and in some cases existing ones) for higher returns.
Permit or licensing risk	Inability of electricity regulator to fairly, efficiently and transparently administer the issuing of mini-grid related permits or licences.	• Ensure the host country has an active, long-term mini-grid regulation in force. • Understand the terms of the regulation and what criteria need to be met in order to get a permit, ideally with a dedicated legal team/advisor.
Country risk	Political risks, change of administration, country economic uncertainties, social issues etc. These risks are not usually specific to a particular mini-grid, but rather to the political and macro-economic stability of the country.	• Diversify a mini-grid portfolio, with projects across different countries. • If available, obtain PRI.
Regulatory risk	This can be a part of country risk but is directly relevant to mini-grids. Unstable and uncertain regulatory frameworks (e.g., grid arrival rules, tariffs and taxation) including non-existence of regulations for mini-grids, make it difficult for investors and developers to plan ahead.	• Diversify a mini-grid portfolio, with projects across different countries.
Payment risk	Customers do not want to pay for the power from the mini-grid or cannot do so due to unforeseen circumstances. If the payment is cash-based and post-paid, developers need to chase up customers individually. This is sometimes referred to as customer credit risk.	• It is important for a local project manager to build personal relationships within the community to collect payment from customers. • Create a sense of ownership within the community. The community feels the mini-grid belongs to it, and it relies on and protects the asset. • Holistic business model that integrates sound technical designs, promotes productive use of electricity and customer relationship management • Install pay-per-use meters
Grid extension risk	A distribution company extends the main grid to the community that a mini-grid already serves, and then the asset becomes unused.	• Three options on grid encroachment, depending on the mini-grid regulation in place: • Main grid disco buys electricity from the mini-grid. • Main grid disco takes over the asset, compensating the developer with a pre-agreed price; however even if regulation specifies this, the grid may not be financially able to honour this contract. • Developer integrates unreliable but cheaper main grid power into its mini-grid energy mix to ensure end-users get stable and cheaper electricity.
Consumption risk	Mini-grid customers' power demand does not grow as expected due to their limited ability to pay, lack of familiarity of using electricity, limited economic activities, etc.	• Engage local communities to stimulate their power demand. This includes customer education and innovative business models such as offering appliance financing and the KeyMaker model.
Labour risk	Inadequate skilled or qualified potential employees who can operate and maintain mini-grids.	• Provide technical training to local technicians. • Work with other developers or donor agencies that run capacity-building programmes • Use remote monitoring and control technology that enables smooth trouble shooting and reporting; support local technicians.

Source: BloombergNEF.

lars to repay loans, where these were issued in US dollars. However, some governments may have restrictions on the amount of local currency to be converted to US dollars, leaving the operator more exposed to exchange rate fluctuation.

Currency volatility risk

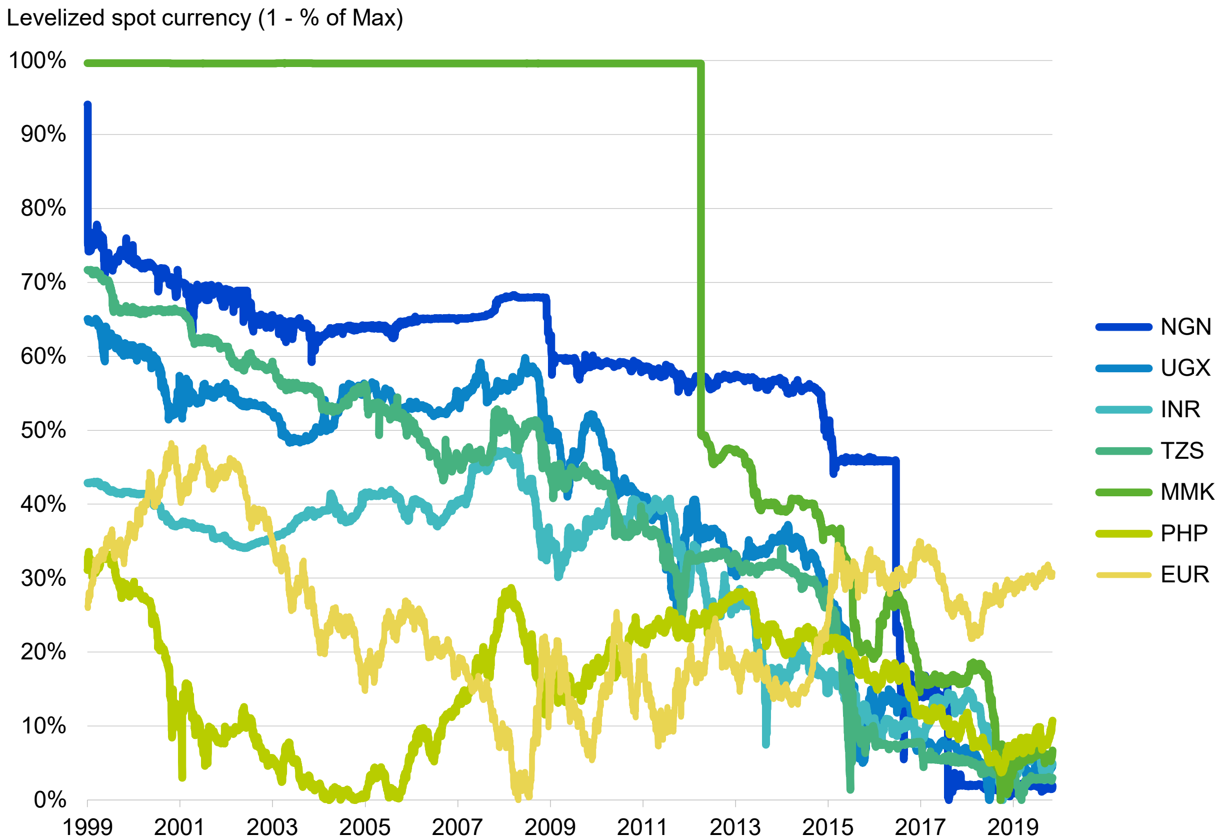
In Nigeria, from 2014 to 2018 the official naira exchange rate depreciated by over 41 percent. Given that the economy depends heavily on oil exports, the weakening of the naira was directly linked to the drop in global oil prices. In 2018, almost 90 percent of Nigeria's export earnings were from the sales of crude oil and processed oils.

In Figure 72, the authors obtained the daily currency US dollar exchange rates and divided them by the maximum of each time period between 1999 and 2019 to produce a levelized figure, allowing for a comparison across the different currencies. The chart shows that all of the currencies examined have been consistently depreciating against the US dollar, but less so in more recent years. Given that the life of a mini-grid is typically modelled at 20 to 25 years and revenues are paid in local currency, it is important for foreign investors to look at the long-term exchange rate to assess the potential risk of currency volatility.

Long-term currency volatility risk can be assessed using the coefficient of variation of each currency (Figure 73). The Philippine peso (PHP) has been the least volatile of the currencies examined over the past 20 years with a coefficient of variation of only 10 percent, making it more stable than the euro (EUR). The Myanmar kyat (MMK) is the most volatile currency.

Figure 72

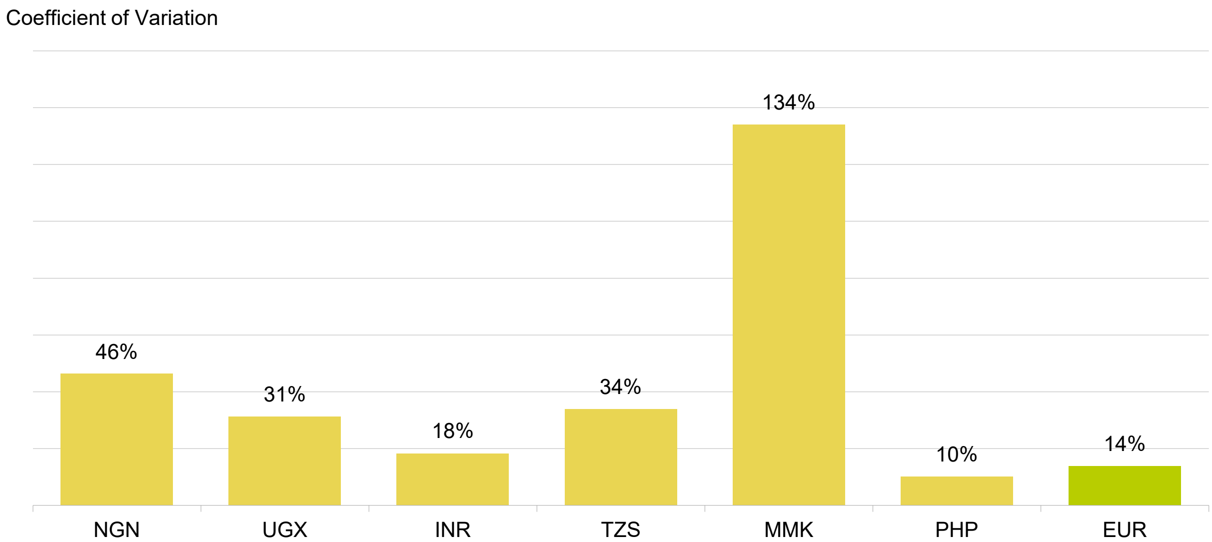
Currency volatility, 1999–2019



Source: Bloomberg Terminal. **Notes:** Higher levelized currency means closer to the US dollar. Downward trends imply depreciation against the US dollar.

Figure 73

Coefficient of variation of currencies, 1999–2019



Source: BloombergNEF. **Notes:** Coefficient of variation is the standard deviation divided by the mean of the daily currency data and is a measure of overall variation; lower is better. NGN = Nigerian naira, UGX = Ugandan shilling, INR = Indian rupee, TZS = Tanzanian shilling, MMK = Myanmar kyat, PHP = Philippines peso, EUR = euro.

Permit or licensing risk

Developers must often obtain a permit or a licence to build a mini-grid and sell generated electricity. Governments may or may not be able to process a permit or a licence efficiently, creating delays. Developers are often required to submit many different documents to various government bodies and information on the licensing process is not always disclosed clearly. Tanzania's regulations allow licences to be granted for multiple mini-grid projects to a single developer, which should reduce administration for both regulators and developers.

Country risks

There are three main types of risks under this category. The first is sovereign – a central bank's decisions may hurt local investments. The second is economic – a country defaults on its debt obligations. The third is political – developers are not able to control country risks; hence, the only way to mitigate these is to diversify their mini-grid portfolio, building projects in different countries. There are some indicators that inform country risks such as country debt-to-GDP ratio, beta coefficients (correlation between country stock market and individual stocks) and country ratings.

Project risks

Payment risk

Mini-grid customers in rural communities typically have low incomes, with limited ability (and sometimes willingness) to pay. If the payment for mini-grid electricity is on a cash basis and paid after use, mini-grid operators need to pursue customers for payment, and risk bad debts. Operators can apply pre-paid billing to mitigate the risk and make payment collection easier.

Grid extension risk

If the main grid reaches an isolated mini-grid, there is a risk that the mini-grid becomes stranded if the country does not have clear regulations that protect it. Some governments have set up rules to compensate mini-grid operators and allow them to sell their electricity to the main grid if it arrives. Even if the country has such rules, there is an additional risk of default by the utility. Tanesco, a debt-ridden state-owned utility in Tanzania, is known to have high risk as an off-taker in the Tanzanian power market. The country has robust grid arrival rules, but developers are anxious about whether the state-owned utility will follow the rules as stipulated.

Nigeria also has clear grid arrival rules, but there is currently no case where the main grid has reached an isolated mini-grid. The grid distribution companies already have problems with revenue collection in their power markets, affecting their ability to pay the bulk electricity trader. This begs the question of whether they will be able to honour the rules should the main grid arrive. However, having robust rules still gives developers and investors greater confidence.

Consumption risk

Mini-grid customers in remote communities typically have low consumption. Some use electricity for the first time after a mini-grid starts operation, and are not familiar with electrical appliances. For example, the United Nations Industrial Development Organization (UNIDO) developed four mini-grids in Rwanda with utilization rates as low as 6 percent. Developers can mitigate the consumption risk by selecting locations with clusters of economic activities before mini-grid development as well as initiatives to stimulate customer demand once operations begin.

Labour risk

Mini-grid developers may struggle to find skilled staff who can manage, operate and maintain mini-grids in or near the project site. They usually offer training to local staff so that they can minimize site visits to rural areas for maintenance and repair. Donor agencies such as GIZ have provided capacity-building programmes in some countries to train local engineers.

Section 8
Economics

Technology advances and cost reductions for PV and lithium-ion battery energy storage have made the economics of solar hybrid mini-grids highly compelling compared to diesel-only systems. However, costs vary greatly by site and are affected by regulatory, transport, and operations and maintenance costs. The shape of electricity demand from customers (*load*) also plays an important role in defining potential profitability. Projects with a strong midday demand that corresponds with a strong midday PV system output can enjoy lower overall operating costs.

8.1 Cost of electricity of mini-grids

The authors analyzed the levelized cost of electricity (LCOE) for various types of mini-grids currently in operation across the six case study countries using the HOMER Pro microgrid model, developed by HOMER Energy. The LCOE is defined as the long-term off-take price on a kWh-basis required to recoup all project costs and achieve a required equity hurdle rate on the investment. The LCOE is the go-to economic metric most often used to compare different power-producing systems. The authors collected data such as capex and opex from developers through interviews and from research literature. The collected data were aggregated to set the most representative cost scenario, and entered into the HOMER Pro microgrid model.

The authors assumed four different technology configurations for two different outage scenarios: 16 hours (grid-connected or weak grid) and 24 hours (isolated), and for two different load profile scenarios: residential customers only and residential plus productive-use customers. Sixteen hours of outage means that an aggregated time of outage interruptions per day is 16 hours. The HOMER Pro allows for simulating outages to occur randomly throughout the year. Customers use electricity from the grid when it is available, and from decentralized energy resources (PV, battery storage and diesel generators) during a power outage. Productive-use customers are anchor customers who have a much higher power demand than residential households during the daytime. Their power demand can be, for example, for agricultural pumps, cold storage and milling machines.

The model uses a load-following methodology, dispatching the cheapest form of electricity to meet demand required for any given hour of the day. In this methodology, the model dispatches just enough diesel generation to meet power demand, which is optimal in mini-grids with renewable power that sometimes exceeds the load. The authors used the load profile calculator of the National Renewable Energy Laboratory (NREL) and input the data into Homer Pro.

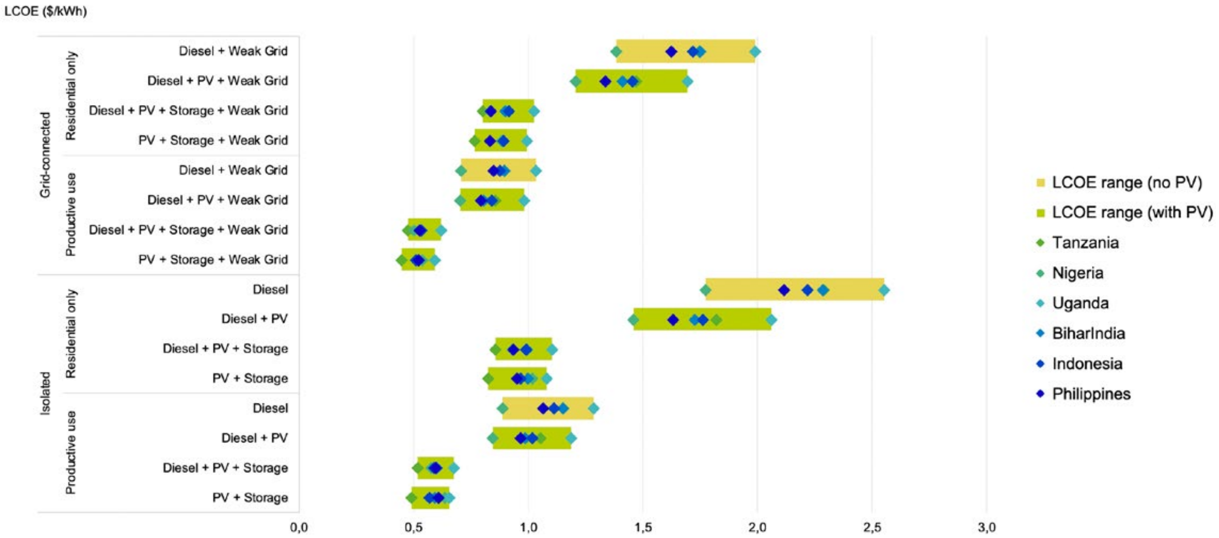
Comparison by technology

Including PV modules in mini-grids generally helps to reduce their operating costs and improve their economics. Across the six countries and one state studied, mini-grids consisting of either PV + storage or PV + storage + diesel (defined here as solar-hybrid projects) generally achieved lower LCOEs than projects using just diesel.

For solar hybrid mini-grids operating in isolated areas and serving productive-use (commercial and industrial) customers, LCOEs ranged from USD 0.49–0.68/kWh. By contrast, LCOEs for diesel generators were USD 0.89–1.28/kWh for the same sce-

Figure 74

Cost of electricity of mini-grids



Source: HOMER Pro model, BloombergNEF, developer input data. **Notes:** For the 'weak grid' scenario, one-hour outages were assumed to occur randomly on average for 16 hours per day in the course of a year. The systems here are the optimal systems HOMER found, so components may vary in size. Assumes 2019 developer estimates. Storage is lead-acid battery storage.

nario. The difference in LCOEs by technology configuration is largely due to the assumed volumes of diesel fuel that would be required to generate from the comparative systems. PV and battery storage reduce run hours for diesel generators, lowering a mini-grid's overall LCOE.

Comparison by geography

Across the six countries and one state surveyed, LCOEs were lowest in Bihar, India, at USD 0.52/kWh and USD 0.59/kWh for PV + storage for productive use in the grid-connected and isolated scenarios, respectively.

LCOEs differ by geography mainly because of varying prices for diesel, equipment, installation and financing. At the low end of the six countries and one state examined, diesel sells for USD 0.58/litre in Nigeria, on average. The price is USD 0.90/litre in the Philippines. However, prices can be 20–30 percent higher when the cost of delivery to particularly remote sites is factored in.

Capex is another differentiator of the LCOEs. The authors assumed capex for solar hybrid mini-grids to range from USD 2,868/kW in the Philippines to USD 4,500/kW in Indonesia. Capex varies significantly by projects even in the same country, and it is difficult to define the most representative figure. The capex may be lower in Asia than in Sub-Saharan Africa because the clean energy market is generally more mature; the presence of a domestic manufacturing sector means equipment is more readily available at a lower cost.

Uganda has the highest LCOEs under all scenarios. For the Uganda analysis, data from just one rather remote project were used as the benchmark for this study: a mini-grid on an island in Lake Victoria. That project may have had a particularly high capex because of the difficulties inherent in getting to the island and a general lack of maturity in the Uganda market. Nigeria has the lowest LCOEs under diesel/diesel + PV scenarios, probably because its diesel price is the lowest of the six countries.

Distribution lines tend to be long in villages in India as well. Bihar's population density is high compared to the other jurisdictions studied, meaning lower distribution system costs as shorter lines to deliver power are required when a mini-grid is built.

Comparison by load profile

LCOEs are consistently lower for mini-grids that serve productive-use customers than for those that serve residential customers. This is because productive-use customers such as agricultural processing facilities and factories tend to use daytime electricity. This correlates better with the generation profiles of PV systems powered by the sun, boosting the utilization rate of the mini-grid and leading to a lower LCOE for the developer. The LCOEs for diesel generator are only lower for the productive-use scenario and not for the non-productive-use scenario. This is because diesel fuel is used more efficiently for the former than it is the latter due to a more stable load profile and the higher output required (i.e., less amount of diesel fuel is spent to produce a kilowatt-hour of electricity for the productive-use scenario).

8.2 Capex and opex

Capex

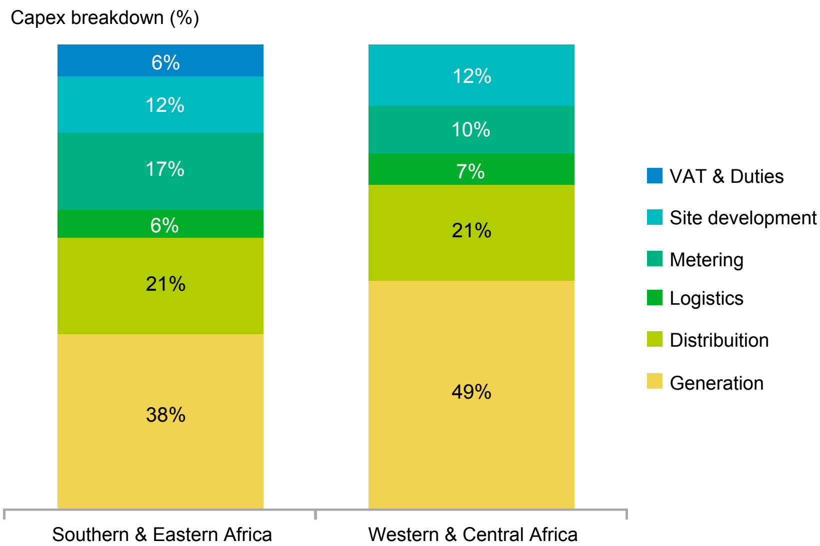
In emerging countries, the total cost of constructing a new project, the capex, for an off-grid solar hybrid mini-grid system combining PV, battery storage and diesel remains excessively high for many rural customers. Capex for solar hybrid mini-grids ranges from USD 1,420/kW to USD 22,689/kW, according to a World Bank Energy Sector Management Assistance Program (ESMAP) survey of 53 mini-grids (ESMAP, 2019). While costs for key equipment such as PV modules and batteries have fallen, costs for other components have not yet dropped and may be difficult to reduce.

In addition, almost no two mini-grids are alike. Projects are typically customized, administrative processes are lengthy and cumbersome, and engineers must often travel to remote sites for installations. According to ESMAP and the Rocky Mountain Institute , capex accounts for 60–65 percent of the cost of electricity for well-run off-grid solar hybrid combining PV, battery storage and a backup diesel generator.

Figure 75 shows a breakdown of capex for mini-grid projects based on the data that AMDA collected from its member mini-grid developers operating mini-grids in Sub-Saharan Africa. Generation accounts for the largest component of capex (i.e.,

Figure 75

Capex breakdown for mini-grid projects in Sub-Saharan Africa



Source: Africa Minigrid Developers Association (AMDA), ECA. **Note:** Site development cost includes hard costs (permits, environmental impact assessment, land lease, contract and legal), soft costs (site survey, technical design, hiring site agents, technical assistance, demand assessment, client development, community and government approval, travel and accommodation). Metering includes costs of overhead accessories for dropline to the home, meters and customer connections including internal wiring and basic power kit of light as well as socket. Logistics includes costs for transport and warehousing. All salary costs for capex are included in site development and logistics.

all costs associated with generation including PV, diesel gensets, hydro power plants, biomass generation plants, energy storage and inverters). This share tends to be larger if energy storage is included in the system, which is typical for solar hybrid systems. The cost of poles and wires for distribution is the next biggest component. Longer distribution lines are required for communities in which the households are scattered across a wide area, which is typical in rural areas in Sub-Saharan Africa. Site development costs are also high in both regions; these could be lowered by streamlining the government's administrative procedures such as licensing and its support for site identification as well as stakeholder engagement. The metering cost component is 17 percent and 10 percent for the southern and eastern African region and western and central African region respectively. There will be trade-offs between the costs of smart meters and services as well as the billing benefits that such meters bring. VAT and duties vary by country. Some countries exempt PV modules and inverters from import duty and VAT.

Development (site development, logistics)

Pre-construction costs can include feasibility studies, system designs, application fees for permits or licences, and time and effort around sourcing for financing. These *soft costs* can differ substantially by organization. Overall, development costs typically account for less than 10 percent of overall capex and are funded directly from the developer's balance sheet. Nearly 60 percent of development costs are expenses for feasibility studies, acquisition of capital and customer engagement (Table 17).

As set out in Figure 76, the feasibility study phase of a typical project can be broken into four stages. Site selection requires analysis of population density, average income of local households, availability of jobs nearby, accessibility to the site and distance to the main grid. Developers must visit potential sites to gather this information and conduct this analysis. However, new technologies and services exist. TFE Energy's Village Data Analytics (VIDA) tool uses satellite images, which can assist developers to speed site identification and improve system sizing. The Reference Electrification Model (REM), developed by Tata Center and the Massachusetts Institute of Technology, helps determine the best technology option for each household for electricity access, estimates costs, and recommends an engineering design for systems. The KTH Royal Institute of Technology developed the Open Source Spatial Electrification Tool (OnSSET), which allows for the estimating, analyzing and visualizing of the most cost-effective option for electricity access.

Obtaining environmental impact assessments and licences or permits can be lengthy and costly for developers, particularly in countries that do not have streamlined rules in place. One developer told

Table 17

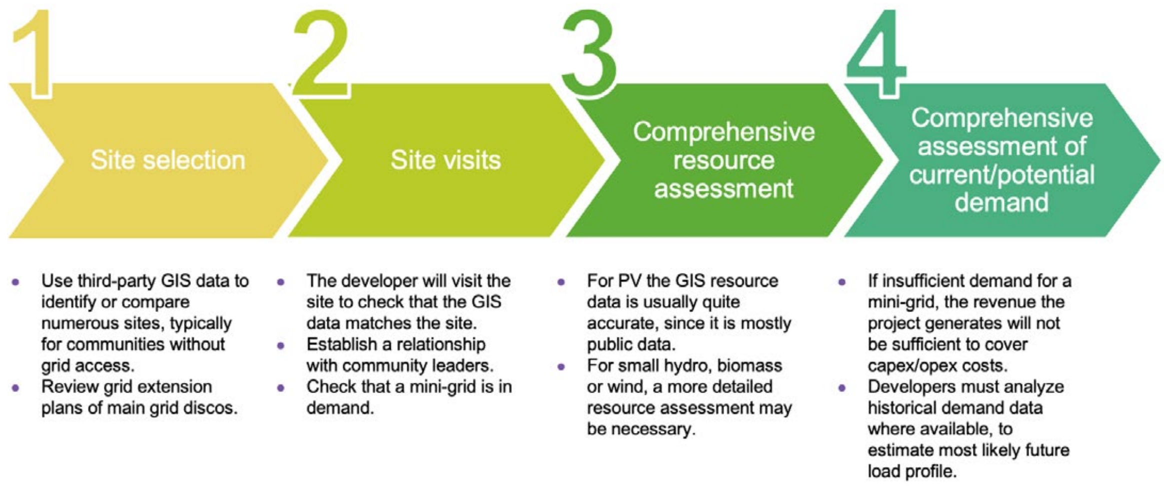
Development costs associated with a typical PV + storage + diesel mini-grid

Project development cost	
Feasibility study	19%
Environmental impact assessment	14%
Generation / distribution licence acquisition	10%
Acquisition of capital including due diligence	24%
Company foundation and establishment	10%
Acquisition of land rights	5%
Setup of village and customer relationship	19%
Total	**100%**

Source: Africa-EU Renewable Energy Cooperation Programme (RECP). **Note:** The figures are rounded.

Figure 76

Mini-grid feasibility study stages



Source: BloombergNEF.

the authors that it costs USD 10,000–20,000 to hire a consultant to carry out an environmental impact assessment in Tanzania and obtaining a license or a permit for a project there can take six months or longer. Governments that make available mechanisms for licensing for multiple projects concurrently would potentially cut transaction costs (Tanzania is an example).

The main cost components of mini-grid installation involve labour and transportation. Engineering labour alone can make up just under 10 percent of total project capex. It is often difficult to find skilled engineers in remote areas in emerging countries who can install mini-grids. As a result, developers often have capacity-building programmes to train local staff on installing and operating mini-grids. However, such training takes time and money, according to one developer. Importing skilled technicians can in some cases be less expensive.

The cost of transporting equipment varies by project location. Mini-grids for rural electrification are typically placed in remote areas lacking infrastructure, including islands. For island sites, developers must also consider timing. For example, transport costs can almost double on Lake Victoria depending on seasonal water levels. In the Philippines and Indonesia, some remote islands are entirely inaccessible during certain months of the year due to weather and sea conditions. Transportation timing can also be affected by development timelines. If it takes longer to secure a licence of permit, or to clear customs for imported equipment, a developer may need to reschedule site delivery. This increases cost.

Equipment (generation, distribution)

The cost of equipment represents the largest single component of mini-grid capex. A typical solar hybrid mini-grid incorporates PV modules, an AC-DC inverter, a battery storage system, a backup diesel generator, distribution lines, poles and smart meters. Nigeria-based developer GVE told the authors that PV modules, inverters, battery systems, cables and meters across their portfolio of mini-grids account for some 60 percent of capex.

In Sub-Saharan Africa, PV equipment is mostly sourced from reputable Chinese suppliers such as JinkoSolar or other manufacturers . While the cost of lithium-ion batteries has come down globally, many developers still use lead-acid batteries. Some opt for lead-acid batteries because their upfront costs are lower in emerging countries, but others use them even though doing so makes the total project-cycle cost higher than it would be using lithium-ion batteries. One possible reason for this is that the financing of lithium-ion batteries can be challenging because of their higher upfront cost and limited supply chains in many emerging markets. That said, some have begun to shift to lithium-ion in recent years (see the Technology Section for more details).

Costs for distribution lines can vary significantly both by location and physical size of the community to be served. Costs are lower where population density is higher, including in communities in Asia. For more dispersed communities, costs can be much higher. One organization surveyed by the authors said that distribution accounts for approximately 70 percent of capex in Uganda. As developers push farther into more complex terrains, costs for distribution lines may rise.

Opex

According to the ESMAP and the Rocky Mountain Institute, operating costs account for 35–40 percent of the total lifetime cost of a typical mini-grid. The remote nature of many projects and the associated lack of skilled local workforces make it difficult to reduce these costs.

Opex can be divided into two parts: fixed and variable costs. Fixed opex is generally inflexible and applies to the life of a project. It includes insurance premiums, regular operations and maintenance, and equipment replacement. By contrast, variable opex changes over time. It includes fuel costs that can vary dramatically from week to week. Typically, variable opex accounts for nearly half of a project's opex, but this can vary based on a project's operation hours and on fluctuations in diesel prices. Developers operating PV + storage projects without diesel enjoy lower opex and avoid potential fuel theft. Such systems have limited flexibility in meeting demand as customers' load cannot exceed the capacity of the battery. Costs for repairs and sudden equipment replacement due to vandalism and theft are also part of variable opex.

Remote monitoring and control

Developers typically provide local residents with training to maintain mini-grids but still must oversee the project, provide troubleshooting, and send skilled technicians to the site if necessary. This can be quite costly; sending technicians to remote sites can exceed USD 5,000 per visit. Remote monitoring and control systems allow developers to monitor and optimize performance of mini-grids from afar and help to reduce opex costs (see the Technology Section for more details).

Mini-grid customers typically have smart meters installed at their homes or businesses. These are linked to a remote information system. Developers can also switch off power to customers or adjust their consumption capacity remotely, providing

Table 18

Opex components

Fixed opex	Variable opex
Customer relationship management	Battery and inverter depreciating
Guards and cleaning staff	Diesel fuel
Insurance	Lubrication oil
Local management and billing	Maintenance (variable)
Local power plant operations	Non-payment and theft
Maintenance including travel costs	Taxes (variable)
Senior management, travel and transaction costs	Technical losses (load dependent)
Taxes and fees	
Technical losses	

Source: BloombergNEF.

telecommunication service is available. As Nigerian developer GVE remarked to the authors: "*We place a cap on households to help GVE manage the demand-side. If users plug in two air conditioners (exceeding the capacity initially allocated to them), they will be cut off for a few seconds. If they continue doing this, the cut-off time lasts for 45 minutes after five attempts. We inform the customers that they used too much power; however, they can request for a higher cap if available at no additional cost.*" This is part of the strategy of upselling energy service.

Diesel fuel cost

Diesel fuel prices vary significantly around the world and lowest-income communities can be hit hardest by significant price swings. Two groups may bear the brunt of price adjustments more than others: off-grid communities heavily dependent on 100 percent diesel-powered mini-grids; and communities connected to highly unreliable grids and reliant on diesel for backup supply.

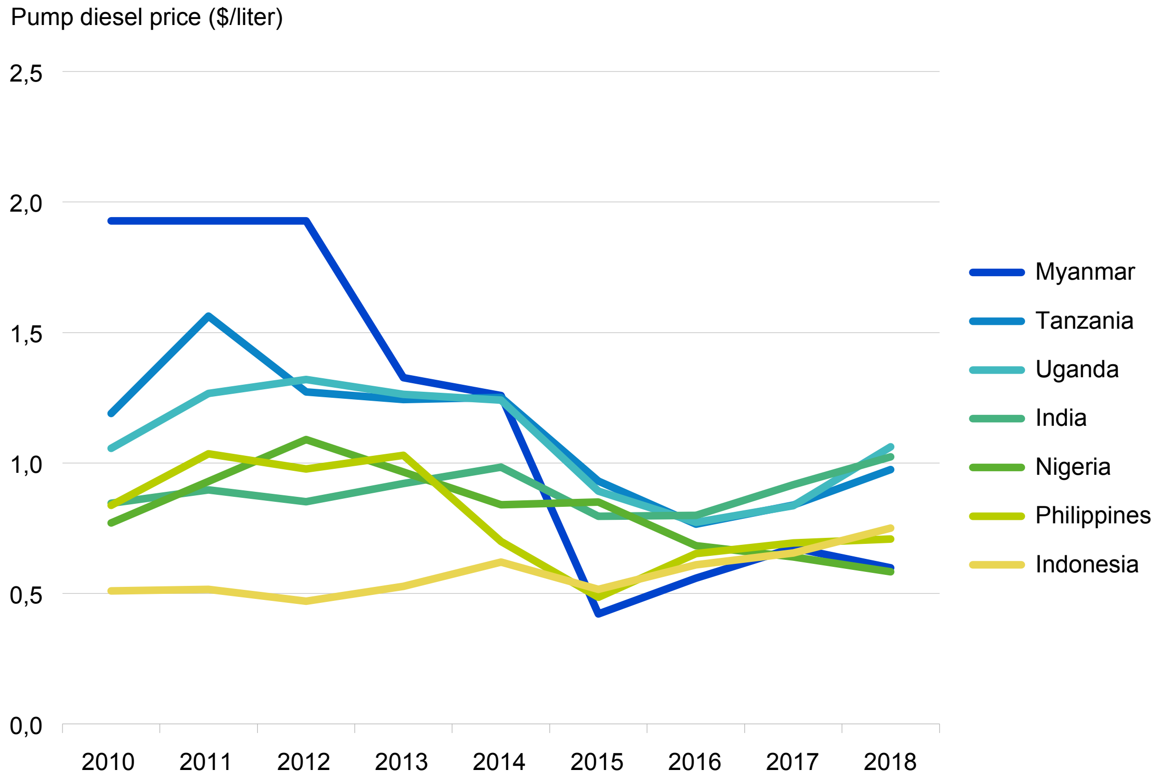
Figure 77 shows the average diesel pump prices in a sampling of key countries. Diesel pump prices tend to correlate with Brent crude, the global benchmark oil price. The cost of diesel delivered to remote areas or islands can be much higher due to long-distance transport often on poor roads. In the Philippines, the majority of systems installed on remote islands use either diesel or heavy fuel oil (HFO). Delivered diesel there can be 20 percent more costly than the national average due to transportation costs by boat (Figure 78). In the Democratic Republic of Congo (DRC), the delivered price of diesel can reach USD 4/litre in very remote locations.

Equipment replacement costs

Battery lifetimes are defined by their chemistry, their life cycles and their ambient environment. When lead-acid batteries are degraded by say 80 percent in five years, developers typically replace them. More recently, developers have considered deploying lithium-ion batteries, not only because

Figure 77

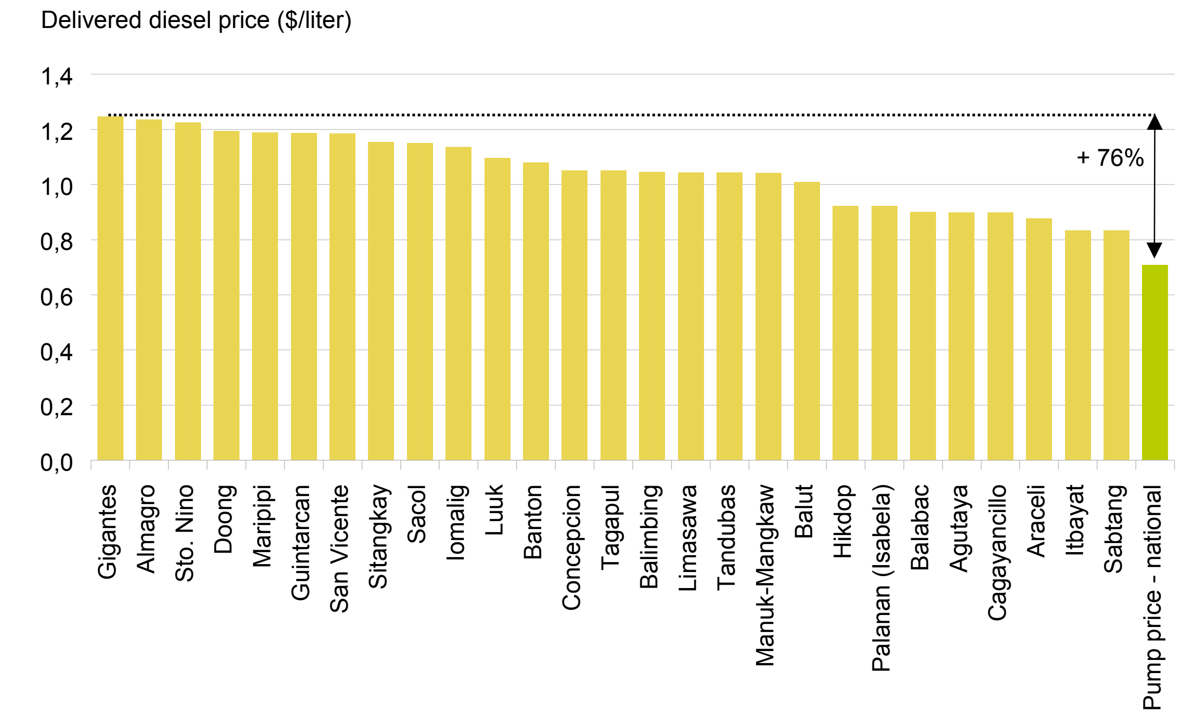
Average diesel retail price



Source: BloombergNEF, Climatescope 2019.

Figure 78

Delivered diesel prices by select diesel mini-grid sites in the Philippines



Source: Silver Navarro, Jr, BloombergNEF, Climatescope 2019. **Note:** USD 1 = PHP 51.783. The average is of all the diesel mini-grids shown in the chart.

their costs have dropped, but because they offer longer potential performance. Additionally, the cost of batteries can be significantly impacted by currency rate fluctuations. Batteries need to be replaced more frequently than other major components of the mini-grid (see the Risk Management Section).

8.3 Productive use of electricity

Economic returns delivered by mini-grids to owners rise with lower costs per connection and/or with higher average revenue per user (ARPU) of the mini-grid. Lower costs are achieved by lowering capex and opex. Higher ARPU hinges on how much electricity customers use and the price they pay per kWh, kW or energy service they receive.

Increasing ARPU is challenging in rural areas where household customers in general have such low incomes they cannot afford to increase their usage. A typical low-income household customer in a least-developed nation uses standard lighting and appliances that consume approximately just 200kWh per year. That represents just 5–7 percent of the consumption of an average UK household (UKPower, n.d.). With modern super-efficient products, electricity consumption can be reduced to 63kWh.

It is important for operators to have productive-use customers as their customers, in particular, in the daytime (Figure 79, Figure 80). Higher daytime utilization of the solar mini-grid benefits the mini-grid operator as providing power directly from PV panels represents zero marginal costs. Batteries represent fixed costs but are depreciated with each discharge. Diesel generators have high variable costs driven by fuel prices.

Figure 81 shows a positive correlation between utilization rates and ARPUs. Each dot represents a weighted ARPU based on the data of multiple mini-grid projects in operation in a specific country in Sub-Saharan Africa. For eastern Africa country A, the ARPU is around USD 3/connection/month at

Figure 79

Mini-grid dispatch profile with an evening peak

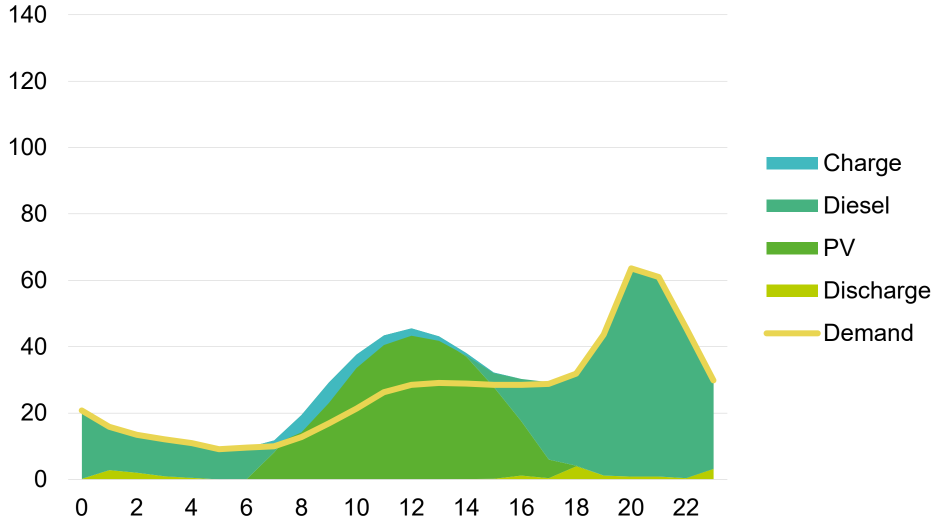
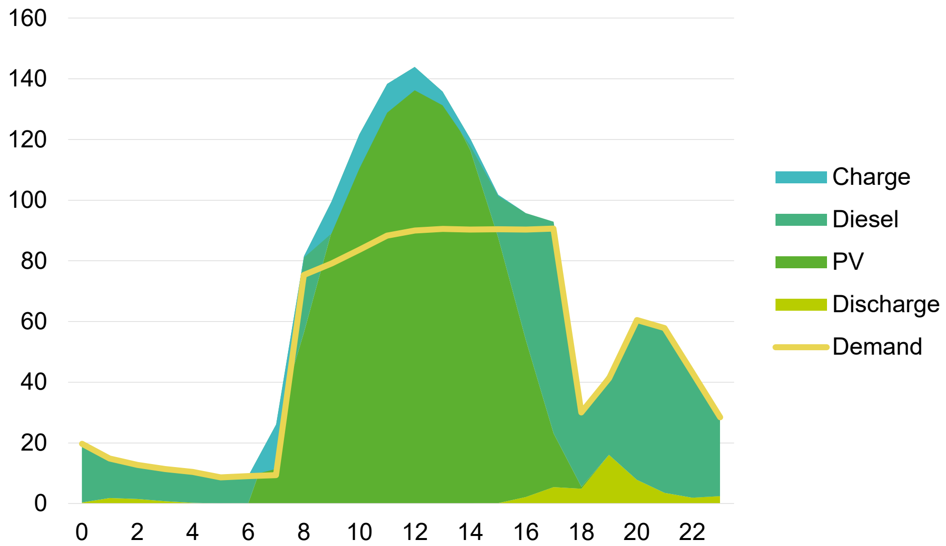


Figure 80

Mini-grid dispatch profile with added midday demand



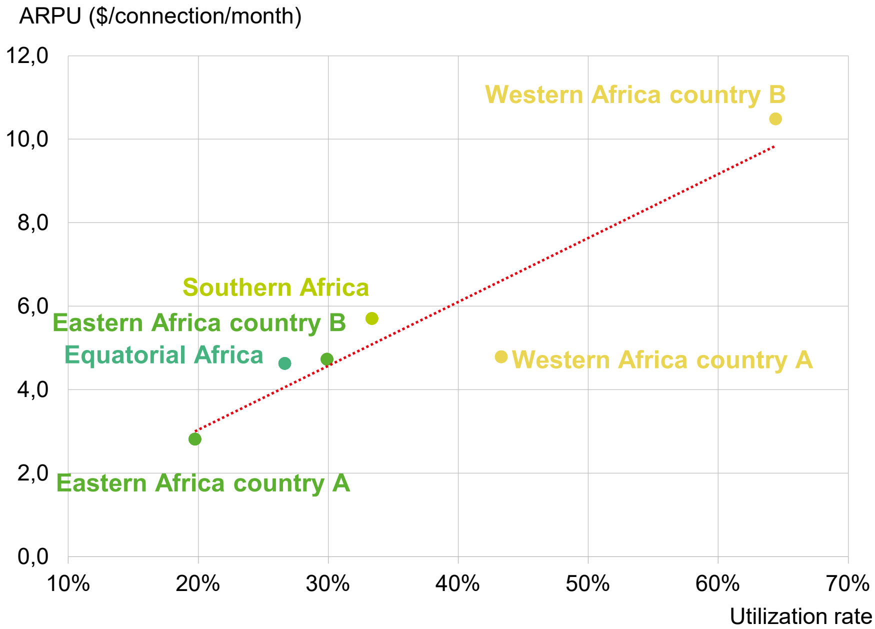
Source: BloombergNEF.

around a 20 percent utilization rate. western Africa country B sees the highest ARPU, over USD 10/connection/month, at around a 65 percent utilization rate. Increasing ARPU is pertinent in improving a developer's economic returns and subsequently attracting private investment.

For the operator, adding daytime demand can, theoretically, cut the overall levelized cost of electricity. Doing so — for example, by targeting certain types of industry — can lead to significant development gains, because midday loads are more likely to consist of income-generating activities such as agricultural/fishery cold storage or processing, or running small workshops. Evening loads are more likely to be residential. Having productive-use customers can also benefit residential customers as their use lowers the overall price of power. In other words, if commercial and industrial (C&I) customers buy power at zero marginal cost during the daytime, it also subsidizes the price for electricity that residential customers pay at night.

Figure 81

Correlation between utilization rate and ARPU



Source: Africa Minigrid Developers Association (AMDA), ECA. **Note:** Each dot represents weighted ARPU in a specific country in Sub-Saharan Africa. Actual country names are not used for the sake of anonymity. The data were collected from AMDA's member developers who are operating mini-grid projects with 11,882 connections.

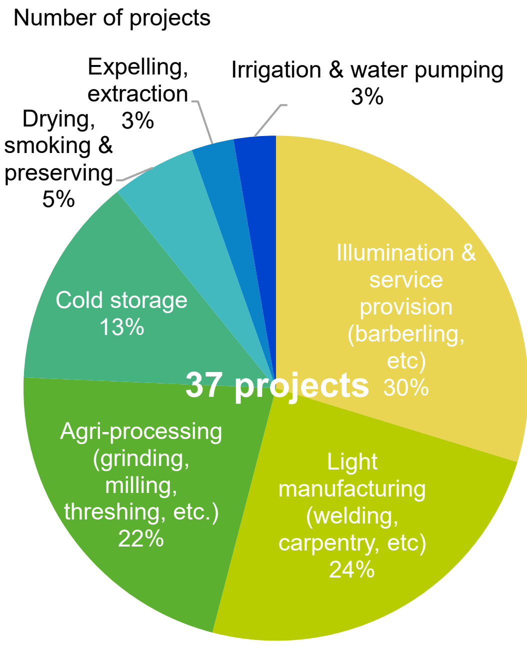
It has become more common for developers to try to adopt business models to take productive use of electricity into the consideration of the technical design of mini-grids or to stimulate customers to use more electricity to achieve higher ARPU after the start of mini-grid operation. According to the Energy and Environment Partnership Trust Fund (EEP Africa), a clean energy financing facility hosted and managed by the Nordic Development Fund (NDF), 48 percent of the applications they received incorporated a component to promote productive use of power in one of its solicitation of proposals to support mini-grid projects in east and southern Africa (EEP Africa, 2019). Of the 37 mini-grid projects financed by EEP Africa, the most common productive-use customers engage in light manufacturing, agri-processing, and illumination and service provision (Figure 82). These mini-grids mostly use solar technology, but some use biomass and hydro as well depending on the minimum capacity requirement. In India, OMC Power and DESI Power adopted business models that serve anchor consumers such as telecommunication towers and irrigation pumps as productive-use customers (see Section 13.8).

Productive-use business models

EEP Africa categorized business models into three types in terms of the productive use of electricity. Figure 83 shows a simplified diagram to explain the models. The energy supply model in which the mini-grid operators only supply electricity to consumers is the simplest model. Operators often design mini-grids to accommodate a primary off-taker, and they are often linked to agricultural production or telecommunication towers. The operators go beyond electricity supply in the two other models. The business acceleration model combines electricity supply and the provision of equipment as well as appliances through direct sales or financing to customers. If equipment and appliances are financed, consumers have benefits if they want to avoid paying or cannot pay for upfront costs. In this model operators are responsible for the inventory, maintenance and repairing of equipment. In the supplier-off-taker model, operators themselves serve as the primary off-taker by establishing and operating commercial and/or industrial activities. For example, they may produce ice and sell it to the local fishing industry. This is similar to the Key-

Figure 82

Productive activities supported by EEP Africa-financed projects

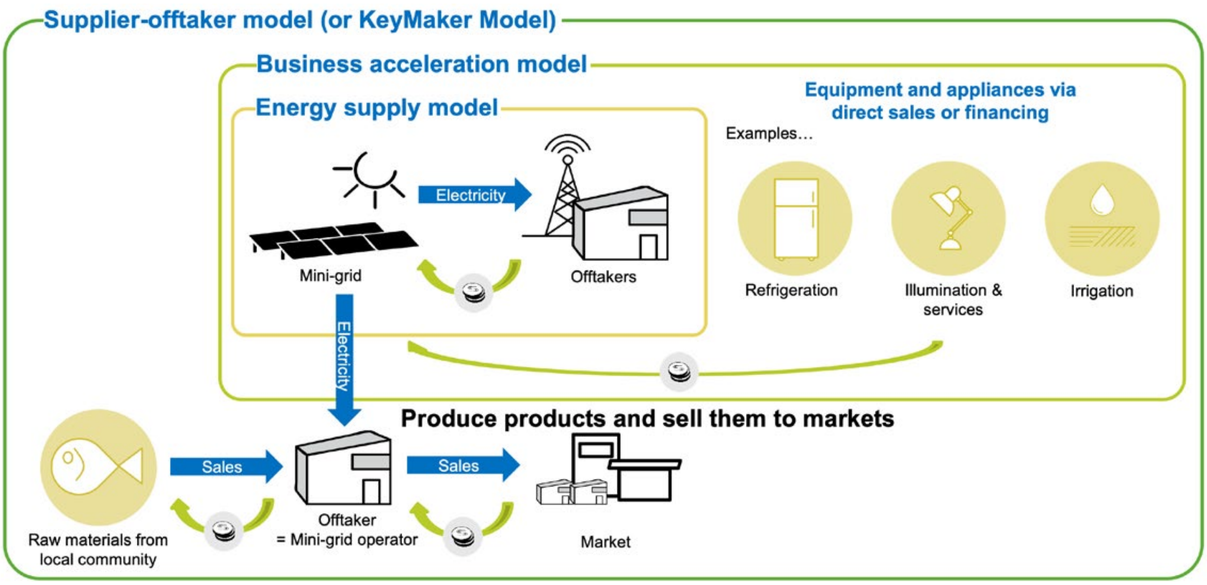


Source: Adapted from EEP Africa.

Maker model, in which 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, usually urban areas where demand is high (Inensus et al., 2019). Such a model can boost revenue for operators and generate income for the local community with which they engage.

Figure 83

Productive-use business models



Source: Adapted from EEP Africa, INENSUS, BloombergNEF.

Ideally, all mini-grid projects should serve productive-use customers to make their projects viable. However, stimulating and managing loads to match the load profile with the generation profile of PV is challenging in practice. Load profiles in general vary across different types of customers. For example, customers do not always run their machines at the same time or they may run them in the evening when PV does not generate electricity. One way to address this challenge and manage load profiles is to adopt a time-of-use tariff to make the use of electricity in the daytime more attractive. That can however suppress demand in certain industries. Another challenge is that actual power consumption can be much lower than the forecast demand. This can lead to oversizing of the mini-grid system, deteriorating the economic viability of the project (Blodgett, 2017). On the other hand, productive-use customers may not be able to depend on the mini-grid if it is too small. An important implication here is that mini-grid developers should be allowed to have flexibility over tariff setting and change technical designs (such as upgrading the mini-grid system) depending on local circumstances. Thus, governments should play a role to allow flexible tariff settings, streamline the licensing processes, and remove regulatory requirements, in particular, for small-scale projects (for example, no requirement for licence acquisition for projects below 1MW).

On the appliance side, FACTOR[e] VENTURES (referred to also in Section 7) uses the term *'income-generating appliances'* to describe equipment that can directly create economic benefits for customers (FACTOR[e] VENTURES, 2019). Together with the Energy Institute at Colorado State University, it conducted a techno-economic analysis of three income-generating appliances — welders, milling machines and solar-powered water pumps — to understand their electricity usage patterns in order. The goal: to inform stakeholders on the potential for these appliances to be powered by renewable mini-grids. The detailed results of the analysis are available here. Green Mini Grid Facility Kenya also drew up detailed guides for mini-grid stakeholders about the use of milling machines and ice makers for the productive use of electricity.

Section 9
Impacts

Access to electricity can bring significant benefits to rural communities. The quality of electricity available from mini-grids not only improves the quality of life of rural households through the provision of basic services such as lighting and mobile phone charging, but also enables local entrepreneurs to generate revenue. These impacts are some of the main drivers for development finance institutions (DFIs), impact investors and foundations backing mini-grids. Impacts may not always be easily quantified and generally take a long period of time to become evident after the start of mini-grid operation. This makes impact measurement difficult, but some organizations have developed innovative impact assessment metrics and collected data to learn, understand and track the impact of mini-grids. Such metrics can be used to attract further investments. They can also be used to inform how rural communities use energy, thereby increasing the quality and relevance of services that mini-grid operators provide.

9.1 Why measuring impact matters

There are concerns among stakeholders working in the energy access sector that quantitative indicators such as the number of households with electricity access can overlook other important aspects of mini-grids. Most governments and many other stakeholders use these indicators to report the results of their financing for rural electrification. These indicators are straightforward, but provide no information on the level of service that households receive. They also focus only on outputs and do not capture other important aspects and impacts of electricity access, some of which can appear in the long term.

The World Bank Energy Sector Management Assistance Program (ESMAP) Multi-Tier Framework (MTF) aims to provide a more nuanced way of looking at energy access through energy services at a household level. The MTF incorporates a wide range of indicators including the availability, reliability, affordability and safety of energy access. These in turn provide insight into the potential impacts of electricity access. The MTF can be used to assess the quality of service provided by the use of the equipment. It is not designed to assess the economic, social and environmental benefits that mini-grid projects provide, but is useful for considering the status of a mini-grid throughout the project's lifetime.

Understanding the complete impacts electricity access projects (off-grid solar or mini-grids) have is critical for stakeholders as they seek to formulate plans for future developments. It is important for DFIs, donor agencies and policymakers to make or amend rural electrification programmes or to plan for financial or technical assistance. It is key for developers and NGOs seeking to report the effectiveness of financings to their funders. It is critical to impact investors, foundations and private companies in evaluating whether their investments are successful and contribute to achieving the Sustainable Development Goals (SDGs).

9.2. What are the impacts of electricity access projects?

Electricity access projects assist the socioeconomic development of rural communities by enabling households to use lighting and appliances, facilitating the delivery of public services (e.g., education and health care), and helping business as well as industrial development (EU Energy Initiative Partnership Dialogue Facility, 2014). Lighting, for example, can improve safety at night, allow businesses to operate longer, and give families more flexibility in scheduling household activities such as studying and cooking. Improved communication is another potential impact as consumers can easily charge their mobile phones at their homes or in their communities without traveling long distances. Replacing fossil fuel use can contribute to improved health and safety of households and reduce energy costs.

Impacts of mini-grids

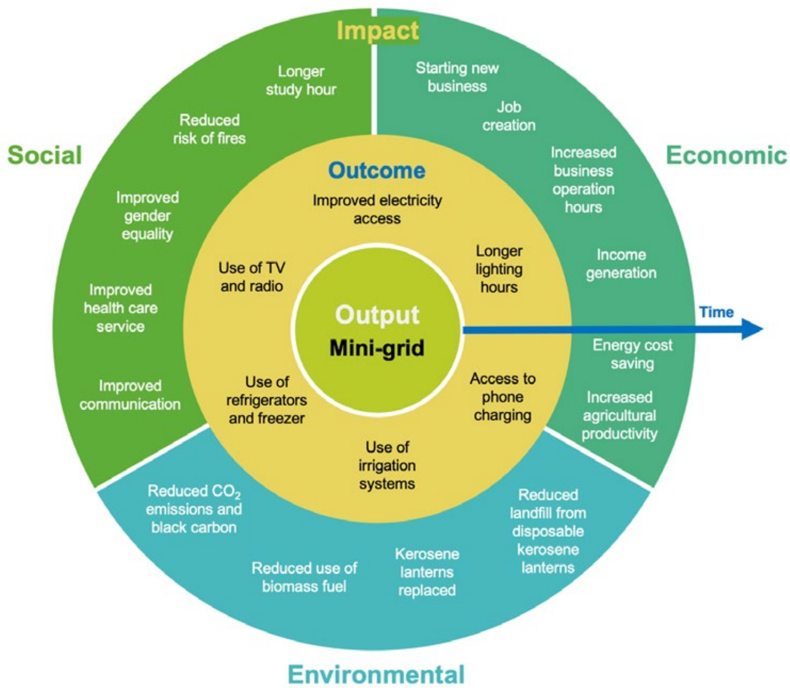
Figure 84 is a framework that splits results from a mini-grid project into three categories: output, outcome and impact. Outputs are products, capital goods and services that result from an activity or intervention. Outcomes then start to bring about change in the short-term, which can lead to longer-term impacts (OECD, 2010).

In the context of mini-grids, output consists of a mini-grid and the number of customers connected to it. Outcome is access to electricity in terms of quality, for example, improved electricity access, longer hours of lighting and changes in the use of appliances and equipment. These are results that the MTF indicators can be used to measure and, where data collection is in place, they are easily quantified.

Impacts are what the access to electricity leads to and they are positioned at the edge of the circle. They may be more diverse than the impacts of off-grid solar because mini-grids may provide more reliable electricity to customers, enabling them to use appliances and equipment with higher power ratings, including those used by commercial and industrial customers. Figure 84 categorizes the potential impacts into economic, environmental and social areas. For example, increasing economic activities and income generation are economic impacts; reduced needs of woody biomass fuel, less landfill from disposable kerosene lanterns, reduced CO_2 emissions as well as black carbon, and fuel

Figure 84

Output, outcome and impacts of a mini-grid project



Source: BloombergNEF, GOGLA, Lighting Global, World Bank Group. Note that the positions of outcomes are not correlated with those of impacts.

savings are environmental impacts; and improved education, safety and gender equality are social impacts. Note that impacts do not simply fit in one of the three areas. For example, improved communication thanks to access to phone charging at home may lead to reduced time to travel for charging. As a result, it can lead to an increase in working hours, thereby leading to income generation.

It is important to note that mini-grids do not always generate the impacts that investors[13] and developers intended. Impacts can be created by combining with other factors irrelevant to electricity access and can sometimes be negative. For example, there is a general understanding that lighting can enable studying after school hours. However, past research suggests that lighting itself is not enough to create positive impacts on education such as better educational performance. According to research by the International Growth Centre, while electricity access can bring educational benefits, it must be combined with investments in improving learning environments in general such as classroom facilities and the number and quality of teachers (International Growth Centre, 2017). The research also mentions that there were negative impacts on test results of some children observed in northern Tanzania, possibly because they spent more time on household work as their parents increased their working hours outside the home.

Impacts also depend on customer types, income levels, existing economic activities, and mini-grid business models. Where there are few economic activities within a community, gaining access to electricity may not immediately lead to job creation and income generation. In such cases, increase of electricity consumption is slow and mini-grid developers have taken action to increase productive activities. Business models such as the KeyMaker model seek to generate a secondary revenue stream for the developer by using mini-grid electricity to process raw materials (fish, meat) procured from the local community, and selling the final goods to customers in urban areas (see Section 4). If the business model works, the project generates indirect economic impacts.

13 The intention can be different depending on the type of investors (i.e., impact investors have different intention from strategic investors in terms of impact creation).

9.3 Existing impacts assessment metrics

While there is no single impact metric for mini-grid projects, some organizations have developed metrics for electricity access projects and collected data that can be applied to mini-grids.

GOGLA's impact metrics

The Global Off-Grid Lighting Association (GOGLA), a global association for the off-grid solar energy industry established in 2012, launched its Standardized Impact Metrics for the Off-grid Solar Energy Sector in 2015 to enhance knowledge and attract investment, working capital and regulatory support. Its Impact Working Group has upgraded the metrics based on the best available data from the off-grid solar industry as well as the research community. The metrics have been adopted by the Impact Reporting and Investment Standards (IRIS), which is an initiative of the Global Impact Investing Network (GIIN) aiming to increase the scale and effectiveness of impact investment. GOGLA aims to review and revise the metrics every 18–24 months to ensure that they are in line with the latest research.

GOGLA sets impact metric frameworks for multiple aspects (Table 19). Its main purpose is to standardize reporting, allowing off-grid solar companies to compare their impacts. GOGLA members have already used the metrics to state the estimated impact of their initiatives, which is summarized in its semi-annual market report (Table 19). Most of the indicators can also be applied to the mini-grid sector.

60 Decibels Lean Data

60 Decibels is an impact measurement company, best known for its Lean Data℠ approach, spun out from Acumen in 2019. Acumen, a non-profit impact investor, invests in early-stage companies that offer products and services enabling the poor to transform their lives. Its impact assessment framework has three dimensions in line with its investment targets:

- Poverty focus – the number and percentage of customers who live below international poverty lines

Table 19

GOGLA's impact metrics for the off-grid solar sector

Impact area	Metric examples	Estimated impact globally
Energy access	Number of people with improved energy access since July 2010	280 million people
Economic activity	People currently undertaking more economic activity	5.1 million people
Income generation	Additional income generated since July 2010	USD 4.9 billion
Kerosene replacement & CO2 reduction	Kerosene lanterns replaced	22 million
Light availability and quality	Additional light hours used by households since 2010	63 billion hours
Energy spending	Savings on energy expenditure by household since July 2010	USD 10.5 billon
Financial inclusion	Number of adults currently benefitting from clean energy financing (pay-as-you-go solar only)	N/A

Source: GOGLA. **Note:** Impacts measured are results published in the Global Off-grid Solar Market Report Semi-Annual Sales and Impact Data, January–June 2019.

- Breadth of impact – the number of people reached by the business
- Depth of impact – the change in the well-being of the household using a product or service

Lean Data — an approach to impact measurement and customer insights — was developed in 2014. It focuses on capturing customer profiles, experience, impact and feedback. 60 Decibels has pioneered the use of (mostly phone-based) surveys to measure social impact across the world. It has worked with many off-grid energy companies and recently published a report sharing its insights.

Acumen and 60 Decibels' press release on news of the spinout stated: "*There is still no commonly accepted approach for gathering and reporting high-quality impact data. There are also no widely adopted benchmarks for impact, making it difficult for investors and enterprises to assess their impact performance against peers.*" The Lean Data approach addresses this gap. On average, 54 percent of the company's customers said their quality of life had been improved by access to a mini-grid. They also suggested that the improvement was not necessarily correlated with the income level within a community (Figure 85, Figure 86) but may be more related to services the customers were able to use thanks to the mini-grid. More insights are in their report: Why off-grid energy matters (2020).

9.4 Impact metrics used by financiers

The Global Impact Investing Network (GIIN), a non-profit organization dedicated to increasing the scale and effectiveness of impact investing, surveyed 13 investors in its network to understand the indicators that they use to assess the impacts of their investments. Figure 87 shows the results. Note that not every financier had invested in the mini-grid sector.

All of the survey participants measured the number of beneficiaries (e.g., those who gained electricity access) of their investments. Eleven participants measured both the reduction of greenhouse gas (GHG) emissions as well as the number of people employed as a result of a project. These metrics are relatively straightforward and easy to determine. Fewer investors adopted indicators to assess social impacts such as investment support or the empowerment of women or a reduction in the number of

Figure 85

Share of mini-grid customers under the relative poverty line

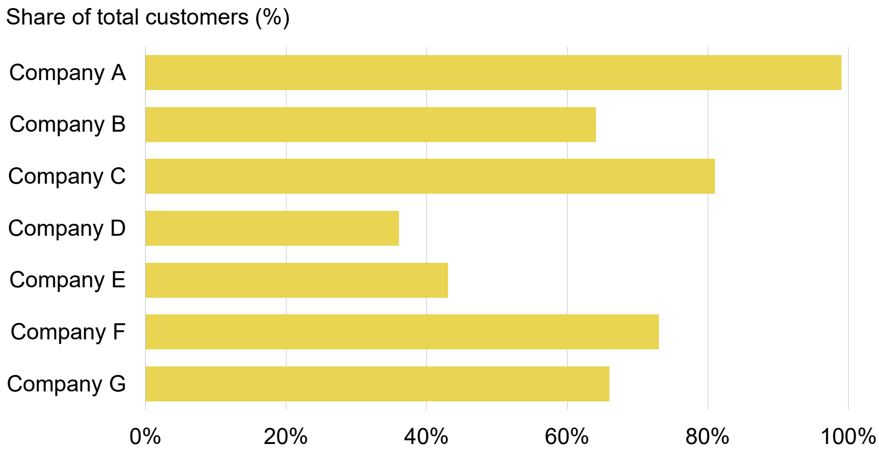
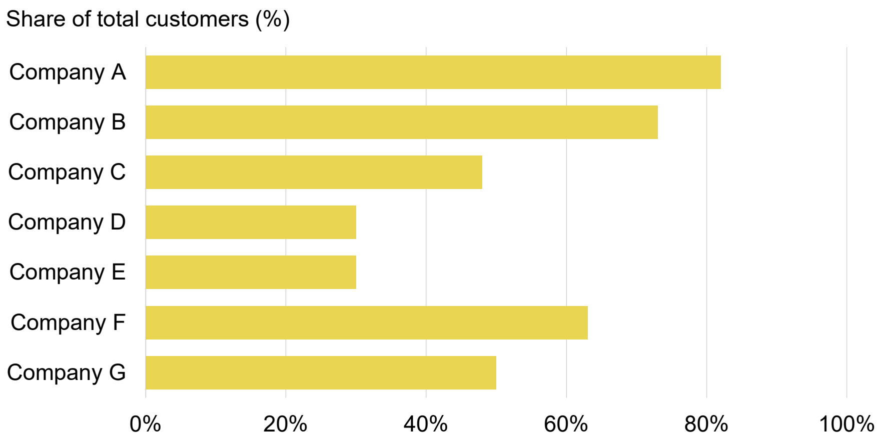


Figure 86

Share of customers who said quality of life improved by access to a mini-grid



Source: 60 Decibels, BloombergNEF. **Note:** Relative poverty line indicates household income of USD 3.2 per day.

deaths or cases of disability. These social impacts can be harder to measure, possibly because gender-related questions have a lower response rate from investees than other impact areas in data collection (GIIN and UK AID, 2014), or it is difficult to identify a direct link between energy and health. In addition, social impacts may appear over a longer time frame than others.

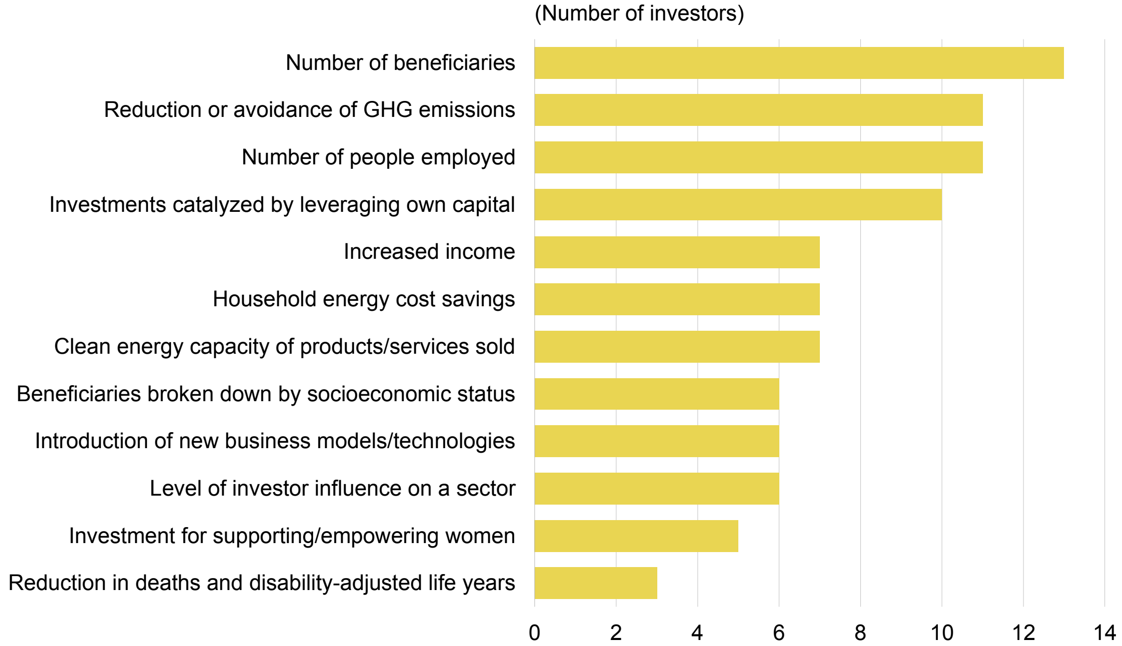
Impact metrics that financiers have adopted also vary according to their objectives. Only seven of the thirteen surveyed financiers aim to catalyze positive socioeconomic outcomes in the local economy or in a specific sector through their investments. Metrics are also used selectively for specific financial transactions, depending on their relevance to the investee company, business model, customer, or type of product or service sold (GIIN and UK AID, 2014).

Bridging impact assessment to SDG-related investments

Impacts of mini-grid projects are linked to at least eight of the seventeen SDGs (Figure 88), beyond SDG7 to ensure access to *affordable, reliable, sustainable and modern energy for all*. Many mini-grid developers receive funding from donor agencies and challenge funds. These financiers have incorporated impact metrics as part of the reporting requirement against the SDGs. For example, the En-

Figure 87

Metrics used for impact assessment by investors in the clean energy sector

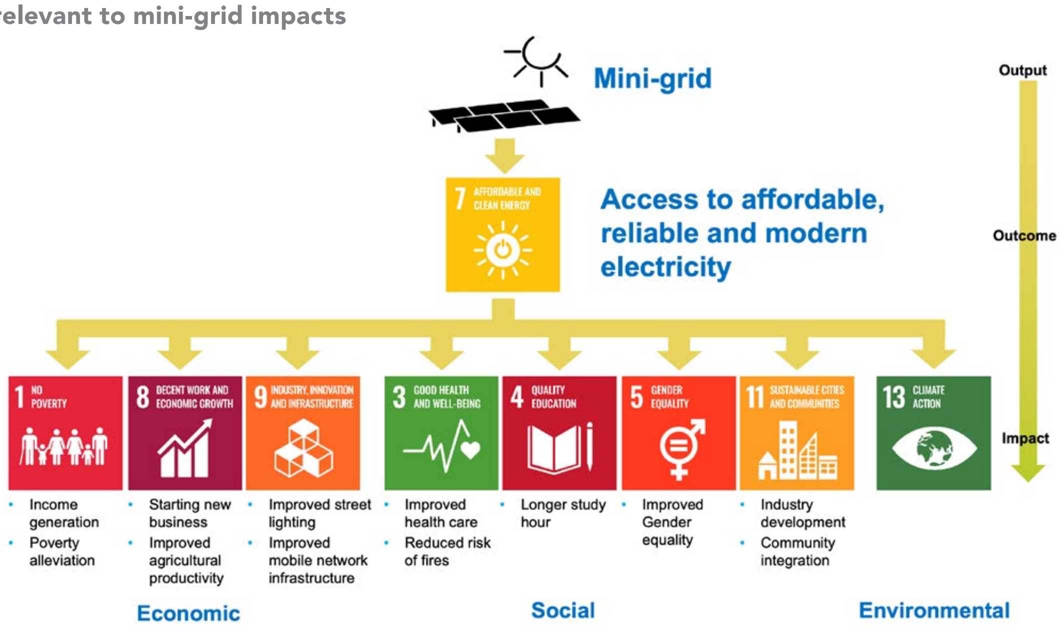


Source: GIIN, BloombergNEF. **Note:** Surveyed financiers include Acumen, Bamboo Finance, Calvert Foundation, Deutsche Bank, Doen Foundation, FMO, Global Alliance for Clean Cooking, Gray Ghost Ventures, LGTVP, Lunch Foundation, IDFC (former OPIC), responsAbility and Shell Foundation. Names of some of the metrics were slightly modified for the sake of simplicity.

ergy and Environment Partnership Trust Fund (EEP) Africa monitors and assesses impacts based on the six indicators that reflect SDGs 1, 5, 7, 8 and 13. These are: savings on energy-related expenditure, women in leadership, people with enhanced energy access, direct job creation, mobilized climate finance and CO_2 emissions reduced or avoided (EEP Africa, 2018).

Figure 88

SDGs relevant to mini-grid impacts



Source: BloombergNEF, UN. **Note:** Impacts under the SDG logos are examples.

As interest in investing in SDG-related themes has increased, impact metrics and insights can be used to attract more investments that aim to achieve the SDGs. These metrics can be used to, for example:

- Assist investors, particularly DFIs, impact investors and strategic investors, to include the mini-grid sector in their scope of SDG-related investing.
- Assist investors in collecting and evaluating data of impacts as a result of their investments. They could inform their stakeholders how impacts of mini-grid projects are contributing to the SDGs.
- Avoid potential *rainbow washing*, where investors label SDGs for marketing purposes rather than creating genuine impacts that contribute to achieving the SDGs (Financial Times, 2019). Hence, customers who value social and environmental impacts can judge more accurately what finance products they should buy.

Part 4

Outlook

Section 10
Outlook

Mini-grids offer the most appropriate approach to provide electricity access to an estimated 111 million households in Sub-Saharan Africa, Asia and small island nations. This takes into account population growth over the next decade and assumes universal access by 2030. The six case study countries analyzed in this report represent a third of the total addressable market. See Appendix C for details of the methodology.

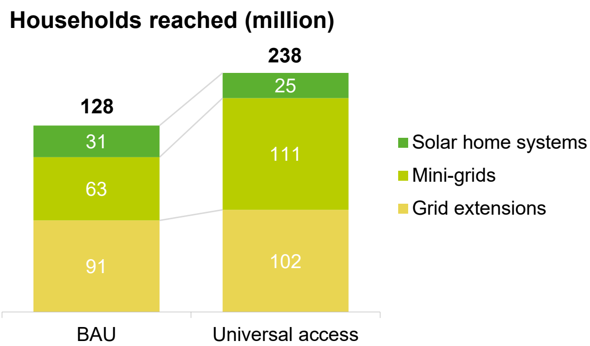
10.1 Addressable market size by 2030

The rising competitiveness of solar and battery storage as well as the improved energy efficiency of appliances will have a profound effect on the way people without access to electricity will ultimately be served. The conventional approach to increasing access to electricity in emerging countries has been to expand the transmission as well as distribution grid with more poles and wires. This capital-intensive approach has typically been driven by governments and has been heavily subsidized because the rural population tends to be both geographically scattered and consume little electricity. In remote areas, this network expense can drive the cost of producing and delivering a kilowatt hour of electricity to more than USD 1. This approach is becoming more financially prohibitive for many governments, as areas where the main grid can readily be extended are being steadily exhausted. This is likely to prompt governments to look to decentralized energy options as a way to achieve universal electricity access.

The authors estimate that 238 million households will need to gain electricity access over the next decade in Sub-Saharan Africa, Asia and island nations to achieve universal access.[14] Mini-grids can serve almost half of these – 111 million households (Figure 89). This technology is the most suitable option for most low- and medium-density areas, and more affordable for low-income families than alternative options. Universal access in these areas requires capital investment of USD 128 billion (Figure 90).

Figure 89

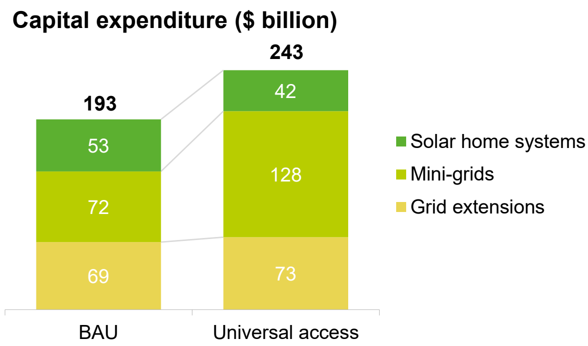
Technology use, 2020–30



Source: BloombergNEF..Assumes all mini-grids are solar hybrid systems.

Figure 90

Estimated capital investment, 2020–30



14 Accounting for population growth.

The required investment is 78 percent larger than a business-as-usual scenario that would assume that electricity access improvement continues on historical trends.

In a business-as-usual scenario, mini-grids would require USD 72 billion, in addition to an investment of USD 69 billion required for grid extensions. The latter would serve a larger number of households as high-density areas would be prioritized for electrification. Solar home systems, mostly small and basic ones, would proliferate where electricity access gaps persist. But still we would be falling short of universal access. In total, universal energy access would require capital investment of about USD 243 billion between 2020 and 2030. Mini-grids would serve 111 million households or 47 percent of the total. Solar home systems would be the least-cost option to offer electricity access to some 25 million households from a capital investment of USD 42 billion. The figure below illustrates the funding gap between the two scenarios. The authors estimate a USD 50 billion investment shortfall, and that a total of 53 million households, or 20 percent of the addressable market will be left unserved in 2030 without proactive measures to fill the gap.

10.2 Regional outlook

Figure 92 and Figure 93 show the estimated number of households currently connected and the required investments by region for universal electricity access by 2030.

Sub-Saharan Africa

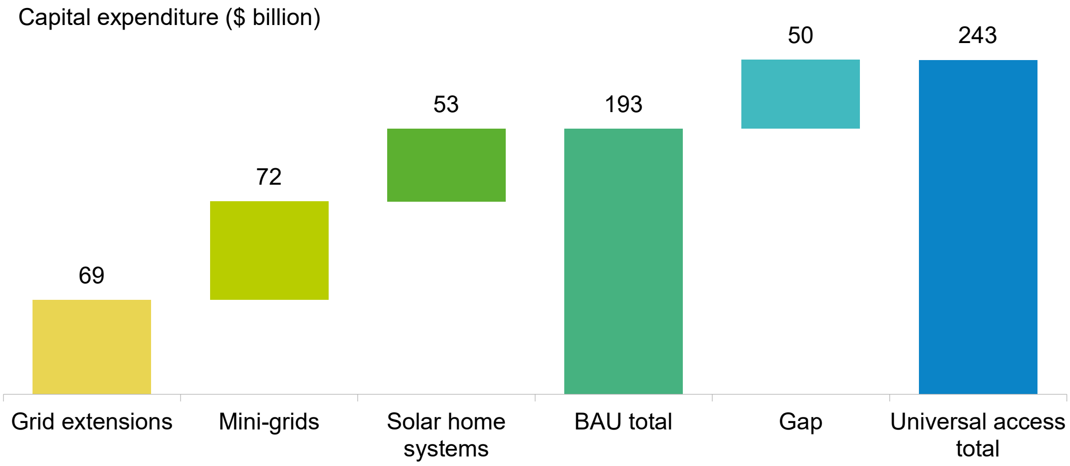
The authors estimate that mini-grids can supply electricity to approximately 81 million households without electricity access in Sub-Saharan Africa through to 2030. This will require a capital investment of about USD 93.1 billion.

Within Sub-Saharan Africa, Ethiopia is the largest potential market. Here, electricity access has improved relatively quickly in parallel with the nation's economic boom of the last few years, although nearly 60 percent of the population of 109 million did not have access to electricity at the end of 2018. The government launched its first tender programme to install 25 solar hybrid mini-grids in 2019.

Nigeria has the second largest number of potential opportunities in Sub-Saharan Africa and the largest within West Africa, given the size of its population without access to electricity. Its electricity grid is notoriously unreliable, driving the vast majority of people and businesses to rely on diesel generators, and increasingly, also solar and storage. The country has set up a robust regulatory environment to make mini-grid projects viable. Its two recent results-based financing (RBF) programmes (i.e., performance-based grant and minimum subsidy tender) are likely to provide direction to other

Figure 91

Projected electricity access investments, 2020–30



Source: BloombergNEF.

Figure 92

Technology use in universal access scenario

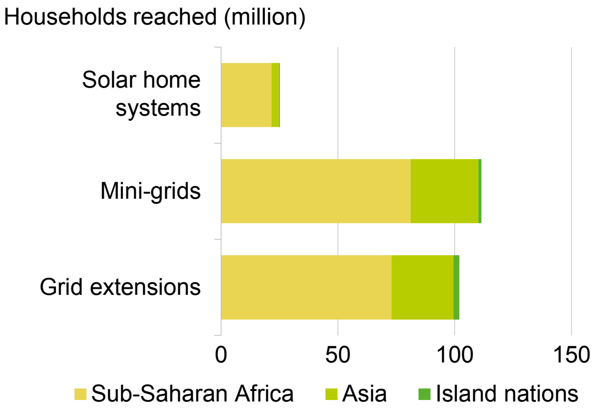
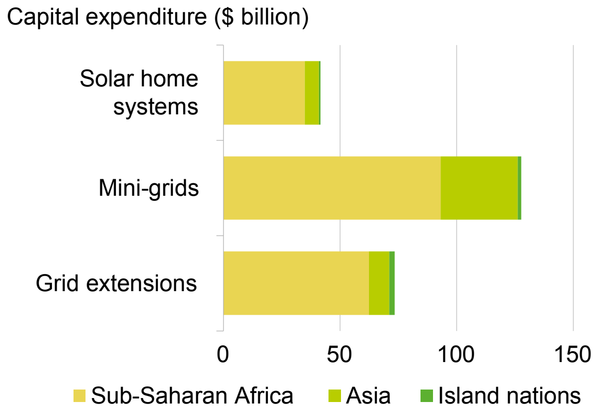


Figure 93

Capital expenditure in universal access scenario



Source: BloombergNEF, Climatescope 2019, World Bank. **Note:** Assumes all the mini-grids to be installed are solar hybrid mini-grids. Also assumes continued population growth as well as universal electricity access by 2030.

Sub-Saharan African countries on how best to target subsidy mechanisms to scale mini-grid markets. Several other governments in West Africa such as Sierra Leone and Togo have also developed mini-grid programmes and regulations with the help of foreign donors. These efforts are likely to boost the role of mini-grids in rural electrification.

In Tanzania, one of the leading mini-grid markets on the continent, the government currently prioritizes grid expansion, with ambiguous plans for decentralized energy. Here, regulations to support or protect mini-grids tend to be less favourable and are not always enforced by the state-owned utility.

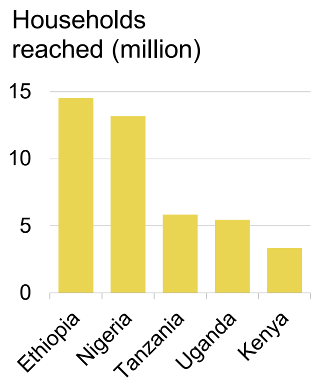
Uganda has been working on a tender programme to install 40 mini-grids . At the end of 2018, Kenya set an ambitious target of achieving universal electricity access by 2022. Its government launched a National Electrification Strategy, in which the country aims to connect about 35,000 households with mini-grids.

Asia

Asian countries have improved electricity access significantly, reaching an average access rate of 94 percent at the end of 2018 . The authors estimate that mini-grids are the most suitable approach for

Figure 94

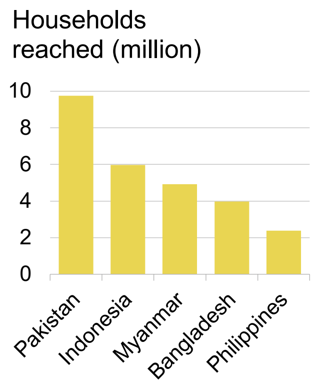
Top five Sub-Saharan African countries by potential market size for mini-grids



Source: BloombergNEF.

Figure 95

Top five Asian countries by potential market size for mini-grids



Source: BloombergNEF.

the remaining 29 million households in the region that remain without access to electricity and for which a total capital investment of approximately USD 33 billion will be required.

South Asia is densely populated and countries have pushed to electrify by expanding the main grid. In 2019, India declared that grid electricity had reached all households, although in reality, the supply is often unreliable. The government has already started shifting policies to improve reliability of the main grid, and further growth of India's mini-grid market depends significantly on how this improves in the next 10 years. Grid reliability is still a challenge in many rural areas and a considerable number of consumers are willing to pay for mini-grid electricity as a result. Voltage fluctuation is also a problem, particularly for industrial customers, suggesting opportunities for commercial and industrial (C&I) mini-grids. In Bangladesh, the off-grid solar market has flourished, improving its electricity access rate from 49 percent to 93 percent between 2010 and 2018 . Developers could use their expertise to aggregate these systems within communities to better manage individual loads, effectively creating DC mini-grids. There have been limited attempts to promote AC mini-grids.

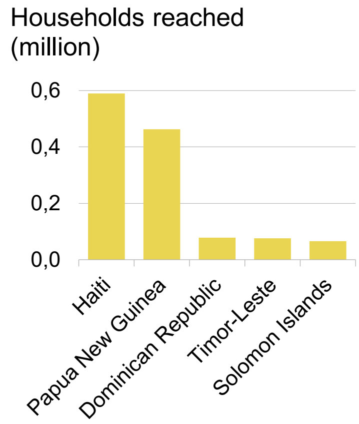
Topography is a challenge to last-mile connectivity everywhere, but especially in Southeast Asia where some countries have thousands of islands. The countries with most people off the grid are Myanmar, the Philippines and Indonesia. In the latter two, government-sponsored island electrification programmes have been a staple of energy policy and hundreds of mini-grids have been installed across the region. Both countries have subsidy schemes that regulate and support such assets. Retrofits of diesel mini-grids with solar and increases in demand on islands that have already been electrified may further expand these markets. Landlocked Myanmar faces very different challenges with a poorer population, but a recent development push and investments from international private entities have moved things forward.

Island nations

In 2018, small island nations, namely the Pacific and Caribbean islands, had a total unserved population of some 15.9 million. This represents only 1.7 percent of the global population without access. Three out of the 17 island nations studied in this report accounted for 85 percent of all mini-grid connections in the region. Haiti achieved 589,000 connections, followed by 463,000 in Papua New Guinea and around 78,000 in the Dominican Republic.

Figure 96

Top five island nations by potential market size for mini-grids



Source: BloombergNEF.

The potential mini-grid market size in these island nations is 1.36 million households or just 1.2 percent of the whole addressable market for mini-grids identified in this research. This would require a capital investment of USD 1.5 billion. Due to the scattered geographies of the islands, universal access solely through main grid expansion is not realistic. Some island nations such as Papua New Guinea have sought to electrify through solar home systems rather than mini-grids. Complex topographies and the remoteness of the islands pose challenges for development and installation of mini-grid projects.

Diesel generators have been commonly used, suggesting opportunities to replace these with renewable hybrid mini-grids. Pacific islands including Nauru, the Solomon Islands, Tonga and Tuvalu are likely to see some development of solar hybrid mini-grids in the next few years. In 2019, ADB announced that it will invest over USD 1 billion in energy projects in Pacific countries from 2019 to 2021 (ADB, 2019).

10.3 Outlook on case study countries

Nigeria

The authors see Nigeria as the largest potential market for mini-grids in West Africa. At the end of 2019, Nigeria had 59 mini-grids (2.7MW capacity), of which 52 used solar. With 200 million people, Nigeria is Africa's most populous nation yet it has a rural electrification rate of only 36 percent, an estimated power demand of 50GW including privately-owned on-site generators and grid electricity (19GW for grid peak demand) and 3–15 hours of outages per day, offering huge opportunities for decentralized energy. The main grid improvement has been slow and is unlikely to change dramatically at least in the next five years.

The Nigerian government claims that the country has the potential to electrify 14 percent of its population by building 10,000 mini-grids of 100kW each by 2023, offering a potential annual revenue of USD 8 billion. Nigeria introduced a robust mini-grid regulation in 2017, including protection of mini-grids below 1MW should the main grid arrive. In addition, Nigeria's Rural Electrification Agency (REA) is currently running an RBF programme as part of the Nigerian Electrification Project (NEP), backed by the World Bank. This consists of a first-come first-serve Performance-based Grant (PBG) programme where developers receive a fixed USD 350 per new connection and a minimum subsidy tender mechanism aiming to roll out solar hybrid mini-grids at up to 250 designated sites, where the per connection subsidy is determined competitively. Each of the winning bidders will develop multiple projects so that mini-grids can be installed at a lower cost to the REA and at a faster speed. One developer already started operating its mini-grid in Niger State in December 2019. All other projects are expected to start operations between 2020 and 2021. Governments in other Sub-Saharan African countries are paying attention to gauge the programme's success. The programme may influence Nigeria's subsequent electrification programmes and other countries' electrification strategies. In addition to public sector interest, interviews for this research revealed strong positive sentiment amongst private players, including from a number that do not currently operate in Nigeria.

Tanzania

Tanzania's situation is less clear. There is a clear argument for mini-grids – despite an impressive quadrupling of the rural electrification rate, only 23 percent of the population has access . At the end of 2019, there were 209 mini-grids installed in Tanzania , of which almost one-third used solar. On a per-MW basis, renewable mini-grids are dwarfed by older hydro and diesel projects.

Tanzania adopted solar hybrid mini-grids earlier than other countries in the continent, thanks to a regulatory framework that is friendly to project development, dedicated rural electrification programmes and assistance by international organizations. However, recently investors and developers have become wary of the state's weak implementation of the regulation, its ambiguous attitude towards decentralized energy for rural electrification and a growing emphasis on grid extensions.

An upside for Tanzania is that PowerGen secured financing of USD 5.5 million from CrossBoundary Energy Access to develop a portfolio of 60 mini-grids in the country in 2019 . The deal may have been possible because of a combination of factors: the country's relatively more robust regulatory framework than that of others (despite some question marks about its enforcement) and the developer's broad experience in mini-grid development in Sub-Saharan Africa, including Tanzania.

The future outlook in Tanzania depends on whether the government will shift support towards decentralized energy and refresh regulations. A second factor to watch closely is large-scale deals, which could signal that the country has cultivated an environment that supports successful scale-up.

Uganda

Uganda is reasonably well positioned for further mini-grid development. At the end of 2019, Uganda had 34 mini-grids installed, totaling 56.8MW – 6 percent of the country's total capacity. Ugandans have improved electricity access gradually over the last decade. In 2018, only 10 percent of the rural population had access, indicating the challenge it would be to reach its 26 percent target by 2022.

In 2018, Uganda's REA undertook a master planning exercise using a least-cost approach that identified 320 sites suitable for mini-grid deployment by 2030. These projects would serve a total of 70,000 households. Over 100 habitable islands are situated on Lake Victoria, where main grid extension is not feasible. This presents a strong opportunity to develop mini-grids.

The government has recently taken an active role in fostering the embryonic mini-grid market. It has initiated a bundled tender scheme, which should more than double the number of mini-grids, with an additional 40 mini-grids to follow.

The cumbersome licensing procedure and unclear grid arrival rules are the two main elements that can hinder project development. New regulation is being drafted, which signals the government's commitment, although its effectiveness in expanding the market has yet to be determined.

See also SEforALL's *Energizing Finance: Taking the Pulse 2019* report for energy access financing including financing for mini-grids in Uganda.

India (Bihar)

The authors identified 146 installed mini-grids with a total capacity of 4MW in Bihar, India, which is 8 percent of the total installed projects in India. It is estimated that about 2.8 million households could be served by 11,200 mini-grids in Bihar.

The main grid has penetrated all villages in Bihar. Although main grid reliability has also improved, frequent outages are still a major problem. Therefore, rural customers are willing to pay a premium for more reliable electricity from decentralized plants. Developers have established a plethora of business models, providing services that complement or substitute electricity access from the main grid. India's regulation is relaxed, although the lack of grid arrival rule makes developers wary of the risk of mini-grid assets becoming stranded.

According to a study by the India-based research institute Council on Energy, Environment and Water (CEEW), 16 percent of surveyed electricity users in Bihar had access to electricity for eight to 20 hours a day in 2018. CEEW categorizes users into groups where either solar home systems, generators or mini-grids are the most suitable technology.[15] The mini-grid sector in the state has performed well in the light of poor main grid resilience, as illustrated by Tata Power's commitment to build 10,000 mini-grids across India (of which a portion could be in Bihar). Greater emphasis on strengthening the main grid could pose a challenge for isolated mini-grids, although there are still likely to be opportunities for serving productive-use customers who require a consistent and predictable electricity supply. In the mid-to-long term, building interconnected mini-grids to support resilience efforts and increase capacity can be a viable option.

Philippines

By the end of February 2020, the Philippines had 326 mini-grids (530MW), the majority of which used fossil fuel. Since 2001 the government has improved its electrification rate through its missionary electrification programme, which has financially supported building and operating off-grid mini-grids in rural areas where grid extension is unviable (called the National Power Corporation Small Power Utilities Group (NPC-SPUG) plants). The majority of the existing mini-grids were built under this framework. Some domestic and international private companies installed solar hybrid mini-grids.

Uptake of the solar hybrid mini-grid market has been slow, primarily because of the complex as well as lengthy licensing processes and lack of incentives, and possibly due to the existing contracts of the fossil-fuel mini-grids that are currently operating. A potential driver for market growth is Bill 175 (the Microgrid Systems Act) that is currently in the legislative process with no definite timeline for enactment. It aims to promote renewable hybrid mini-grids below 1MW (primarily, solar hybrids) in off-grid and weak grid areas in the country. If enact-

15 They belong to Tier 2 under the CEEW category. This is equivalent to Tier 2 and 3 in the World Bank ESMAP Multi-Tier Framework. The authors applied this framework to estimate the potential size of Bihar's market assuming almost all households are connected to the main grid but many have unreliable grid electricity.

ed, the government will disclose candidate sites for mini-grid development and invite competitive bids, with more streamlined administrative processes than today. The legislation is critical for the government to meet the universal electricity access target by 2022.

See also SEforALL's *Energizing Finance: Taking the Pulse 2019* for energy access financing including mini-grids in the Philippines.

Indonesia

With 17,500 islands, Indonesia has a very strong reason to use mini-grids. It currently has 1,061 known mini-grids installed, of which just over 600 are solar-based. These have been mostly developed with the technical support of donor agencies.

The archipelago claims a rural access rate of 96 percent. However, this figure is based on the number of villages that have electricity access and does not necessarily mean that every household within a village has electricity. Decentralized energy is more suitable on remote islands where grid extension is not viable. The country already has an estimated 3–4GW of installed diesel mini-grids, offering huge potential to substitute diesel.

Despite large potential for market growth, Indonesia is a difficult market for international entities. The state-owned utility *Perusahaan Listrik Nagara* (PLN) is effectively responsible for serving all areas, and close cooperation with the PLN is a must for private sector entities. Almost all the organizations that have worked with the PLN to date have been domestic. In addition, there are strict ownership limits for foreign entities in commercial generation plants of below 10MW, including mini-grids. It is unlikely that the government will lower these barriers in the near future, despite there being a strong need due to the topology of the country.

Mini-grids are likely to continue to be the preferred off-grid solution. However, Indonesia has a unique situation compared to the other countries analyzed – developments will be driven by the public sector via the state-owned utility PLN and not the private sector. The PLN's dominance has made it a challenge for private entities to help close the electrification gap on the remaining 4 percent of the population.

Part 5

Case studies

Section 11
Case study – Uganda

Uganda currently has 34 mini-grids known to be installed. For developers, the biggest obstacles to further build-out are cumbersome government approval processes and regulated tariffs that make it difficult to recover project costs without subsidies. In 2017, the government identified sites using a least-cost electrification approach and introduced a bundled tender scheme to scale mini-grids in the country.

11.1 Overview

Just one in four Ugandans had access to electricity at the end of 2018. In rural areas, the numbers are bleaker still, with just one in 10 having access. While the government has stated its goal of achieving 26 percent rural electrification by 2022, that appears quite unlikely unless the decentralized energy technology market scales rapidly.

Today, Uganda has 34 known mini-grids commissioned, of which have a known operating year (Figure 97, Figure 98). The combined total installed capacity of the 34 projects is 56.8MW, representing 6 percent of the country's total capacity of 940MW.

Uganda's Rural Electrification Agency (REA) has undertaken a master planning exercise and identified opportunities to build mini-grids providing power to 62,000 households across 10 service territories by 2029 (UOMA, 2019). Potential sites were selected based on the criteria of having more than 50 households clustered in one particular area and having expected grid extension costs not exceed USD 2,000 per customer.

Despite the opportunity for further mini-grid development in Uganda, the market has been slow to take off, largely due to a fragmented regulatory environment. Among other issues, the country's current policies fail to explicitly set an energy access target to be met through mini-grids. In addition, the current licensing process lacks transparency, and rules around main grid arrival at installed mini-grid sites are unclear. In 2017, as part of the efforts to achieve the 2022 target, the Ugandan government, with support from the German Agency for International De-

Figure 97

Uganda's installed mini-grids, by projects

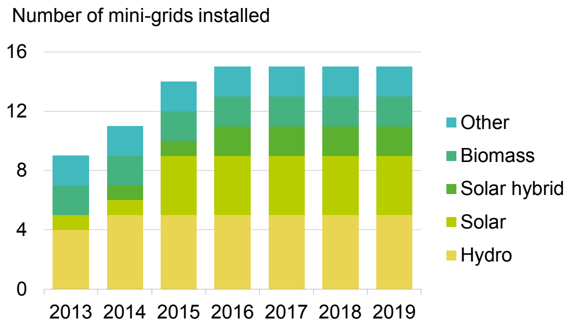
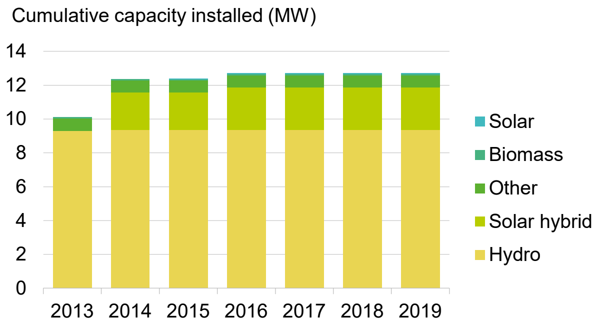


Figure 98

Uganda's installed mini-grids, by capacity



Source: BloombergNEF, Carbon Trust, CLUB-ER, surveyed developers. **Note:** Operating projects without a specified commissioning year are not included.

velopment (GIZ), launched a bundled tender mechanism with a goal of installing 40 mini-grids. The target date of project completion is December 2020.

11.2 Distributed power market structure

In 2001, the Uganda Electricity Board (UEB) was split into three parastatal entities: the Uganda Electricity Generation Company Limited (UEGCL), the Uganda Electricity Transmission Company Limited (UETCL) and the Uganda Electricity Distribution Company Limited (UEDCL) (Figure 99).

In 2003, UEGCL subleased its generation operations to a subsidiary of the South African state-owned utility Eskom. Responsible for operating and maintaining generation assets, Eskom is now the largest generation entity in Uganda.

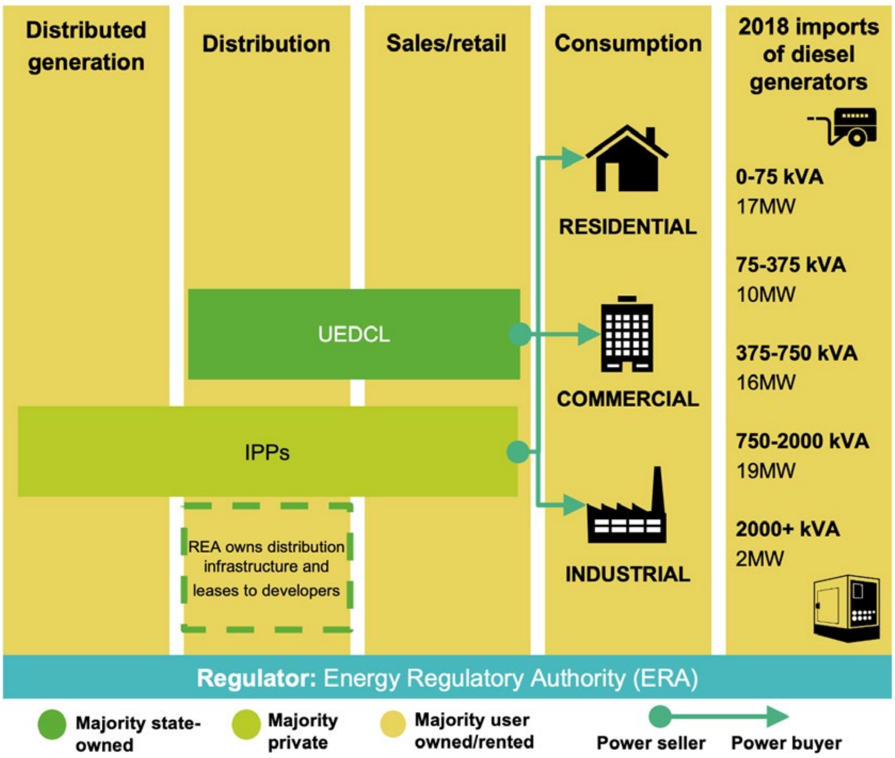
Similarly, in 2005, UEDCL awarded a 20-year concession for distribution and retail to the Ugandan energy distributor Umeme. Umeme was formed in 2004, and currently distributes 98 percent of all grid electricity consumed. Outside Umeme's control area, various private distribution companies operate government-owned assets in seven service territories. UEDCL operates assets in the six remaining territories.

In Uganda, utilities, private companies, communities, or some combination of the three operate mini-grids. Generally, a private-sector player develops and operates the mini-grid, owning the generating asset and bearing the cost of construction. Today, seven independent power producers (IPPs) operate mini-grids in the country, including the firms Equatorial Power and Pamoja Energy. UEDCL also runs a small number of mini-grids (Anton Eberhard, 2016).

The Electricity Regulatory Authority (ERA) is the primary regulator of Uganda's mini-grids. It administers licence approval, sets tariffs and maintains technical standards. The REA has no direct regulatory authority over mini-grids, but ERA consults

Figure 99

Uganda's distributed power market structure



Source: BloombergNEF.

with REA for reviews and approvals. REA finances and owns the distribution infrastructure of mini-grids through the Rural Electrification Fund (REF), leasing assets to private mini-grid developers (Nygaard, 2018).

11.3 Current market status

Uganda's renewable-hybrid mini-grid market is less mature than those in neighboring Kenya and Tanzania both in terms of the number of projects completed and the number of players operating. Uganda has 34 installed mini-grids that serve approximately 20,000 households. That's less than 1 percent of the 7.3 million households in the country.

Solar and hydro make up the vast majority of projects in Uganda – 40 percent and 34 percent respectively (Figure 100). Almost 70 percent of the projects are privately-owned while over a quarter are owned, operated and managed by local communities (Figure 101).

A number of private developers are currently operating in Uganda's mini-grid market or plan to enter soon (Figure 102). In interviews with the authors, developers said Uganda lacked adequate regulations and experienced local labour. They also highlighted the complex processes for land rights acquisition. Despite this, however, they are examining opportunities in the country's most isolated areas such as the islands in Lake Victoria. Already, Bugala Island has a 1.6MW solar hybrid mini-grid to serve its 30,000 inhabitants. Kalangala Infrastructure Services (KIS) operates the project under a public-private partnership with the Government of Uganda, the government-funded InfraCo Africa, and the private infrastructure developer EleQtra.

Financial support for projects operating in Uganda today has come almost entirely from development financing institutions (DFIs) and donor agencies. Most of the funding has been grant-based with a small portion coming via equity investment. Developers have yet to access loans from commercial lenders as their business models fail to meet the 7–10-year tenors banks require (Sustainable Energy for All, 2019).

The mini-grid tender launched by REA in 2017 has the potential to be a game-changer for the local market for solar hybrid projects. Under the scheme, bidders were shortlisted at the end of 2018. Since, Winch Energy and WeLight Africa have been selected to install their projects by December 2020.

11.4 Policy and regulations

Historically, the Ugandan government has prioritized grid extension over distributed energy in its long-term electrification policies. In 2013, the government released its Rural Electrification Strategy and Plan (RESP), which called for 26 percent rural electrification by 2022. Specifically, REA said it

Figure 100

Uganda's installed mini-grids, by technology

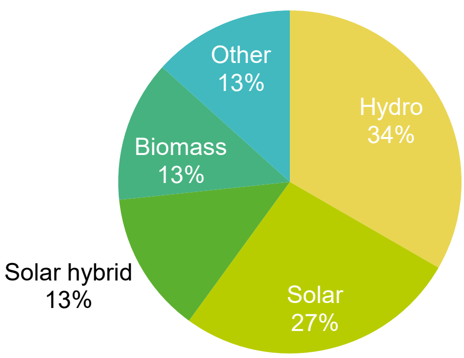
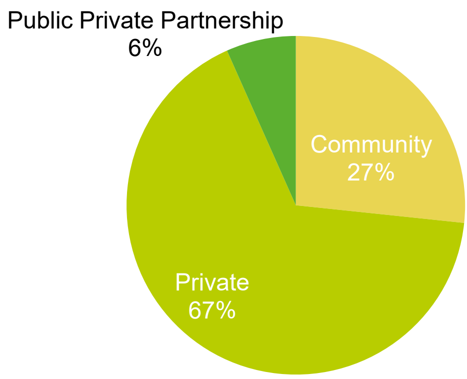


Figure 101

Uganda's installed mini-grids, by ownership



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, surveyed developers.

Figure 102

Mini-grid developer landscape in Uganda

Source: BloombergNEF, company logos.

would extend the grid to connect an additional 1.28 million households. By contrast, 8,500 households would receive service from mini-grids with 130,000 solar home systems also to be installed to meet the target. Under RESP, on-grid electrification efforts represented 91 percent of the projected total cost of USD 952 million. Only 6 percent of the total was allocated for off-grid energy technologies.

More recently, however, the government's thinking on distributed energy has evolved to the point where it recognizes that over-emphasizing grid infrastructure will leave the majority of the rural population without electricity access. Released in 2018, the Electricity Connections Policy sought to address the low connection rates, which earlier policies were unable to improve. It recognized the high connection charges, high wiring costs for households and a lack of incentives to achieve electricity access under a plan aimed primarily at grid expansion. The new policy also aligned targets in earlier policies, aiming to achieve 30 percent national electrification by 2020, 60 percent by 2027 and 80 percent by 2040 (Ministry of Energy and Mineral Development, 2018)[16] (Figure 103 and Figure 104).

16 A 30 percent national electrification rate by 2020 was set out in the Second National Development Plan, and an 80 percent target by 2040 was set in Uganda Vision 2040.

The authors expect that the 2020 national electricity access target of 30 percent will be achieved thanks largely to rapid distribution of off-grid solar kits. However, reaching the 2022 target is unlikely without further scaling of decentralized energy technologies given that just 10 percent of the rural population in Uganda had access to electricity at the end of 2018.

Mini-grid regulations

Inadequate regulations represent the biggest bottleneck to mini-grid development in Uganda by fundamentally undermining investor confidence. Appearing to recognize this, the government has been working in consultation with the German government on developing a more enabling environment for mini-grids, for example the previously mentioned tender scheme.

Licensing

Licensing is one of the biggest hurdles to mini-grid development in Uganda. According to the Electricity Order (ERA, 2007), off-grid mini-grids smaller than 2MW are exempt from any licensing requirements. In reality, however, a certificate of exemption for each project from the ERA is still required. Securing such an exemption can be a lengthy process taking a year or longer.

Figure 103

Uganda's national electrification rate and associated targets

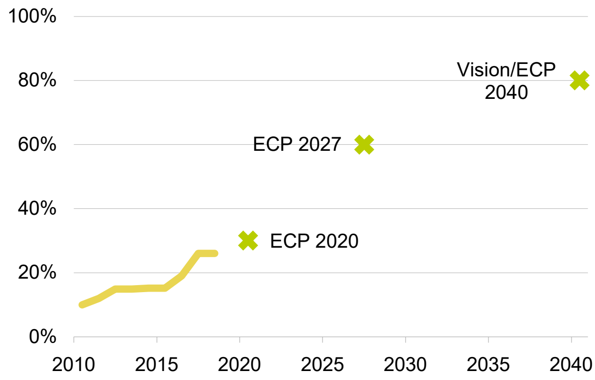
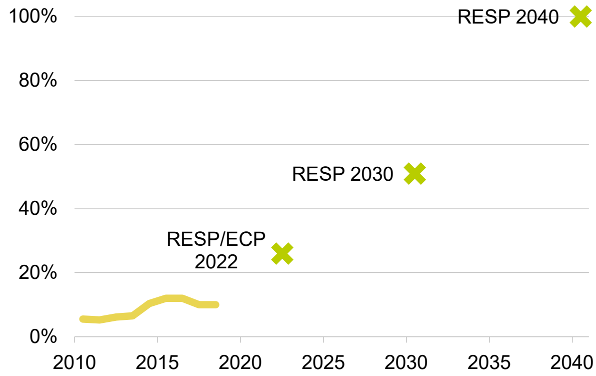


Figure 104

Uganda's rural electrification rate and associated targets



Source: BloombergNEF, Climatescope 2019, Rural Electrification Agency, National Planning Authority.

Developers must complete feasibility studies and acquire approvals from the National Environmental Management Authority (NEMA) for any site. They must submit environmental reports to NEMA for review with ERA having no role in that part of the process. After submitting these reports, developers can apply for a licence exemption that costs USD 3,500. Only those granted exemptions then have exclusive rights to generate, distribute and sell electricity in the given area (USAID, 2017).

Mini-grid on Kitobo Island, Lake Victoria

A project commissioned in Uganda in 2016 highlights the inherent challenges of operating a mini-grid when tariff rates are relatively regulated and power demand is both limited and uncertain.

Italian developer Absolute Energy operates a mini-grid on Kitobo Island consisting of 230kW PV, 520kWh vanadium redox flow batteries and a 70kVA diesel generator to serve its 2,000 inhabitants. The island is one and a half to three hours by boat from the nearest largest city of Entebbe. ERA granted Absolute Energy a framework concession for over 23 islands and a licence exemption.

Under the current regulatory tariff environment in Uganda, mini-grid developers cannot set cost-reflective tariffs. This is primarily because the regulator seeks to shield consumers from high electricity bills. On Kitobo, Absolute Energy has charged UGX 903 (USD 0.2675) per kWh, a rate determined by the regulator after negotiation. A 50 percent capex subsidy equivalent to USD 0.2675/kWh was granted. In contrast, the authors estimated the levelized cost of electricity (LCOE) to be USD 0.86/kWh – more than triple the tariff.

In addition, the output from the Kitobo project at times went largely to serve a single customer – a nut-grinding machine, which requires 22kW to operate but does not run full-time. The result was strain on the mini-grid at the times when the grinder operated. As of September 2017, Absolute Energy and the local community had plans to install a water purification machine (5kW) and an ice machine (30kW) but these machines were not envisaged to run at the same time. This suggests that it is not easy to manage load at a lower cost of electricity even when there are only very few demands centred on the mini-grid.

Above 2MW, developers of stand-alone and grid-connected mini-grids must obtain licences for generating, distributing and selling electricity. This licensing process is unpredictable, opaque and time-consuming, according to market participants. Developers say there is lack of clarity on documents required and on how the licence approval process actually works (USAID, 2017). Developers receive no provisional development rights during the review, adding further uncertainty.

Mini-grid tariffs

Mini-grid developers can propose tariffs higher than on-grid alternatives to the ERA for review. However, in response, the ERA can amend the proposed tariffs to come closer to matching prices paid on the grid of approximately USD 0.20/kWh. This may be particularly challenging for developers who find that the revised tariffs render their projects unworkable without subsidies. The REA funds distribution infrastructure via REF, and this covers both connection and house wiring costs. This serves to reduce project capex (REA, n.d.).

Arrival of the main grid

There are no clear rules in Uganda for how a mini-grid is to interact with the central grid in the future when the main grid gets built out to where a mini-grid is located. However, developers recognize that the grid is unlikely ever to get connected to where they have been operating on Lake Victoria. According to the Ugandan government, there are more than 100 inhabitable islands on the lake with 300–600 households each, and all will gain electricity access by mini-grids.

Tenders

The Uganda Ministry of Energy & Mineral Development (MEMD) leads the Promotion of Mini-Grids for Rural Electrification (Pro Mini-Grids) initiative with support from the German Federal Ministry for Economic Cooperation & Development (BMZ), the German Climate Technology Initiative (DKTI), the European Union and (GIZ). The initiative started in 2016 and is due to conclude in 2020. GIZ aims to spur private investment through assisting government and the private sector in four areas: policy and steering, regulatory instruments, technology and design, and productive use.

The Pro Mini-Grids initiative also includes a tender process launched in September 2017 that aims to ensure long-term quality of supply and accelerate private investment. Within the initiative, the tender mechanism is a government-led approach that bundles sites that developers can bid to serve. A simplified licensing procedure cut the time in half, to three months from the standard six. Using a least-cost electrification planning model developed by the Massachusetts Institute of Technology, the tender sought to estimate grid-extension costs versus mini-grid costs. The pilot phase aims to use this mechanism to provide power to up to 15 villages in the south of the country and 25 in the north. The winning bidders, Winch Energy and WeLight Africa, are eligible to receive a subsidy of up to 70 percent of the low-voltage distribution capex with the 10–year concession. Given that low-voltage distribution is typically 20–40 percent of the overall capex, the subsidy equates to a sizeable 14–28 percent of the overall capex. Interestingly, GIZ has stated that successful developers have been able to access debt financing due to the increased economies of scale and lower perceived risk.

Table 20

Uganda's licensing and tariff requirements for mini-grids

Generation capacity (kW)	Generation licence required?	Tariff approval required?
<100	No	Yes
100-2,000	No	Yes
2,000+	Yes	Yes

Source: BloombergNEF, Uganda Electricity Order 2007, Electricity (Application for Permit. Licence and Tariff Review) Regulations, 2007.

Section 12
Case study – Tanzania

Tanzania's renewable hybrid mini-grid market took off in the early 2010s, earlier than elsewhere in Sub-Saharan Africa, thanks primarily to robust regulations and international assistance. However, weak implementation of policies, rule changes and ambiguity about the role mini-grids play within the larger goal of improving energy access are making developers uncertain about the market's future.

12.1 Overview

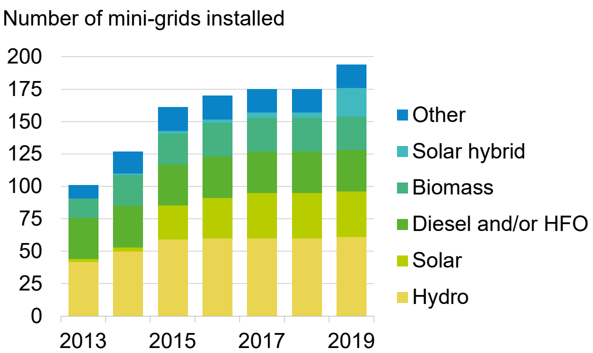
Tanzania has one of the lowest electrification rates in East Africa. At the end of 2018, one-third of the general population, and only a quarter of the rural population had access to power. The Tanzanian mini-grid market started developing earlier than others in Sub-Saharan Africa thanks to a well-designed regulatory framework, along with financial support from DFIs and donor agencies.

Today, Tanzania has 209 known mini-grids installed. With an aggregate capacity of 231,7MW, these projects account for about 15 percent of the country's total capacity of 1,461MW.[17] Of these projects, almost one-third are either solar or solar hybrid mini-grids. On a per-MW basis, renewable mini-grids are dwarfed by older hydro and diesel projects (Figure 105, Figure 106).

Market growth has slowed, however. Weak enforcement of existing regulations plus rule changes have made players wary of developing new projects. Mixed signals from the government are partly to blame. The Ministry of Energy and Minerals' latest long-range electrification strategy emphasizes grid expansion and large generation capacity building but leaves the role of mini-grids somewhat ambiguous (Ministry of Energy and Minerals, 2016). These factors might have contributed to the slowdown in project development over the past few years.

Figure 105

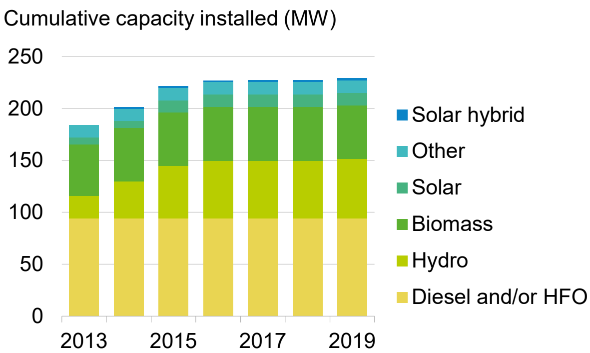
Tanzania's installed mini-grids, by projects



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, World Resource Institute, surveyed developers. **Note:** Operating projects without a specified commissioning year are not included.

Figure 106

Tanzania's installed mini-grids, by capacity



17 This excludes projects where either the operation year or project status was not specified.

12.2 Distributed power market structure

Tanzania's mainland power sector is dominated by the state-owned vertically integrated utility Tanzania Electric Supply Company (Tanesco). Tanesco owns most of the country's bulk generation directly. In the distributed segment of the power-generation market, however, private companies hold sway.

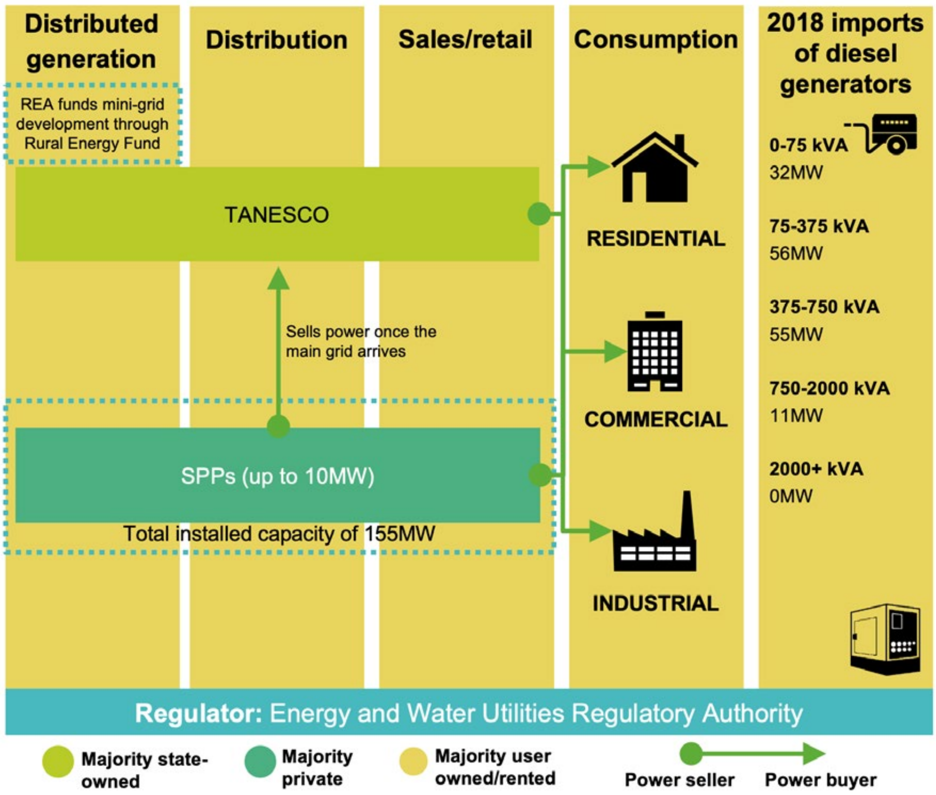
Tanzania's Small Power Producers Framework policy defines any project 10MW or smaller in size as a small power producer (SPP). The framework allows electricity from mini-grids to be sold directly to consumers, or to Tanesco if the central grid expands to where a mini-grid is operating. As of the end of 2018, there were nine registered SPPs serving off-grid communities.

The Energy and Water Utilities Regulatory Authority (EWURA) oversees technical and economic regulations in the power sector. It sets grid electricity tariffs and fixed tariffs paid to SPPs, develops guidelines and oversees licensing. Tanzania's Rural Energy Agency (REA) is the government's dedicated organization for electricity access and manages the Rural Energy Fund (REF). The REF is funded by international donor agencies, DFIs and the government via the annual budget and from commercial generation levies. It also provides financing to fund rural energy projects in the form of:

- Grants for feasibility studies up to USD 100,000 or 80 percent of the study cost
- Grants of USD 500 per household connection to distribution grids or mini-grids, or a maximum of 80 percent of the project's transmission and distribution costs
- Construction loans up to 85 percent for <3MW generation projects (70 percent for projects greater than 3MW).

Figure 107

Tanzania's distributed power market structure



Source: BloombergNEF.

12.3 Current market status

The mini-grid market in Tanzania took off earlier than in neighbouring countries. Favourable regulations and rural electrification programmes have attracted a diverse range of developers (Figure 108). The authors identified nine developers active in the market with Jumeme and PowerGen as the two largest in terms of the number of mini-grids installed.

After successfully developing projects in Kenya and Zambia, PowerGen began installing mini-grids in Tanzania in 2015. The organization will expand its portfolio further with a project financing deal it secured with CrossBoundary Energy Access (CBEA) and other financiers in July 2019. CBEA has an agreement with the Renewable Energy Performance Platform (REPP), managed by Camco Clean Energy, to finance an initial debt investment of USD 5.5 million to build 60 mini-grids in Tanzania (Rockefeller Foundation, 2019). In August 2019, PowerGen also acquired EON subsidiary Rafiki Power, which has built eight mini-grids ranging from 5kW to 50kW for customers in Tanzania.

Co-funded by the EU, solar hybrid mini-grid operator Jumeme aims to build 300 systems and serve 1 million people by 2022. In March 2019, it announced it was constructing 11 more mini-grids to serve more than 80,000 Tanzanians. These were commissioned in June 2019.

Devergy, a Tanzanian social energy utility, was founded in 2010 and began operating its first mini-grid two years later. The company installed an adaptive DC mini-grid system to supply 60 to 400 households with electricity. It sets up local kiosks where customers pay for use of electricity at daily, weekly or monthly rates via mobile money. As a complementary revenue stream and a way to boost household consumption, customers can also purchase DC-compatible and energy- efficient appliances from the kiosks. Devergy communicates with its mini-grids through wireless Internet communication systems that enable remote monitoring and control down to the individual household and meter level (USAID, 2018).

With both on-grid and off-grid projects throughout West and East Africa, German company Redavia rents solar hybrid mini-grid systems to household and commercial and industrial (C&I) customers. After a certain period and depending on the structure of the rental contract, customers have the option to own the system.

The government has recently stepped back on encouraging mini-grid development, and ap-

Figure 108

Mini-grid developer landscape in Tanzania

Source: BloombergNEF, company logos.

pears to be prioritizing grid expansion for electricity access. This has led to uncertainty among developrs around how the government recognizes the role of mini-grids in its rural electrification strategy, which has hindered growth and may lead to stagnation in the coming years. Some developers the authors spoke to stated that they may focus their efforts on expanding into other countries in the region.

12.4 Policy and regulations

As of the end of 2018, Tanzania's national electrification rate was 33 percent. In rural areas where two-thirds of the population resides, the rate was considerably lower at 23 percent (World Bank, n.d.). The Tanzanian government aims to have all 12,268 villages in mainland Tanzania electrified through grid expansions or off-grid renewable energy by 2021 (REA, 2017). This means that all public buildings, including schools, clinics and churches, will have access to electricity when the target is met, but not necessarily households. Overall, Tanzania has established robust regulations for mini-grids compared to other countries in Sub-Saharan Africa. However, recent actions have called the government's commitment into question with developers complaining of weak enforcement of regulations.

Rural electrification mechanism

The government designed its national electrification policy with international interventions in mind. Specifically, it developed the National Rural Electrification Programme (NREP) to proceed the country's participation in the Scaling-Up Renewable Energy Programme in Low Income Countries (SREP), administered by Climate Investment Funds (CIF).

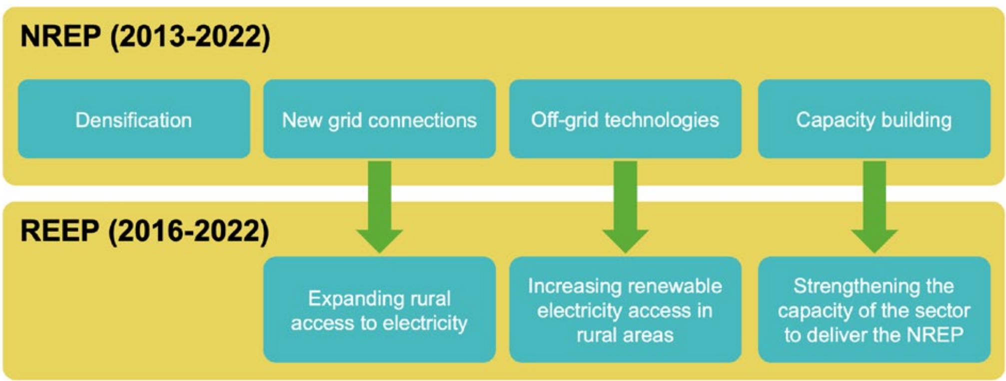
In 2016, the International Development Association (IDA), CIF and other development partners combined to provide USD 467 million in loans, grants and direct aid to implement the Rural Electrification Expansion Programme (REEP). The programme addresses three of the four electrification goals outlined in the NREP (Figure 109). As a result, it aims to connect 2.5 million rural households. REEP applied a *programme-for-results* mechanism that links the disbursement of funds directly to the delivery of defined results.

Results-based financing programmes

The REA has established a number of results-based financing (RBF) programmes to assist mini-grids to date. In its first programme, the REA disbursed USD 500 and USD 600 grants per new connection for a hydro mini-grid and a solar hybrid mini-grid respectively under the Tanzania Energy Development and

Figure 109

How Tanzania's Rural Electrification Expansion Programme (REEP) builds off its National Rural Electrification Programme (NREP)



Source: BloombergNEF, World Bank (2016).

Access Expansion Project (TEDAP) administered by the World Bank in FY2014/15.[18] As a result, USD 2.3 million was awarded to three hydro mini-grids connecting over 4,600 customers.

In 2016, the UK's Department for International Development (DFID) and the Swedish International Development Cooperation Agency (SIDA) financially assisted a new RBF programme. In its first call, REA dispersed grants for new connections of mini-grids based on the level of electricity service provided, with USD 600 per Tier 5 connection for grid-connected mini-grids, and USD 500 per Tier 4 connection as well as USD 300 per Tier 3 connection for isolated mini-grids (REA, 2016). In November 2019, REA announced the second call for applications to disburse grants for only Tier 4 and 5 connections (REA, 2019). In this call, SIDA was the only international donor agency to participate.

Mini-grid regulations

Tanzanian regulator EWURA has set relatively clear regulations around mini-grids. Through its Mini-Grids Information Portal, it provides regulatory information such as on licensing requirements and the process to obtain financial support. However, mini-grid developers reported to the authors of this report that regulations are not always enforced as promised, leading to confusion in recent years. In addition, recent regulatory changes have raised the hurdle for sub-100kW mini-grids, which now for the first time must receive tariff approval from EWURA. These elements could be part of the reason why market growth has levelled off in the last few years.

Small Power Producer Framework

Tanzania defines an SPP as a generation facility below 10MW that produces power from renewable or fossil sources, or has cogeneration, or is a hybrid system. SPPs can sell power to Tanesco's main grid or its isolated mini-grids. They can also sign Standardized Small Power Purchase Agreements (SPPA) directly with wholesale or retail customers (Public-Private Partnership Legal Resource Center, n.d.). Under this framework, projects receive a fixed tariff for the lifetime of the SPPA. Payments are invoiced in US dollars and may be adjusted to another hard currency subject to the mutual agreement of the parties to the SPPA. Tariff rules and licensing requirements are established based on project size (Table 21).

Tariffs

Developers can propose to EWURA a specific retail tariff structure (e.g., a flat tariff, time-adjusted tariff, or a combination of the two) for mini-grid projects below 100kW (Very Small Power Producers or VSPPs). However, if 15 percent of the households served by the mini-grid petition EWURA, the regulator undertakes a tariff review. EWURA then has the power to adjust the tariff for VSPPs if it deems it to exceed relevant cost-recovery levels. While this has the potential to worry developers, EWURA has reviewed few projects to date and has never adjusted tariffs (Electric Capital Management, 2019).

100kW-1MW mini-grids (SPPs) receive fixed tariffs for electricity, regardless of whether they sell to Tanesco's isolated grid or to the main grid. The tariffs are specified by technology and cost-reflective on paper as they are examined based on operating expendi-

Table 21

Tanzania's tariff and licensing requirements under SPP Framework after the 2018 rule change

Size (kW)	Generation licence required?	Tariff approval required?	Tariff structure flexibility?
<100	Yes	Yes	Yes
100-1000	Yes	Yes	No (fixed tariffs)
1000+	Yes	Yes	No (fixed tariffs)

Source: BloombergNEF, EWURA.

18 Tanzania's fiscal year starts in July (e.g., FY2014/15 = July 2014–June 2015).

tures, capital depreciation, interest expenses, and cash reserves for emergency maintenance and taxes.

Licensing

Prior to the 2018 rule change, any project below 1MW in size was exempt from licensing and only required registration with EWURA upon commissioning. Since the change, developers have been required to obtain licences for all projects. They have also had to demonstrate proof of government support, proof of an agreement with an off-taker to buy their power and obtain a number of other project development certificates (Figure 110). Developers regard this licensing procedure as cumbersome; it generally takes over a year to complete.

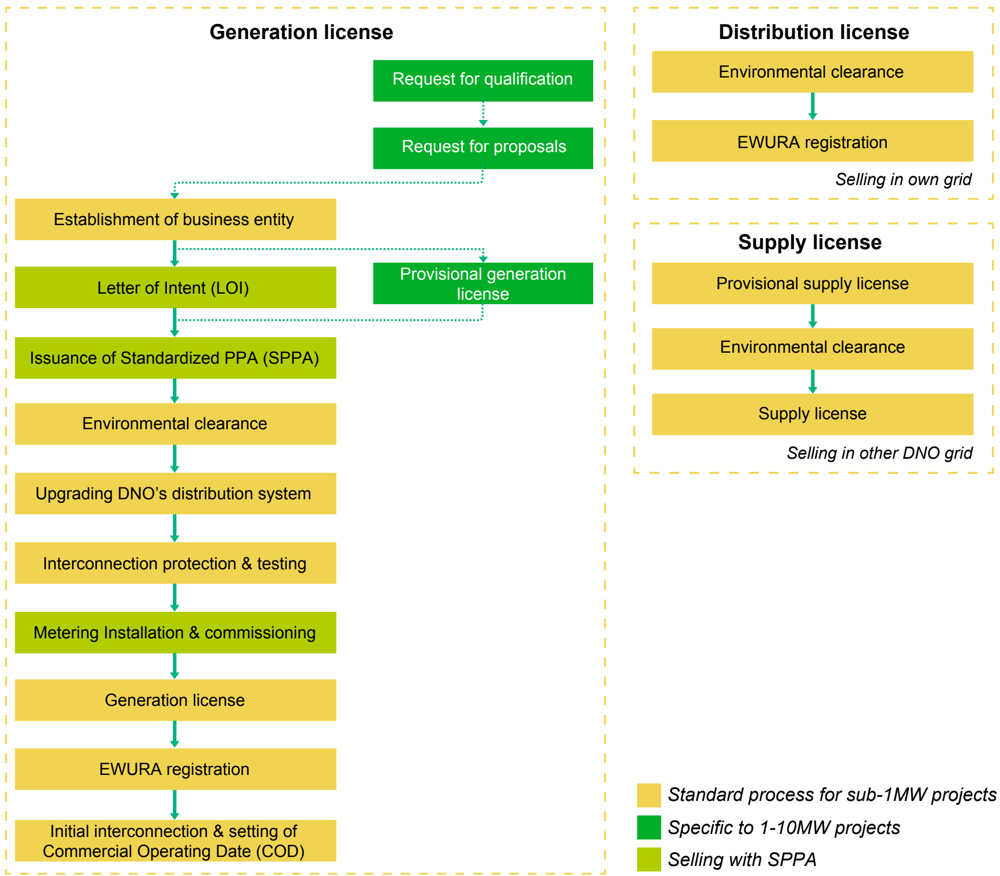
Grid arrival rules

By law, when the main grid expands sufficiently to arrive at a mini-grid, a VSPP, SPP or small power distributor (SPD) owner becomes eligible to receive compensation depending on how long the mini-grid has been operating, so long as specified conditions are met. An SPP developer is also eligible to sell electricity to the main grid. The applicable tariff for the connected mini-grid varies depending on whether the project's SPPA was executed before or after August 2015. If the execution is after then, the technology-specific tariff is applied (The United Republic of Tanzania, 2019).

Developers explained to the authors that grid arrival rules are not always enforced as promised. Negotiations are difficult with the state utility, which seeks to lower the tariff as much as possible. This perhaps reflects the fact that Tanesco is cash-strapped, partly due to the low grid tariffs it receives. Given the potential risk of being insufficiently compensated by Tanesco, some developers say they are specifically avoiding building mini-grids within 7–10km of the main grid.

Figure 110

Tanzania's mini-grid licensing processes



Source: BloombergNEF, Mini-grids Information Portal. **Note:** These licensing processes apply to solar-based mini-grids and vary slightly from those used for biomass and hydro projects.

Section 13
Case study – Nigeria

The Nigerian mini-grid market has in recent years generated growing interest from developers not just because of the size of its growth opportunities but because of its robust regulatory environment. A recently introduced results-based financing (RBF) mechanism showcased how governments elsewhere can potentially assist with bulk scaling and financing of mini-grids. The mechanism is straightforward, transparent and partially mitigates currency risk.

13.1 Overview

Nigeria has the largest population (200 million) and economy (USD 397 billion) in Africa. Only 36 percent of the rural population had access to electricity in 2018; nationwide the figure was 55 percent. Where the grid is available, consumers experience frequent power cuts ranging from four to 15 hours per day. Few interviewed by the authors hold out hope that expansion of the central grid planned for the next five years will dramatically improve the situation. Hence consumers seeking uninterrupted service will continue to be compelled to take matters into their own hands with distributed energy systems.

By the end of 2019, Nigeria's estimated installed mini-grid capacity was about 2.8MW, with 59 projects serving rural consumers. These are mostly residential-based mini-grids with some developed for specific productive uses. If fully commercial-served mini-grids are included, the number is expected to be significantly higher. Separately, Nigerians spent USD 16 billion in 2016 alone to fuel privately-owned diesel/petrol generators to meet the shortfall in demand.

Nigeria's failure to provide stable grid power has fertilized the ground for strong off-grid development. In 2017, the country introduced a mini-grid regulation managed by the Nigerian Electricity Regulatory Commission (NERC) supporting isolated and grid-con-

Figure 111

Nigeria's installed mini-grids, by project

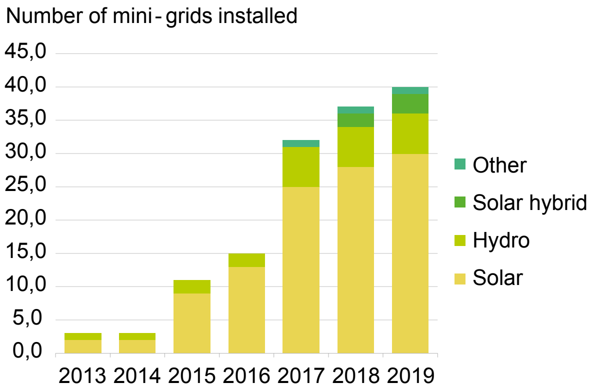
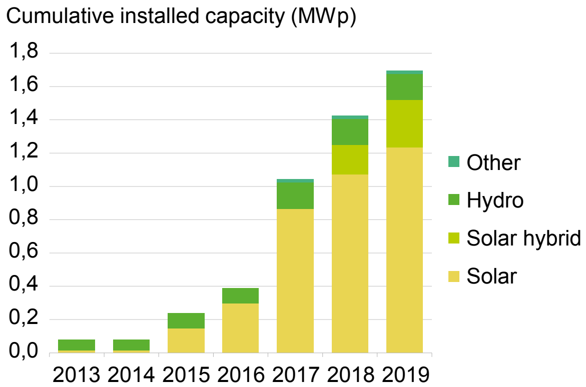


Figure 112

Nigeria's installed mini-grids, by capacity



Source: BloombergNEF, GIZ, Carbon Trust, surveyed developers. **Note:** Operating projects without a specified commissioning year are not included.

nected mini-grids between 100kW and 1MW in size. To operate, these must obtain mini-grid permits from the NERC. Mini-grids below 100kW must register with the NERC, but obtaining the permit is optional. If Nigeria's central grid is later extended to the site of the mini-grids, developers are to be paid for their depreciated assets plus any operating revenue generated over the prior 12 months.

These regulations are regarded as robust and have signaled the government's commitment to distributed energy systems. Developers have responded but most have pursued smaller projects because building projects above 1MW often requires time-consuming approvals (e.g., a generating company licence).

13.2 Distributed power market structure

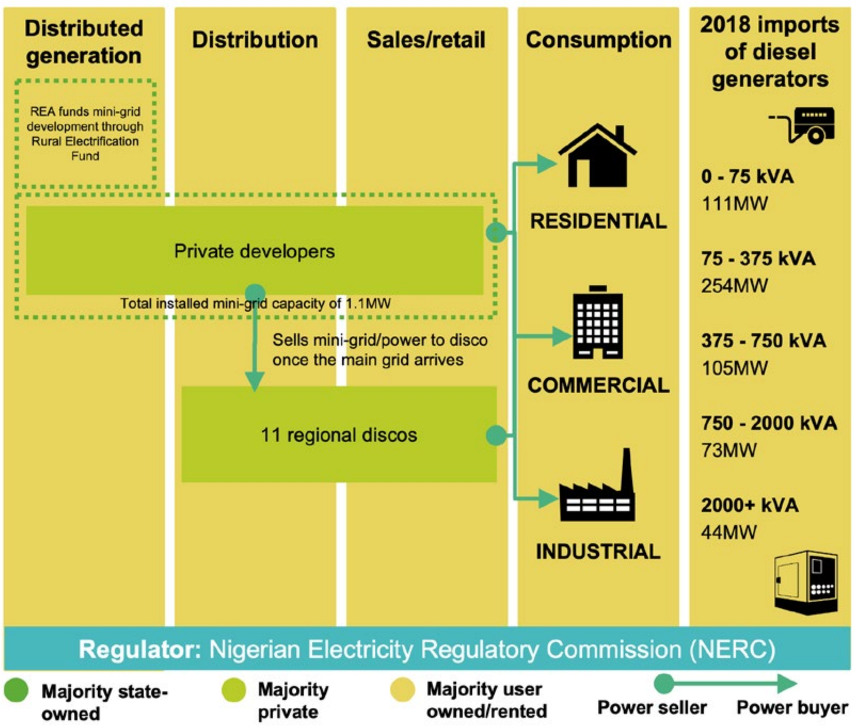
In Nigeria, private companies have installed and are operating the majority of mini-grids under public-private partnership models (Figure 113). They usually own the generation equipment and bear the capex, meaning they develop the project with their own (or shareholder) capital and agree an off-take agreement with the government or a community. Developers can establish isolated mini-grids and set their own tariffs so long as they hold mini-grid permits; in this process, the tariff must be approved by the NERC.

Nigeria has 11 distribution companies (discos) with load allocated by region – Abuja, Benin, Eko, Enugu, Ibadan, Ikeja, Jos, Kaduna, Kano, Port Harcourt and Yola. Each owns and operates distribution grid assets that include transmission lines (mostly 11kV/33kV cables), substations, meters and other distribution equipment. While the regional discos are privately owned and managed, only one is permitted to operate per region.

The NERC issues and monitors generation, transmission and distribution licences. It also issues mini-grid permits, and sets and reviews retail electricity tariffs based on the Multi-Year Tariff Order (MYTO)

Figure 113

Nigeria's distributed power market structure



Source: BloombergNEF.

policy. The Nigerian Electricity Management Services Agency (NEMSA) is charged with inspections and certifications of mini-grids, and inspections must take place in order for the NERC to approve the mini-grid permit. Nigerian developer GVE's mini-grids were the first to be inspected by NEMSA, and its projects were benchmarked against the grid code.

13.3 Current market status

In Nigeria, private-sector players primarily develop solar hybrid mini-grids with financial backing from DFIs and donor agencies. The mini-grid development sector is more crowded in Nigeria than elsewhere, reflecting the fact that the market has significant potential to provide electricity access and displace existing diesel generators, with 587MW of diesel generators imported into the country in 2018 alone (Figure 114).

The World Bank, the African Development Bank and Nigeria's Rural Electrification Authority (REA) have recently made major commitments to the country's mini-grids with a USD 550 million fund for the Nigeria Electrification Project (NEP) of which USD 220 million is dedicated to implementing an RBF programme through a performance-based grant (PBG) and minimum subsidy tender mechanism to help developers finance solar hybrid mini-grids.

The minimum subsidy tender process is part of the NEP, which aims to provide power to 300,000 homes and 30,000 local businesses in 250 locations across four states (Niger, Ogun, Sokoto and Cross-River states). The goal is to scale mini-grid adoption at the least cost (see the Policy and regulation section for more details). The World Bank and REA will select developers with the experience and capability to install mini-grids at lowest cost. Developers will then build a portfolio of projects at designated sites. The winning bidders gain access to the technical information of the sites through the REA and will be able to build up their mini-grid portfolio, which will help them secure financing for future projects.

The PBG programme selects developers who submit mini-grid proposals on a first-come, first-served basis and provides a fixed grant of USD 350 per new connection for their mini-grid (where each mini-grid may contain about 29 or more connections). In December 2019, PowerGen Renewable Energy Nigeria, a subsidiary of PowerGen commissioned a solar hybrid mini-grid including 64kW PV with 360kWh batteries in Rokota community, Niger state, reaching 3,000 people. This is the first project to be commissioned under the NEP. PowerGen Nigeria plans to develop nine more projects under the NEP programme.

GVE, Nigeria's largest mini-grid developer that is also taking part in the NEP, already has a portfolio of 14 mini-grids in operation with a combined installed capacity of 589kW of PV and 4,200kWh of lead-acid batteries. It has 395kW of PV with 670kWh of lithium-ion batteries currently under construction. GVE

Figure 114

Mini-grid developer landscape in Nigeria

Source: BloombergNEF, company logos.

invested some USD 4 million in mini-grids in Nigeria between 2013 and 2019. As part of the *Energizing Economies* programme, GVE has recently signed a deal to develop a 1MW commercial renewable hybrid mini-grid project to provide power to the Wuse market in Abuja. The full list of participants in the NEP was not yet known at the end of 2019.

A few private financiers are active in Nigeria today. NEoT Offgrid Africa, an investment platform launched by France-based NEoT Capital and EDF in 2017, aims to invest hundreds of millions of dollars in distributed renewable energy projects in Africa through late 2021 (NEoT Capital, 2017). NEoT Offgrid Africa invested an undisclosed amount in Rensource's special purpose vehicle, Sabon Gari Energy Solutions. The investment was used to develop a mini-grid project consisting of 1.3MW of PV to supply reliable electricity to 12,000 shops in the Sabon Gari Market in Kano, the second-largest city in the country (Rensource, 2018).

In the commercial mini-grid segment, Rensource, a three-year-old off-grid solar energy firm, has raised USD 20 million in a Series A round equity funding jointly led by African venture capital fund CRE Venture Capital and impact investor the Omidyar Network in December 2019. The round also saw participation from Inspired Evolution, Proparco, EDPR, I&P, Sin Capital, and Yuzura Honda. Rensource's funding round follows sustained investor interest in Africa-focused off-grid and renewable energy start-ups seeking to plug electricity gaps. In June 2019, Arnergy, another solar mini-grid company, also raised USD 9 million in its Series A round equity funding .

Commercial banks have thus far been largely absent from Nigeria's mini-grid market. Developers regard commercial bank debt as too costly and too inflexible, with interest rates offered of reportedly over 25 percent and tenors lasting just two years, at best. There is no project financing product available in Nigeria allowing vendors to borrow solely against predictable cash flows, which is why it's good to see PowerGen Nigeria in the picture, since it managed to secure project finance debt in Tanzania. Instead, local banks require developers to provide physical assets as collateral. Even then, lenders tend not to accept solar equipment as collateral but instead require that borrowers own real estate that can be used for that purpose.

As a result of all of the above, developers have to date mostly financed projects off their own balance sheets, either in US dollars for multinational corporations or in Nigerian naira in the case of local developers. The Nigerian Bank of Industry (BOI) is the only institution able to provide naira-denominated financing for mini-grid developers under its '6 billion naira' solar fund.

13.4 Policy and regulations

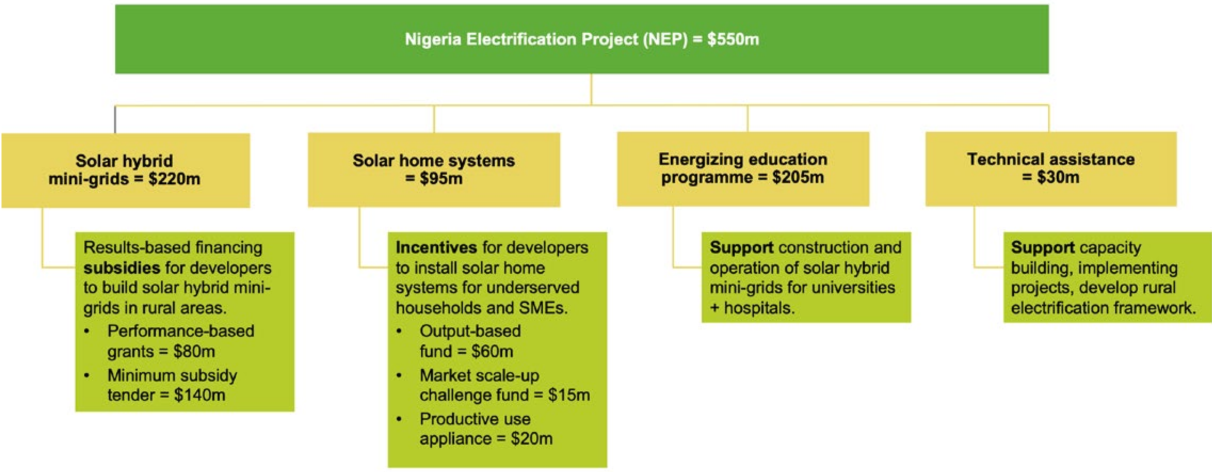
A turning point for Nigeria's mini-grid sector came with the ratification of a key regulation for Mini-Grids in May 2017. The new rule issued under Section 70 (8) of the Electric Power Sector Reform Act (EPSRA) sought explicitly to enhance private-sector electricity access activities.

At the end of 2019, NERC developed a web-based tool to streamline the mini-grid registration process for developers and released a downloadable simplified MYTO Excel-based model to help developers determine what cost-reflective tariffs to charge end-users. While many developers have in-house tools to make these calculations, they still found it reassuring to see the regulator take such a modern approach. Moreover, the downloadable mini-grid MYTO model allows developers to verify their own tariffs. This increases transparency and the chance that a proposed tariff will receive approval. Typically, the tariff a developer submits to the NERC must be in line with the mini-grid MYTO tariff calculator. If it is not in line with the NERC tool, developers must provide a valid reason for the difference when seeking mini-grid permit approval.

The World Bank issued a USD 350 million loan to the Federal Ministry of Finance to implement the five-year programme known as the Nigeria Electrification Project (World Bank, 2018). The programme consists of four components (Figure 115); its goal is to increase access to electricity services for households, public educational institutions and micro, small and medium enterprises throughout Nigeria.

Figure 115

NEP Overview



Source: BloombergNEF, REA.

In March 2020, the African Development Bank (AfDB) and Africa Growing Together Fund (AGTF) agreed to jointly provide USD 200 million for the NEP (AfDB, 2020). The fund focuses on helping the REA achieve its 100 percent electrification (or universal energy access) target by 2030 and help de-risk and scale-up private sector investment. The fund is focused on both mini-grid and other off-grid solutions. Combining this with the USD 350 million commitment from the World Bank brings the total commitment to USD 550 million for the NEP.

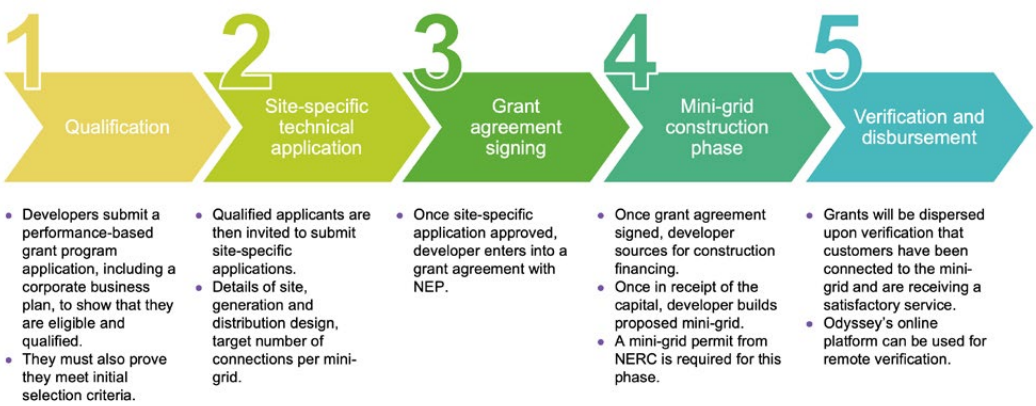
Results-based financing

Performance-based grant (PBG) programme

Nigeria achieved another important milestone when it launched an RBF mechanism for financing new solar hybrid mini-grid projects in 2018 within the NEP. The PBG programme aims to close the viability gap for mini-grids developed on a spontaneous basis. Grants of USD 350 per new connection are available on a first-come first-served basis, with a minimum total grant request of USD 10,000 per mini-grid (with about 29 connections per mini-grid at minimum). Isolated solar hybrid mini-grids are eligible for the grants, but grid-connected projects are not.

Figure 116

Overview of PBG process



Source: BloombergNEF, REA.

Developers need to carry out geospatial studies, energy audits and community surveys to select their proposed viable sites. The grants are available for qualified projects on a rolling basis until the funds are exhausted. Figure 116 gives an overview of the five phases of the PBG programme, from qualification to grant disbursement.

The PBG programme aims to help developers raise other sources of financing over the capital markets. Given these grants are denominated in US dollars, this also enables developers to source for US dollar-denominated financing as this partially mitigates risk for the lender, be it debt or equity. As a potential financing strategy, more risk-averse lenders can even cap the percentage of the construction capex they are willing to finance at the timing of post-construction payout of the grant as a percentage of the overall capex.

If successful, the programme has the potential to be a game changer and similar mechanisms could be rolled out across Sub-Saharan Africa.

Minimum subsidy tender programme

Separately, the World Bank and the REA are planning to implement minimum tenders to install 250 new mini-grids at least cost. The REA initially screened 2,000 sites, then narrowed them to 250, filtering projects out by choosing sites with a larger number of inhabitants, more economic activity and nearby infrastructure. The programme has two phases:

- Tender for 57 sites across four states: Niger, Sokoto, Ogun and Cross River.
- Scale-up to complete construction of the 250 sites across these four states, potentially adding more states in this phase.

Winning bidders of the minimum subsidy tender programme can potentially claim grants of more than the fixed USD 350 per connection that the PBG programme offers. However, the tender aims to drive this figure lower, if at all possible, although it may be higher depending on competition.

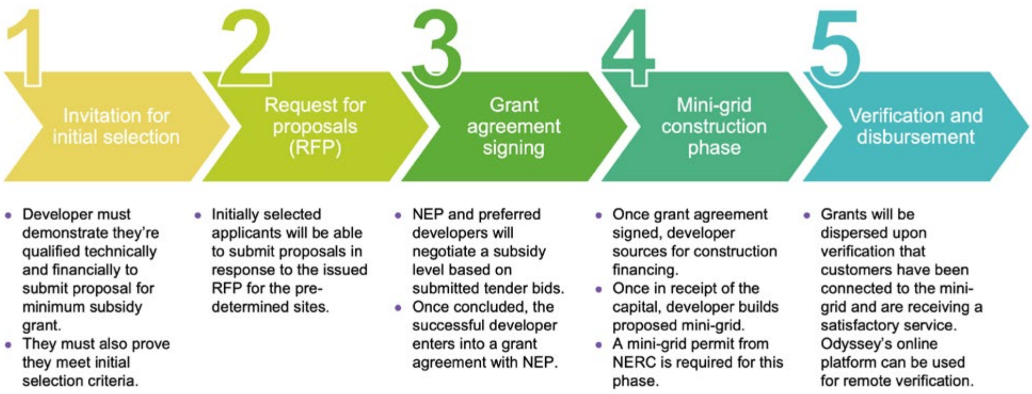
As of October 2019, the original list of 64 developers had been culled to 16. Five or six who can build mini-grids at the pre-selected sites at lowest grant cost per new connection will be awarded contracts.

Each winning bidder will have access to a database that includes technical information about each of the 250 sites to help them develop site-specific business models. These developers will need to develop multiple mini-grids (potentially 40–50 per developer) and will still need to raise capital from the financial markets, be it debt or equity.

Figure 117 shows the overall process of the minimum subsidy tender process. As with the PBG programme, once developers have built their mini-grids and connected their customers, the grants will be disbursed upon verification that customers have been connected to the network and have been provided satisfactory service (PV magazine, 2019).

Figure 117

Overview of minimum subsidy tender process



Source: BloombergNEF, REA.

Comparing the PBG and the minimum subsidy tender programme

While developers will always receive a fixed USD 350 per new connection in the PBG programme, the amount of the grant can be above or below USD 350 per new connection under the minimum subsidy programme. For example, if all bidders bid USD 500 per connection, the REA would need to increase the subsidy by USD 150 per connection above the PBG level. If the winning bid prices are below USD 350 per connection, the REA would successfully minimize the cost to install mini-grids.

In both cases, the grant typically is to be paid out three months after the project is commissioned and developers can prove to the REA that the end-users are receiving reliable power from their mini-grids.

Nigerian developers informed the authors that they prefer the minimum subsidy tender since the 250 sites are already defined for them, reducing upfront project development costs. All the developers need to do is to validate the information that the REA has given them regarding the pre-determined mini-grid sites. All project technical data for the REA's pre-determined sites are available on Odys-

Table 22

PBG versus minimum subsidy tenders

Key criteria	Performance-based grants (PBG)	Minimum subsidy tenders
Budget	$80m	$140m
Location	All 36 states, developer to submit proposed sites.	250 sites in five states designated by REA.
Subsidy per connection	Fixed at $350 per new connection.	More or less than $350 per new connection. Developers submit their bids to meet their hurdle IRRs.
Mini-grid development experience	Proof of designing and building at least one mini-grid of 10kW or larger within the past five years that is still operational.	Proof of two mini-grids of 10kW or larger.
Mini-grid operation experience	Proof of operating one mini-grid of 10kW or larger within the past five years, not necessarily continuously. The mini-grid needs to be still operational.	Proof of two mini-grids of 10kW or larger.
Experience in raising debt/ equity financing	Experience of securing finance of amount of $100,000 or larger, or naira equivalent, in equity, debt or both, for at least one infrastructure project in the past five years.	Proof of minimum $5m is required for at least two infrastructure projects.
Liquid assets	Total assets must exceed liabilities for past two years.	Minimum of $1m or its naira equivalent in liquid assets in financial statements.
Nigerian-registered business	Registered with the Corporate Affairs Commission and must have a certificate of incorporation in Nigeria. These need to be done prior to signing a grant agreement.	Same as PBG.
Registered taxpayer	Registered with the Federal Inland Revenue Service (FIRS) with a valid Tax Identification Number (TIN) through which deductible taxes shall be remitted to the Federal Government of Nigeria.	Same as PBG.
Qualified staff	Demonstrate a qualified team (with CVs) dedicated to environmental and social risk management.	Same as PBG.

Source: REA.

sey's NEP platform (discussed below). Table 23 lists key differences between the two RBF programmes.

While the minimum subsidy tenders cover only four states (Sokoto, Ogun, Niger and Cross River states), the PBG does not specify locations, hence, diversifying risk. This may even suit the developers' current business operations/plan. It is possible for developers to submit applications for both the PBG and the minimum subsidy tender programmes at the same time, which may increase their chances of receiving subsidies.

Mini-grid acceleration schemes

Mini-grid acceleration scheme (MAS) – isolated projects

The REA announced the results of a separate mini-grid acceleration scheme (MAS) on 20 October 2019 (Odyssey, 2019). The government agency stated that: "*MAS is a nationwide, non-site-specific, open competitive tender designed to select mini-grid companies.*" It also noted that: "*The winners of the tender will be supported in deploying their proposed mini-grid projects with an in-kind partial capital grant – in the form of distribution and metering equipment – and technical assistance.*" The successful bidders were Nayo Tropical Technology, Havenhill Synergy Ltd., GVE Projects Ltd. and ACOB Lighting Technology Ltd.

Odyssey partnered with the Nigeria Electricity Sector Programme (NESP) to host the MAS tender, which aims to promote productive-use business models for mini-grids electrifying 21,000 connections including residential, public, commercial and productive users at an affordable tariff by the end of July 2020.

The scheme is implemented by the REA, championed by the Federal Ministry of Power (FMP) and supported with EU funds plus backing from the German government via its Nigerian Energy Support Programme (NESP), implemented by the German Agency for International Development (GIZ). The REA did not state how many mini-grids will be developed by the winning bidders but the call for the tender concerned construction of "*isolated mini-grids up to 1 MW*" in generation capacity.

Once built, the mini-grids supported by the programme will be operated on a commercial, public-private partnership basis. By the end of 2020 some of Nigeria's remote rural and underserved communities will have access to reliable, clean electricity at an affordable tariff that, according to the REA, would have been economically unviable without the scheme.

Interconnected mini-grid acceleration scheme (IMAS) – grid-connected projects

The interconnected mini-grid acceleration scheme (IMAS) proposal call went out in May 2019 and applications were accepted up until 14 August 2019, the deadline set by the REA. Similar to the MAS (above), the IMAS is a nationwide non-site-specific open competitive tender and targets developers who can build a sustainable business model to provide stable electricity to grid-connected but poorly-served communities in Nigeria (a minimum of 15,000 customers), where such projects would have been unfeasible without the IMAS.

The difference between the two schemes is that in the IMAS, developers were invited to submit proposals to design, construct, commission and operate an interconnected solar-based mini-grid of up to 1MW on a commercial public-private partnership, partnering directly with the interested distribution company. The winners of the tender will be supported in deploying their proposed interconnected mini-grid projects with a partial capital grant (in the form of procured distribution and metering infrastructure equipment) and technical assistance.

In 2019, as proof of concept, the Nigerian government partnered with the Kaduna disco and Torankawa community in Sokoto state to build a 60kW PV hybrid mini-grid with 216kWh batteries and a 100kVA diesel generator . The project consisted of 4 kilometres of local distribution wires and 335 smart meters and was designed to operate as a grid-connected or isolated mini-grid, serving some 350 households and 20 small businesses. This was a government-funded project that was able to provide uninterrupted power with 0 percent collection loss using pre-paid meters. For its first commercial interconnected mini-grid, the private company Nayo Tropical Technology has partnered with the Ibadan disco in Mokoloki, Ogun state to develop a 180kW PV hybrid mini-grid containing 144kWh of lead-acid batteries and a 62kW backup diesel generator . It is designed to serve up to 200 households, 28 small businesses and eight public institutions with a peak demand of 55kW. The project will be the first commercial tripartite contract where the mini-grid operator will pay a distribution usage fee to the disco.

On 3 April 2020, the REA announced the results of its IMAS tender (Table 23) and bidders (i.e., developers) were selected to partner with the seven discos listed. The REA aims to get these projects online by the end of September 2020, providing end-users with affordable electricity tariffs. This date may be impacted by the coronavirus pandemic.

Web-based REA data hub

Odyssey created an official web-based NEP hub that enables an efficient project evaluation process and data-driven decision making. Odyssey built the tool to manage data for thousands of feasibility studies. Developers and the REA use it to verify and track all connections installed under the NEP and project performance remotely, aiming to minimize the administrative costs associated with running the NEP. It is also used to support the MAS and the IMAS. The Odyssey platform enables developers to:

- Generate forecasted load profiles and simulate generation system sizes, optimized distribution designs for hundreds of potential mini-grid sites using the Homer Pro plugin.
- Run data queries and analytics across hundreds of mini-grid projects to understand customer loads and cost trends.
- Create more comprehensive proposals modelled via third-party tools such as HOMER Pro.
- Align commercial investors on the platform to help developers reach financial close.
- Streamline evaluation of project proposals in the tendering programmes and make evaluation transparent.
- Monitor performance of the projects after construction.

Licensing

Nigeria allows private companies to build projects and sell electricity to customers. Its regulations define mini-grids as being 1MW or smaller and either isolated or connected to the main grid. For an independent power producer (IPP) to supply electricity to two or more neighboring businesses/households using a mini-grid 100kW to 1MW in size, it must secure a mini-grid distribution permit from the NERC regardless of grid-connection status. For sub-100kW projects, a permit is optional. Steps required for permits vary slightly according to the size of the mini-grid and whether it is connected to the main grid or isolated (Table 24).

Isolated mini-grids

Isolated or off-grid mini-grids have been defined by Nigerian regulators as falling into two specific size categories: sub-100kW and 100kW–1MW. A

Table 23

Results of Nigeria's IMAS tender

Regional disco partner	Developer/Winner
Abuja disco	GVE Projects Ltd
Benin disco	Rubitec Solar
Ibadan disco	Nayo Tropical Technology
Ikeja disco	A4&T Power Solutions
Jos disco	ACOB Lighting Technology Ltd
Kaduna disco	Sosai Renewable Energies
Port-Harcourt disco	Darway Coast Nigeria

Source: REA, Nigeria.

Table 24

Steps required for permits for <1MW Nigeria mini-grids

How to get a Nigerian mini-grid permit?	Inter-connected	Isolated Mini-grids	Isolated Mini-grids
Intended mini-grid capacity	**≥ 100 kW**	**≥ 100 kW**	**< 100 kW**
Is a permit required?	**Yes**	**Yes**	**No**
Identify eligibility of unserved area	1	1	1
Contact community for operating agreement	2a		
Contact disco for operating agreement	2b		
Sign exclusivity period agreement with community	3a	2	2
Sign exclusivity period agreement with disco	3b		
Sign and register tripartite contract	4		
System design (i.e. mini-grid specs)	5	3	3
Sign commercial agreement with community	6a	4	4
Sign commercial agreement with disco	6b		
Acquire land and necessary building approvals	7	5	5
Apply to NERC for operating permit for intended area	8	6	
Construct, test then commission mini-grid	9	7	6
Register mini-grid with NERC			7
Submit two copies of supporting documents to NERC		8	
Number of key steps	12	8	7

Source: BloombergNEF, Rural Electrification Agency. Grey means step is 'not required'.

sub-100kW mini-grid can opt for either a registration with NERC or for a mini-grid permit. A permit is generally more desirable than a registration certificate as it confers on the operator the right to compensation when the main grid arrives at the site (i.e., there is no compensation if the project is just registered). To qualify, however, the project must adhere to minimum network technical and safety standards defined by the NEMSA. If the main grid gets built out by the regional disco to reach the mini-grid site, the operator can either:

- Convert the project into an interconnected mini-grid, or
- Transfer the asset to the disco and get paid in return.

These options mitigate the risk for developers.

Projects of 100kW–1MW are legally required to have mini-grid permits from the NERC before starting operations. Without an approved mini-grid permit, projects have no guaranteed protections should the central grid expand into their territory.

Interconnected mini-grids

While some mini-grids are built in remote areas lacking central grid access and then encompassed by the central grid when it is expanded outward, others are built from day one adjacent to the central grid. These interconnected mini-grids are linked to the regional disco but deliver power to areas where power delivery is particularly challenging. In these cases, developers must enter tripartite contracts with the local community to be served and the disco. The tripartite contract must then be approved by the NERC to be official. Developers must also secure mini-grid permits.

Interconnected mini-grids are targeted at communities classified as 'under-grid', that is, grid-connected but with frequent/lengthy outages and usually relying on expensive diesel/gasoline gensets to meet demand during outages. The proven ability to pay for expensive fuel to meet demand is what really differentiates them from the isolated mini-grids where residents may not necessarily need or be able to pay for power.

Above 1MW projects

If the mini-grid exceeds 1MW in generating capacity, the developer must secure an Independent Electricity Distribution Networks (IEDN) licence (Table 25). Mini-grid developers in Nigeria with projects whose capacities exceed 1MW must hold NERC generation company licences. The mini-grid regulation does not protect these projects.

Tariffs

Before the mini-grid regulation was ratified, the mini-grid tariff structure was unregulated, whereby the mini-grid developer can charge whatever the customer is willing to pay for their power.

NERC developed a downloadable Excel-based tool (made available in 2019) to help developers and communities agree on reasonable cost-reflective tariff rates mini-grid developers should be charging end-users. The downloadable mini-grid MYTO tariff calculator allows developers to input all their cost assumptions, customer load, grants etc into the model and get a tariff that they should be charging. If for some reason the developer's internal (proprietary) mini-grid tariff model is not in line with this (above the MYTO tariff calculator), they need to provide a clear justification for why the tariff is different to NERC before submitting the application. Typically, if 60 percent of the potential customers in a community agree to a tariff proposed by the developer, NERC will approve this tariff.

Import restrictions

Nigeria offers tax exemptions on some clean energy equipment, but developers complain these are not being effectively implemented (Table 26). They also cite regular issues with bringing imports entirely into the country.

Table 25

Nigeria's key mini-grid regulations at a glance

Policy	Description
Mini-Grid Regulation, 2016 *100kW to 1MW*	**Isolated mini-grids** require signed agreements between mini-grid operators and the communities they serve. If such projects have mini-grid permits from the NERC, the disco must pay off the mini-grid owner with 100 percent of the depreciated asset value (capex) plus one year of revenue. While the NERC has determined a depreciation schedule, it has not yet been published. **Interconnected mini-grids** require an agreement among the mini-grid operator, the community and the disco.
Independent Electricity Distribution Networks (IEDN) Regulation, 2012 *1MW+*	For any power project planning to distribute power **above the 1MW threshold** of the mini-grid regulation, the GENCO must hold an IEDN licence from the NERC.
Application for Licences (Generation, Transmission, System Operations, Distribution & Trading), 2010 *1MW+*	For any 1MW+ project to transmit, distribute or **generate power for sale (i.e., when a PPA is involved)**, the developer must apply for a generation licence at a cost of USD 10,000 for projects 1–10MW. The licence and operating fees regulation details fees involved with obtaining this generation licence. The application process timeline should not exceed six months, according to the NERC.

Source: NERC. Note: Renewal is guaranteed if the renewal fees are paid and all requirements met. Developers informed the authors that once a licence is granted, renewal is pretty much guaranteed.

Under the rules, PV modules with bypass diodes must pay a 5 percent import duty plus 5 percent VAT while the import duty on solar cells without bypass diodes is 0 percent. This is because the government wants to encourage locally assembled PV modules. However, these efforts have largely failed; no developer the authors spoke to has used locally assembled PV modules. Batteries are taxed a total of 27.5 percent, broken up as 20 percent import duty and 7.5 percent VAT.

There are also high transaction costs related to customs handling. Merchandise can often sit in port for weeks, at high cost to the importer. Developers complained about delays in removing merchandise from port after it arrives. Some developers reported they typically budget an additional 1–2 percent of the total value of imported goods as *settlement fees* to clear the goods quickly.

Table 26

Nigeria's tariffs on solar and batteries

Code	Official Description	Interpretation	Import Duty	VAT	Total
8502 - 391000	Solar-powered generator	PV module with a bypass diode	5%	5%	10%
8541 - 401000	Solar cells whether or not in modules or made up into panels	PV module without a bypass diode	0%		0%
8506 - 500000	Primary cells and primary batteries made of lithium	Lithium-ion batteries.	20%	7.5%	27.5%
8507 - 100000	Lead-acid, of a kind used for starting piston engines	Lead-acid batteries.	20%	7.5%	27.5%

Source: BloombergNEF, Nigeria Customs Service (NCS). **Note:** A bypass diode makes the solar module have a constant energy wavelength, without a diode, it does not have a constant energy wavelength and cannot be used for power generation. However, solar modules ship with bypass diodes included and therefore incur duty 8502.

Section 14
Case study – India (Bihar)

Bihar has a 100 percent electrification rate at the household level but the power supply from the main grid remains intermittent. Rural communities often pay higher rates for a reliable electricity supply via diesel-powered generators and the state therefore offers ample opportunities for mini-grid development. Bihar and India in general has seen rapid improvements in electricity access over the last few years under the *Saubhagya* scheme. The main use case for mini-grids lies in improving the reliability of the grid power supply through connection to sub-stations and providing power for commercial and industrial (C&I) customers. There is an appreciation of mini-grids in state-level policy, but more work needs to be done to develop the sector.

14.1 Overview

In 2019, the Indian government announced that the country had achieved 100 percent household electrification through grid extensions under its *Saubhagya* scheme. According to official statistics, just 18,734 households or 0.01 percent of all those in the country have yet to be electrified (The Ministry of Power, n.d.). However, the government makes its 100 percent claim by employing quite a loose definition of *electrification*. For its purposes, all households in the village are considered electrified if public buildings and 10 percent of the total number of households in that community are connected to the main grid. In addition, a large portion of households formally connected receive only limited service.

Situated in the east of the country, Bihar is one of India's poorest states and has historically suffered one of the its lowest electricity access rates (CEEW, 2018). Despite these severe disadvantages, Bihar has seen less mini-grid investment and project development than its much larger neighbor Uttar Pradesh. Still, there are 146 mini-grids installed worth 4MW in generating capacity (Figure 118, Figure 119). Barriers have included a lack of sufficient regulations and uncertainty about main grid arrival rules.

Figure 118

Bihar's installed mini-grids, by project

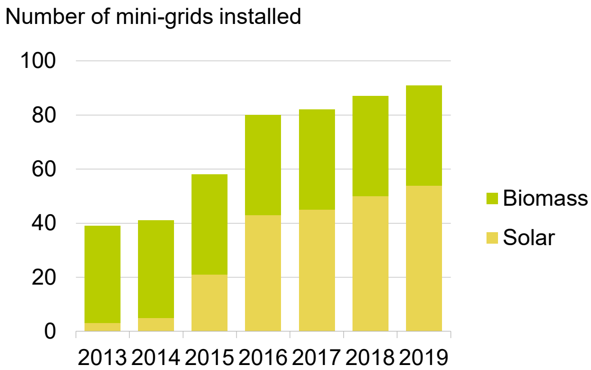
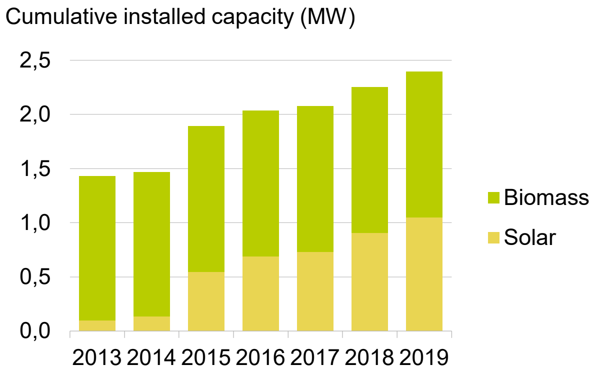


Figure 119

Bihar's installed mini-grids, by capacity



Source: BloombergNEF. **Note:** Operating projects without a specified commissioning year are not included.

14.2 Distributed power market structure

India's power market includes a mix of state-owned and private entities. At the national level, the Central Electricity Regulatory Commission (CERC) regulates inter-state transfer of electricity. The Bihar Electricity Regulatory Commission (BERC) coordinates state-level regulations and implementation, including determining tariffs and overseeing licensing. Stakeholders interviewed by the authors noted that having to deal with both state-level and national authorities has been a challenge in setting up their projects.

14.3 Current market status

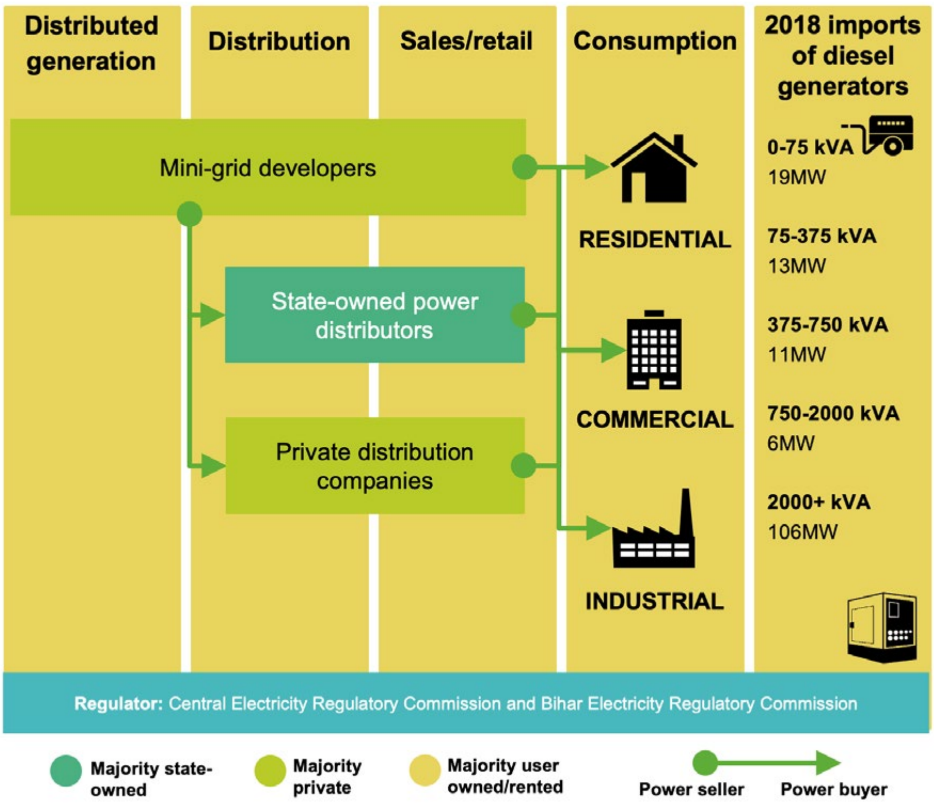
The authors identified 146 installed mini-grids in Bihar, which represent 8 percent of all projects confirmed to be operating in India. Typical mini-grids serve residential and commercial customers, and small factories. They often include anchor loads such as agricultural facilities, telecom towers, water purification or cold storage facilities.

Mini-grid developers have flexibility in tariff setting. For instance, one developer interviewed by the authors charges a discounted tariff when the power demand of its main customer exceeds a certain threshold (e.g. 100kWh/month). While mini-grid tariffs are higher than those offered by the main grid, customers are often willing to pay a premium for reliability.

Grid reliability varies significantly by location within Bihar. Rural households were far from access to reliable grid electricity as of 2018, according to a survey from the Council on Energy, Environment and Water (CEEW), a Delhi-based think tank (Figure 121). However, overall main grid reliability has improved in recent years (Figure 122), posing a potential risk that mini-grids could become stranded. Still, quality of power (e.g. voltage fluctuations) con-

Figure 120

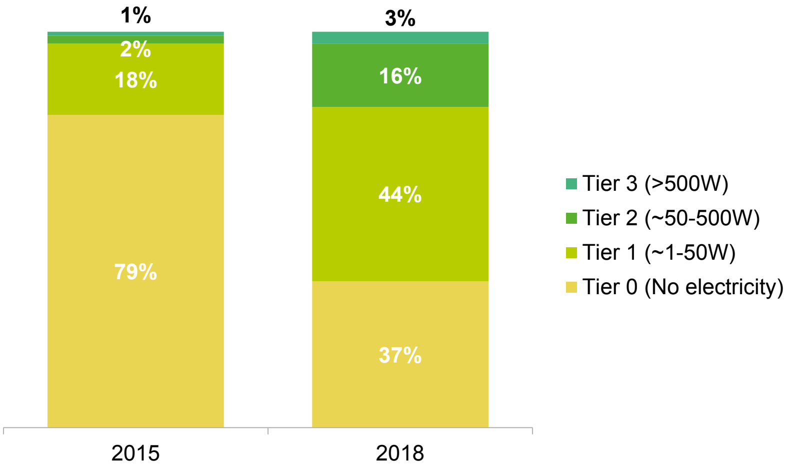
Bihar's distributed power market structure



Source: BloombergNEF. **Note:** Backup diesel imports are at the national level.

Figure 121

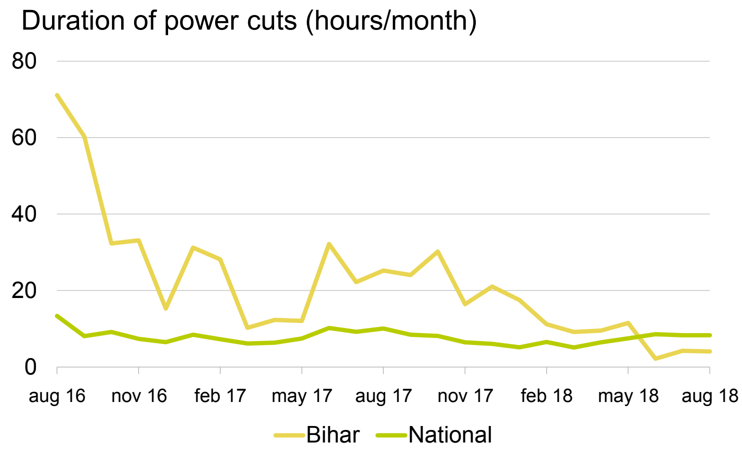
Bihar's distribution of households by electricity access tier



Source: BloombergNEF, CEEW. **Note:** Tier system used differs from the Multi-Tier Framework.

Figure 122

Bihar's duration of power outages



Source: BloombergNEF, Government of India.

tinues to be a problem, according to one research organization. There remain opportunities for double-digit megawatts of mini-grids for commercial and industrial customers who prioritize reliability.

While large corporates and non-governmental organizations (NGOs) have financed mini-grids in Bihar, virtually all developers of such projects have been local companies (Figure 123). Most of their focus is not only on Bihar, but on several states such as Utter Pradesh and Odisha. Haryana-based OMC Power and Bihar-based Husk Power have been active in Bihar since as early as 2008. The former is well known as one of the leading builders of mini-grids that serve major anchor customers paired with commercial and residential customers nearby.

In 2017, OMC Power received a USD 9 million equity investment from Japanese trading house Mitsui. Husk Power raised USD 20 million from Shell Technology Ventures, Swedfund International and ENGIE Rassembleurs d'Energies in January 2018. The developer earlier focused on building biomass mini-grids, but more recently turned its attention to solar hybrid mini-grids in collaboration with ABB.

Shell Foundation and the Rockefeller Foundation have provided important assistance to India-based

Figure 123

Mini-grid developer landscape in Bihar

Source: BloombergNEF, company websites.

mini-grid developers. In November 2019, Rockefeller and Tata Power announced plans for the development of 10,000 new mini-grids throughout India to serve over 800 million people by 2026 (The Rockefeller Foundation, 2019).

14.4 Policy and regulations

Approved in May 2017, Bihar's Policy for Promotion of New & Renewable Energy Sources aims to install 100MW of <500kW renewable mini-grids by 2022 (CEED). If successful, this would account for about 3 percent of an overall target of 3,533MW of clean capacity additions by the same year.

Mini-grid projects may be built under three state policy framework models:

- **Tendering** – The Bihar Renewable Energy Development Agency (BREDA) may issue a tender under the existing central off-grid electrification scheme known as *Deen Dayal Upadhyaya Gram Jyoti Yojana* (DDUGJY). However, to date, the government has yet to hold a tender or announce plans for one.
- **State subsidy** – BREDA can offer subsidies to developers but has yet to release details on how and at what level it will do so. In exchange for accepting subsidies, developers would need to structure their tariffs to customers in compliance with the state's anticipated mini-grid regulation.

Box 13

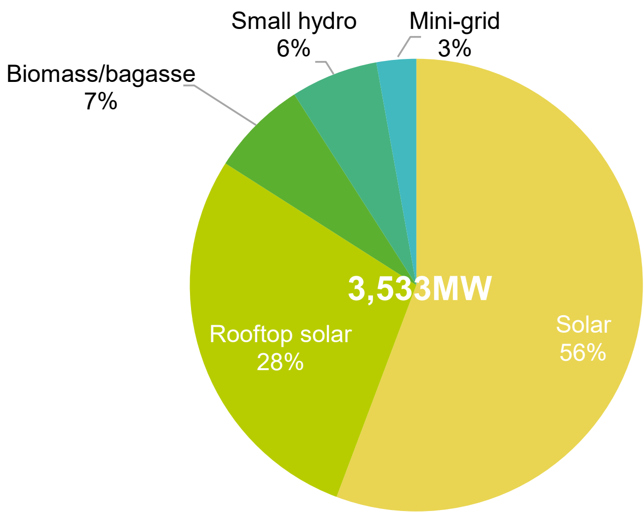
Serving anchor loads

DESI Power builds biomass and solar hybrid mini-grids that supply electricity to anchor consumers such as irrigation water pumps, agricultural facilities, shops and telecom towers. These customers are the main revenue sources for DESI as they have larger and more predictable power demands than those of residential customers.

DESI charges anchors on a per-unit-of-consumption basis, while a flat tariff is used for residential consumption. Separating consumers by type and applying different tariff structures is a useful way of optimizing revenue generation. Residential consumers may not have significant energy requirements, hence a fixed tariff eliminates the need for installing meters at their premises and DESI can assess mini-grid consumption via centralized monitoring. On the other hand, the cost of installing meters is a smaller proportion of the potential revenue from commercial consumers who have higher energy requirements.

Figure 124

Bihar's policy for Promotion of New & Renewable Energy Sources 2022, targets by technology



Source: BloombergNEF, CEED 2017. **Note:** Small hydro refers to hydro projects less than 25MW that are expected to deliver power to the nearest power sub-station.

That regulation was expected to be released by the Bihar Electricity Regulatory Commission (BERC) in 2018 but had not been issued by the end of 2019.

- **Energy service company (ESCO)** – ESCOs can develop mini-grids without subsidy in Bihar. They can choose the location independently and charge consumers a mutually agreed tariff under this model. OMC Power, Husk Power, DESI Power, Freespanz and Tara Urja are notable ESCOs currently active in Bihar.

Mini-grid regulations

Bihar's 2017 Policy for Promotion of New & Renewable Energy Sources suggests that BERC *"should develop a mini-grid regulatory framework"*. However such a framework specific to mini-grids has yet to come into existence. This limits the government's ability to enforce the recommendations laid out in the policy.

Licensing

India has no licensing requirements for off-grid projects, including mini-grids. This generally reduces the time and complexity for mini-grid development in the country. According to the Electricity Act, 2003 (Ministry of Law and Justice, 2003), any generation company may develop, operate and maintain a generation plant without obtaining a licence so long as technical standards relating to grid connectivity are met. This also applies to mini-grids in Bihar.

Cost-reflective tariffs

For projects not seeking direct subsidies in Bihar, there are no regulations on mini-grid tariffs. As a result, developers can set tariffs as they see fit and charge customers at cost-reflective rates.

Arrival of the main grid

The biggest concern for investors and mini-grid developers is the viability of a business if the main grid is extended to their area of operation. Unlike the policies of some other states, Bihar's Policy for Promotion of New & Renewable Energy Sources does however state several options:

- Continue to operate, i.e. parallel to the grid.
- Sell excess or all power to the disco at a feed-in tariff annually determined by the regulator.
- Transfer ownership of the assets/distribution network to the disco.
- Developers may be able to engage with the disco as a distribution franchise.

Despite a general level of flexibility in Bihar, developers raised concerns around the lack of regulation that could undermine the above options. Some developers suggested that they will avoid connecting to the central grid until such rules are made more explicit.

Box 14

Customers opt for mini-grid power over the central grid

The arrival of the central grid may not mean the end of autonomy for an existing mini-grid. Take for instance Husk Power's 32kW biomass gasifier, 20kW PV array and lead-acid battery mini-grid project near the town of Pipra Kothi. Since the project was commissioned in 2017, the distribution grid has expanded to come within 2.5km of the community of 250 households and businesses served by the mini-grid. This raised the prospect of customers switching to the central grid for power – and paying lower tariffs. However, customers opted to stay with the mini-grid, primarily because they value the more reliable electricity it provides. Husk employs a local electrician, a security guard and an operator to manually add feedstock to the biomass gasifier. All ensure more reliable power delivery.

Section 15
Case study – Phillipines

Communities on remote islands in the Philippines typically rely on fossil fuel-based mini-grids. The majority were built under the government's electrification mechanism, but many of them do not supply reliable electricity, partly due to the very high cost of electricity generation and growing power demand. Transporting fuel to remote islands can add 20 percent to the average cost per litre of fuel. Legislation may assist solar hybrid mini-grids for unserved and underserved communities, if enacted.

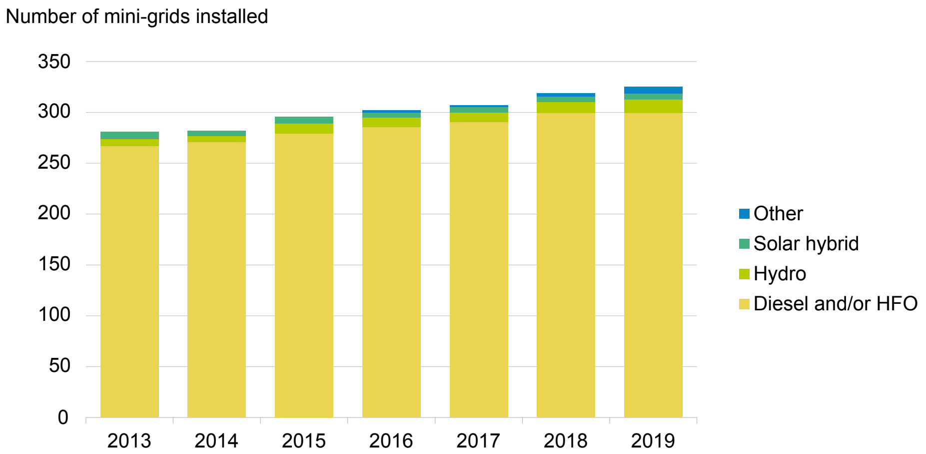
15.1 Overview

The Philippines consists of 7,641 islands, of which about 2,000 are inhabited. The country achieved an electrification rate of 89 percent by the end of 2018, up from 85 percent in 2010. The majority of the population resides on the large islands of Luzon, Mindanao and Visayas. An estimated 11 million people live without access to electricity, most of them on remote islands where there is no grid. The government aims to reach 100 percent electricity access for targeted households identified in the 2015 census by 2022, and universal access by 2040 that includes households beyond the census (Department of Energy, 2016). It recognizes that these targets are unlikely to be met without decentralized energy technologies such as mini-grids.

According to the Department of Energy, a total of 326 mini-grids with a total capacity of 530MW were installed as of February 2020. The majority of these were built within the missionary electrification framework and run on fossil fuels (See Section 16.4). There are many (but unquantifiable) power supply networks on very small islands that are organized informally (Paul Bertheau, 2018). In July 2019, Senator Win Gatchalian, chair of the Senate Committee on Energy, filed Senate Bill 175[19] to promote renewable hybrid mini-grids for unserved and

Figure 125

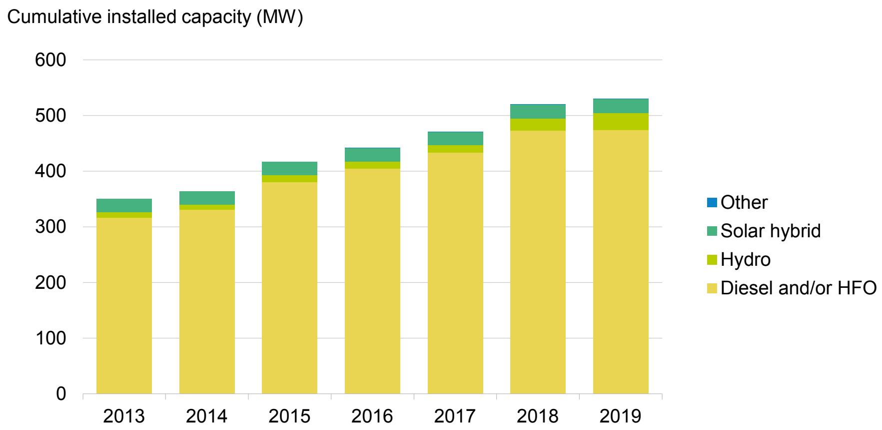
Philippines' installed mini-grids, by project



19 Senate Bill No. 2218 in the 17th Congress in May 2019 became Senate Bill No. 175 in the 18th Congress in July 2019.

Figure 126

Philippines' installed mini-grids, by capacity



Source: BloombergNEF, Department of Energy, the Philippines, National Power Corporation.

underserved areas to achieve the electrification target in a more cost-efficient manner. If the bill is implemented, some existing regulatory hurdles for mini-grids would be lowered.

15.2 Distributed power market structure

The Philippines has 150 franchise areas and each has electricity supplied by a distribution utility that may be an electric cooperative (121 electric co-operatives operate across the country) or a local government- or private investor-owned utility (e.g., Meralco).

Off-grid electricity is mostly supplied by the Small Power Utilities Group (SPUG) under the National Power Corporation (NPC). Some electricity is supplied by New Power Providers (NPPs), qualified third parties (QTPs), distribution utilities or independent power providers (Department of Energy, 2016). The NPC-SPUG is a state-owned entity that pursues the government's missionary electrification plan initiated in 2001 (Department of Energy, 2001) to install decentralized electricity for consumers in remote communities. NPPs are private entities that took over existing assets from the NPC-SPUG either by outright purchase or lease or by installation of new facilities. They are in charge of power generation. QTPs are private entities that generate and distribute electricity in remote villages in areas where the franchised utility is not able to provide service. The government introduced the NPP and QTP schemes to facilitate private investment in the mini-grid sector.

There are a few examples of private entities that have developed mini-grids outside these three forms. Meralco, the largest private distribution company that covers metropolitan Manila, has installed mini-grids supplying electricity to villages (called barangays) on Cagbalete Island and Verde Island. One developer formed a joint venture with an electric cooperative, installed a mini-grid then transferred the asset to the cooperative.

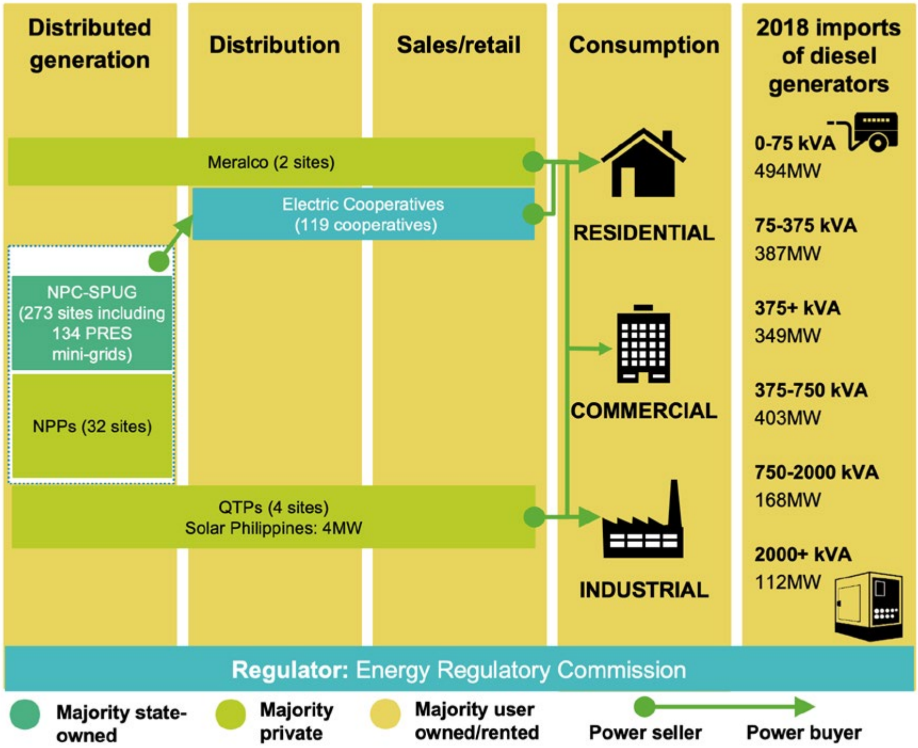
15.3 Market status

Mini-grids are predominantly NPC-owned or under public-private partnership. NPC-run SPUG operates 273 mini-grids of which 134 were installed in mainland Masbate and on Ticao Island under the Philippine Rural Electrification System (PRES) (Figure 128). Private developers need to be approved as NPPs or QTPs or else collaborate with an electric cooperative to develop mini-grids. New solar hybrid mini-grid projects would mostly take one of these forms. QTPs need to build their own distribution system in unserved areas.

Most of the SPUG mini-grids use either diesel or heavy fuel oil (HFO) to generate electricity. This is

Figure 127

Philippines' distributed power market structure



Source: BloombergNEF, Bertheau et al., PGS Consulting. Diesel generator imports are estimated based on unit sales.

costly because delivered diesel fuel costs can be up to 76 percent more expensive than the national average pump price of USD 0.71/litre in 2018.

The solar hybrid mini-grid market has just started maturing with only seven mini-grids installed at the end of 2019. These were generally retrofits of existing diesel generators. The National Electrification Administration (NEA), the Asian Development Bank (ADB) and foreign governments financed the work (Figure 130). There is a mixture of domestic and international players in the market, including both large corporates and start-ups. Most developers are working on one or two mini-grids. The growing participation of mini-grid developers suggests their recognition of the market's growth potential to substitute the use of fossil fuel or to develop green field projects. Still, the market is at a very early stage.

Domestic actors

Solar Para Sa Bayan, a subsidiary of solar developer, Solar Philippines, has installed at least one mini-grid to date . Other domestic energy companies are also moving towards renewables and decentralized energy. In 2019, Meralco, the largest regional distribution company, switched on its second mini-grid with generation capacity of 120kW to serve more than 800 households on Cagbalete Island, Quezon province . AC Energy, a subsidiary of Ayala Corporation, aims to invest in renewables by targeting 5GW in Southeast Asia by 2025.[20] One Renewable Energy installed a 52kW solar hybrid mini-grid serving 200 households on Malalison Island. The island was outside the area served by SPUG, hence, the developer was selected by the local electric cooperative through a competitive bidding process. It handed over the mini-grid system to the cooperative after installation and continues to be involved in billing.

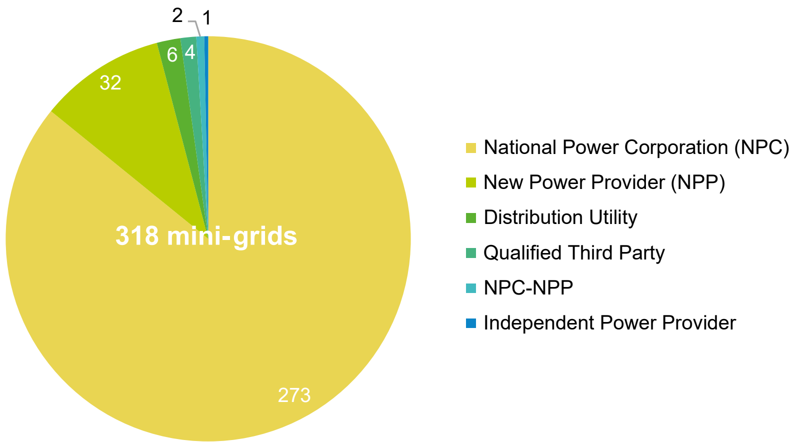
International actors

Singapore-based InFunde Development, on behalf of Infraco Asia, a part of the UK-based Private Infrastructure Development Group (PIDG), aims to deploy both AC and DC-coupled mini-grids for

20 IEEFA, *The Philippine Energy Transition*, March 2019

Figure 128

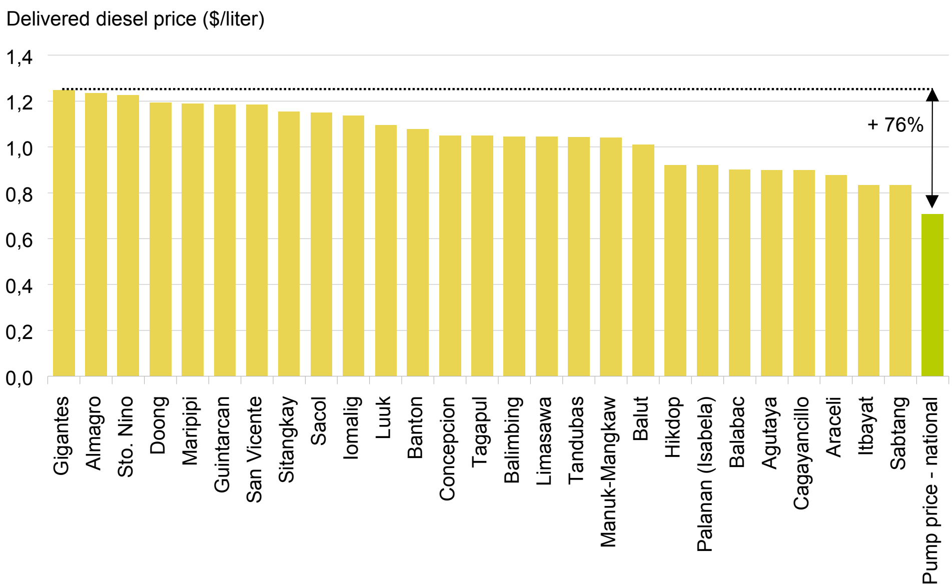
Philippines' installed mini-grids by ownership



Source: BloombergNEF, Department of Energy, the Philippines, National Power Corporation. **Note:** Includes only projects with ownership information available.

Figure 129

Estimated Philippines' delivered diesel prices for select NPC-SPUG diesel mini-grids in 2018



Source: Silver Navarro, Jr, BloombergNEF, Climatescope 2019. **Note:** USD 1 = PHP 51.783. The average is of all the diesel mini-grids shown in the chart.

off-grid communities. The company partnered with Cambodia-based start-up Okra Solar, and completed a pilot project to provide DC-coupled mini-grids to connect 62 households in Busuanga, Palawan Island . The technology allows electricity to be directed to where it is needed and to use DC appliances. InFunde Development is also developing a 1.2MW AC-coupled mini-grid to supply electricity to around 4,000 households. It has a pipeline of projects to cover about 200,000 households.

In January 2019, Singapore-based developer WEnergy Global announced a new investment entity with Tokyo Electric Power Co. Power Grid (Tepco PowerGrid), ICMG Partners and Greenway Grid Global called CleanGrid Partners with a total investment of USD 60 million,[21] The developer aims to duplicate the model in other parts of Indonesia,

21 WEnergy Global, Singapore's WEnergy Global, ICMG Partners and Japan's TEPCO-PowerGrid working together on a $100 million Fund for Clean Energy Projects in SEA, 22 January 2019

Figure 130

Mini-grid developer landscape in the Philippines

Source: Companies, BloombergNEF.

Myanmar and the Philippines. The Sabang Renewable Energy Corp (SREC), a consortium of WEnergy Global, Vivant Energy Corp and Gigawatt Power, launched a 2.4MW PV mini-grid on Sabang, Palawan Island, in November 2019 (WEnergy Global, 2019). Pilipinas Shell Foundation is developing 20 mini-grids for rural communities on Palawan Island.

15.4 Policy and regulations

Missionary electrification

The core of the rural electrification framework in the Philippines is missionary electrification. According to Republic Act 9136, which came into force in 2001, the National Power Corporation performs *"the missionary electrification function through the Small Power Utilities Group (SPUG) and shall be responsible for providing power generation and its associated power delivery systems in areas that are not connected to the transmission system."* Missionary areas refer to designated off-grid, unviable, and underserved areas. SPUG serves 242 missionary areas (Asian Power, 2016). The NPC discloses locations of the SPUG plants (referred to as mini-grids in this report) on its website.

The electrification scheme is funded by two revenue sources: electricity sales in the missionary areas and universal charges for missionary electrification (UCME) collected from all rate payers in the country as determined by the Energy Regulatory Commission (ERC). The UCME covers the gap between the true cost of the mini-grids operated by SPUG and the subsidized approved generation rate (SAGR) that is determined by the ERC. In the Philippines, the true cost of these generation plants on remote islands is USD 0.20–0.72/kWh according to the NPC, as most of the assets burn expensive diesel or HFO. This is well above the tariffs of USD 0.11–0.12/kWh charged to grid consumers (Figure 131).

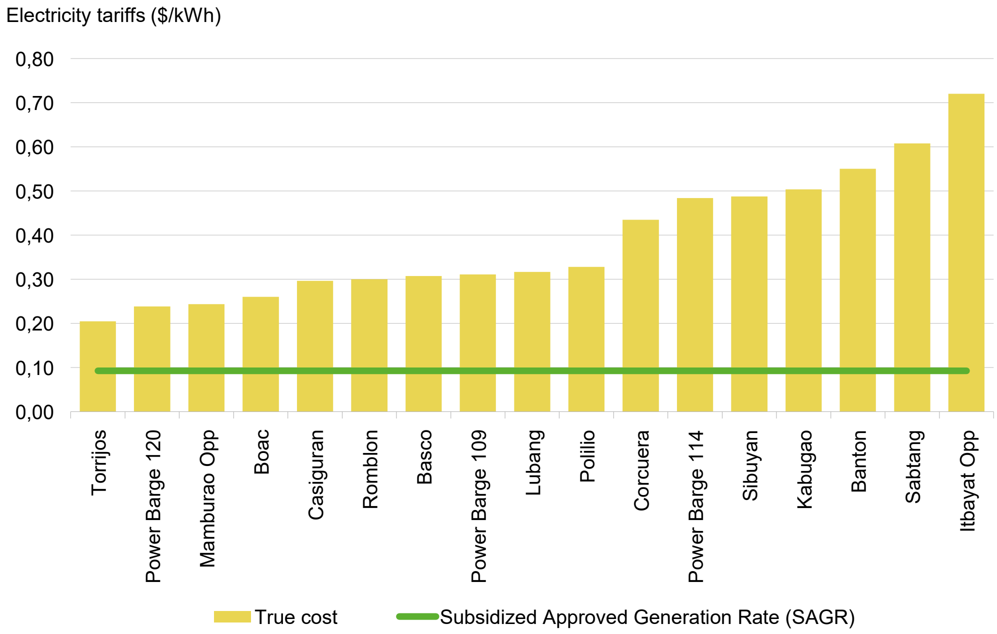
The country's electricity access rate improved from 76 percent to 89 percent between 2001 and 2018. While the missionary electrification programme has supported rural electrification to some extent, it has also increased the cost of electrification, due to high generation costs coupled with the increase in mini-grid installations, as well as population and power demand growth in the missionary areas. The number of mini-grids installed using fossil fuel grew to 301 between 2001 and 2019.

Another issue is the relatively low reliability of mini-grids. More than 55 percent of the country's mini-grids supplied electricity for less than eight hours a day as of December 2019, according to the Department of Energy (DOE). Of this figure, the 134 PRES mini-grids installed in mainland Masbate and on Ticao Island supplied electricity for five hours per day. This is due to several factors including the high cost of generation, the timings of fuel delivery to the islands and unreliable payment of UCME by the government.

On 16 December 2018, the DOE announced that the country plans to phase out the UCME gradually, depending on economic conditions in the remote areas. It said that if such a fund is needed, it should be charged to the government, not grid ratepayers.

Figure 131

Gap between true costs and the SAGR in the Philippines



Source: BloombergNEF, National Power Corporation. **Note:** USD 1 = PHP 51.856.

It is currently unclear whether the phase-out will actually happen, and, if it does, what the timeline for the phase-out would be. However, reaching a 100 percent electrification rate within the next two years is unlikely without some form of public funding as electrification on the remote islands is not otherwise financially viable.

Use of solar hybrid systems has the potential to reduce generation costs, particularly on remote islands, as solar hybrid systems use much less fossil fuel than diesel generators. However, there are some practical challenges. The missionary electrification mechanism does not distinguish between different technologies. For the local electric cooperatives that handle retail distribution, solar hybrid systems are a relatively new technology while diesel generators are already established. It is also challenging for the cooperatives to access funds from financiers or private sector partners as they perceive a lack of business track record and creditworthiness (Paul Bertheau, 2018).

Mini-grid regulations

For developers, becoming an NPP or QTP is a bottleneck as the process to obtain a permit is cumbersome and lengthy and makes it difficult for them to secure financing for mini-grid projects. New legislation however intends to address this challenge.

Licensing

No explicit licensing process for mini-grids exists in the Philippines, making the application process at least as long and costly as that for utility-scale projects. Even small projects need to go through the cumbersome licensing process, which disadvantages smaller developers that lack the overhead resources of large developers.

In March 2019, President Duterte signed the Energy Virtual One-Stop Shop (EVOSS) Act that aims to streamline the process of permits for power generation, transmission and distribution in the country. The EVOSS is an online portal that allows energy developers to apply for permits or licences, submit all the required documents and monitor the approval process (ZICO, 2019). The law also requires all the government bodies involved to follow a strict timeline. Their failure to act within the timeframe results in the automatic approval of an application and a potential penalty against public officers. As of February 2020, EVOSS had yet to include NPP and QTP licensing processes, but it should cover them once the software work has been completed.

As part of the implementation of Senate Bill 175, the DOE and the ERC aim to establish a streamlined process to approve the licence for a micro-grid system provider.

Grid connection rules

Developers initially pay the costs of grid connection, but this is paid back to them over time by the ERC.

Net metering

A net metering programme was launched in 2014 to allow end users to produce power at facilities 100kW or smaller and export excess energy to the grid. Exported energy is paid at rates corresponding to the blended generation charge of the distribution utilities (DUs). Like the feed-in tariff mechanism, surplus electricity generated under net metering agreements has priority of dispatch ahead of other forms of generation.

Microgrid Systems Act

Senate Bill 175 (the Microgrid Systems Act) currently under legislation will, if enacted, set up a new policy framework to promote renewable hybrid mini-grids to provide reliable electricity to communities on remote islands. At the beginning of January 2020, the Senate Committee on Energy was finalizing the Committee Report on the bill, which will then go through the necessary legislative processes before it becomes law.

The bill targets unserved and underserved areas nationwide, thus, any areas without access to reliable electricity are within the scope including those designated under the missionary electrification policy (see below). However, there can be changes to this depending on the results of the discussion in the Technical Working Group meetings in the Senate. According to the DOE, approximately 900 areas are currently unserved in the Philippines.

There was no definite timeline for the passage of the bill into law as of the beginning of January 2020. The government would need to urge on enactment of the bill to achieve its electrification goal by 2022.

Table 27

Key duties under the Philippines Microgrid Systems Act (Senate Bill 175)

Duties of Energy Regulatory Commission (ERC)	Duties of Department of Energy (DoE)

• Within six months from its enactment, the ERC is to establish and disclose:
  • New mechanisms to accredit entities that install mini-grid systems as micro-grid system providers (MSPs)
  • The maximum total capacity of mini-grids that can be connected to a specific distribution system
  • Technical and service standards for mini-grid systems
  • Rules for grid-connected mini-grids to trade electricity with the main grid.
• Determine benchmark rates (so the maximum retail rate or generation rate) for different mini-grid systems that MSPs will collect from their customers
• Monitor contracts and the operations of all awarded MSPs.
	• Release an updated list of potential areas for mini-grid development (such as off-grid areas and unreliable grid areas).
	• Establish and conduct a streamlined competitive selection process of MSPs and announce an annual schedule of the process.
	• Determine a detailed procedure for the transition of electricity services from distribution utilities to awarded MSPs in unreliable grid areas.

Source: Congress of the Republic of the Philippines, BloombergNEF. **Note:** The listed duties are not exclusive. See the bill for more details.

15.5 Other barriers

In July 2019, President Rodrigo Duterte signed into law House Bill 8179 granting a 25-year franchise to Solar Para sa Bayan, built by the founder of Solar Philippines (CNN Philippines, 2019). The bill allows the company to establish distributed energy systems, including micro-grids, in off-grid and unreliable grid areas. Stakeholders including the Philippine Solar and Storage Energy Alliance (PSSEA) and Meralco strongly opposed the legislation, arguing it would give Solar Para sa Bayan a competitive advantage in the mini-grid market.

Section 16
Case study – Indonesia

As an archipelago, Indonesia is unlikely to be completely electrified through the main grid. There is therefore the potential for mini-grids to support Indonesians in otherwise hard-to-reach regions. The authors identified 1,061 installed mini-grids in the country. If the private sector is to be involved in further installations, cooperation with the government and the state-owned utility, *Perusahaan Listrik Nagara* (PLN) is vital.

16.1 Overview

Indonesia includes more than 17,500 islands, of which around 1,000 are inhabited (NREL, 2016). Over 98 percent of Indonesians had access to electricity at the end of 2018. The rural access rate of 96 percent equates to approximately 4.5 million people without access to electricity in these areas. Generally, islands in the eastern region tend to have lower electricity access rates (ADB, 2016).

Grid extensions are often not feasible in island nations. Rural Indonesians rely almost exclusively on tens of thousands of diesel generators serving villages or hamlets. As of 2013, the state-owned utility PLN operated some 3.1GW of diesel generators and 600 mini-grids (BloombergNEF, 2018). In 2018 alone, the country imported over 23,000 diesel generators. This suggests a huge potential for substituting diesel with renewables.

Indonesia has installed a total of 1,061 mini-grids, mostly led by the national government with support from international donor agencies (Figure 132, Figure 133). Although not reflected in the database, a further 655 mini-grids have been installed by provincial governments. Thanks to their efforts, electricity access has improved steadily in the last several years. However, participating in the mini-grid market is quite difficult for private entities, particularly non-Indonesian companies. Despite the PLN not having exclusive powers over the transmission, distribution and sale of electricity, it still dominates

Figure 132

Indonesia's installed mini-grids, by project

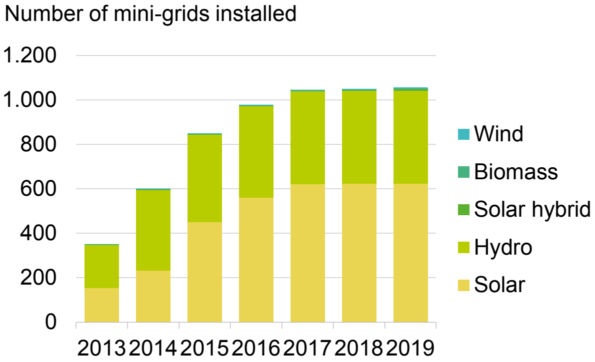
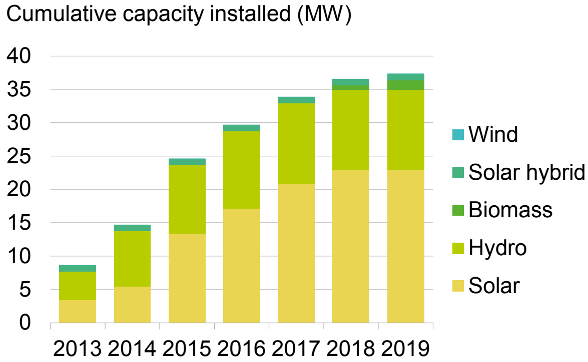


Figure 133

Indonesia's installed mini-grids, by capacity



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, surveyed developers. **Note:** Operating projects without a specified commissioning year are not included.

the power market, making it difficult for other entities to obtain business licences. Limits on foreign ownership of businesses operating in the country presents an additional barrier.

16.2 Distributed power market structure

The PLN dominates the power market in Indonesia, covering generation, transmission and retailing. However, it does not cover all areas of the island nation; remote islands, and some concentrated industrial areas in particular, leave some room for other entities to participate in the distributed power market.

Independent Power Producers (IPPs) holding generation licences may build plants up to 50MW and sell power directly to consumers in non-PLN service areas. They may also build mini-grids and sell electricity to the PLN in its service areas, which requires negotiation and close cooperation with the utility.

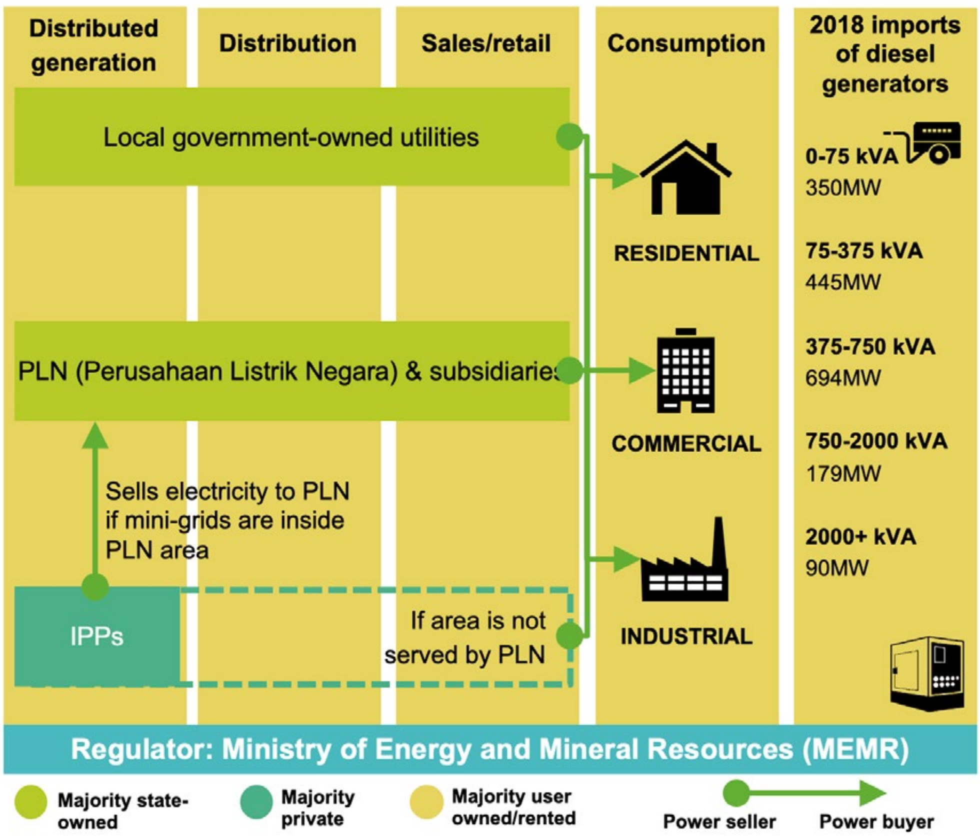
The Ministry of Energy and Mineral Resources (*Kementerian Energi dan Sumber Daya Mineral Republik*, or ESDM) oversees the energy sector. The Directorate General of Electricity creates the national electrification plan, issues generation licences to IPPs and approves tariffs in cooperation with the PLN. The Directorate General of New, Renewable Energy and Energy Conservation (EBTKE) is in charge of planning, regulations and of the mini-grid programme (IRENA, 2018).

15.3 Current market status

The authors identified a total of 1,061 mini-grids installed in Indonesia, including almost 630 solar or solar hybrid, some 422 hydro, and a handful of biomass and wind-based systems. The total generation capacity is 38MW (Figure 135). Since the 1990s, a large number of hydro mini-grids have been developed with support from the government and in-

Figure 134

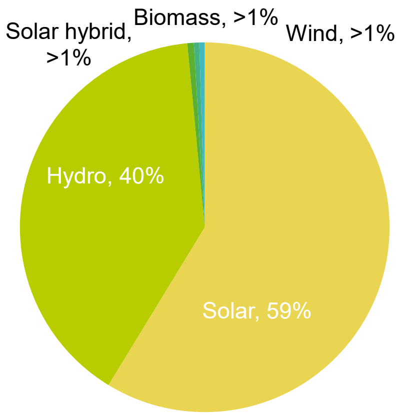
Indonesia's distributed power market structure



Source: BloombergNEF.

Figure 135

Indonesia's installed mini-grids, by technology



Source: BloombergNEF, GIZ, Carbon Trust, CLUB-ER, surveyed developers.

ternational agencies. GIZ, for example, supported NGOs and local turbine manufacturers to deploy micro-hydro projects.

Most projects were built with direct and indirect technical support from the Energising Development (EnDev) programme, which has promoted access to affordable and sustainable energy since 2005 . As many as 72 projects were installed by IBEKA, an Indonesia-based social enterprise that builds mini-grids for off-grid communities. Various government ministries such as the Ministry of Cooperatives and SMEs and the Ministry of Villages, Development of Disadvantaged Regions and Transmigration, and local governments financed construction of these projects .

Mini-grids are usually handed over to local governments after installation, but three types of entities continue to operate and maintain the mini-grids: co-operatives, village-owned enterprises and communities. The co-operative ownership model used to be common, but the national government is now more supportive of the village-owned enterprise model.

There are very few private entities in the mini-grid sector in Indonesia (Figure 136). Private-sector participation has been in engineering, procurement and construction (EPC). One active developer is Clean Power Indonesia, which has developed biomass mini-grids that use bamboo and other forest-based biomass as feedstock in rural communities in the PLN service areas. Singapore-based developer Canopy Power has not completed any mini-grids for rural electrification but has installed three mini-grids for private resort islands since September 2019. The company not only sells mini-grids but offers *energy-as-a-service* to customers.

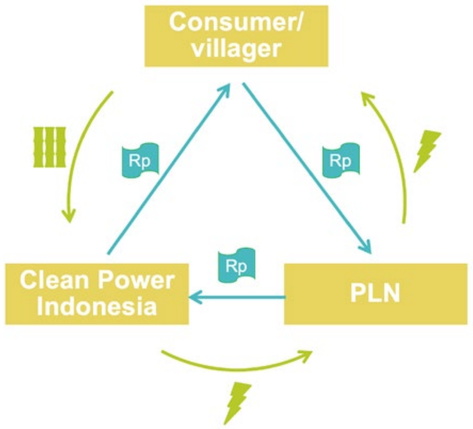
Figure 136

Mini-grid developer landscape in Indonesia

Source: Organizations, BloombergNEF.

Figure 137

Business model of Clean Power Indonesia



Source: BloombergNEF. Adapted from Alliance for Rural Electrification (ARE), 2019.

From 2015 through 2017, corporate interest in the Indonesian mini-grid market appeared to be growing. In 2015, Caterpillar and Fluidic Energy signed an agreement with the PLN to develop 500 mini-grids serving 325,000 households . In 2017, Electric Vine Industries (EVI) and ENGIE announced a commitment to install mini-grids in 3,000 villages in Papua province (EQ International, 2017). In the same year, General Electric and the Ministry of Villages, Disadvantaged Region Development and Transmigration signed a memorandum of understanding to electrify 13,000 remote villages through various approaches (GE, 2017).

Since then, there have been relatively few updates on these initiatives, suggesting that the market has been more challenging than some developers had initially anticipated.

16.4 Policy and regulations

Indonesian law allows only one entity to distribute and sell electricity in any area. The PLN has the right of first refusal before the government may offer the opportunity to other entities. Permits can be granted if the area is not already covered by an Electricity Supply Business permit holder or if a permit holder is not able to provide reliable electricity access.

To obtain the rights to a business area, IPPs need to make a request to the Ministry of Energy and Mineral Resources (ESDM) through the Directorate General of Electricity (DGE). The application must be supported by an analysis of the electricity needs and business plans for the requested business area

Box 15

Private sector collaboration with PLN & local communities

Clean Power Indonesia has a 700kW biomass mini-grid to provide electricity to 1,250 homes in three villages in Mentawai, Indonesia. Ankur Scientific, the technology provider, has signed an agreement with the PLN and is responsible for the maintenance of the 6x100kW and 2x50kW biomass gasifiers, supported by the local villagers. The PLN owns the mini-grid, and has signed a 20-year power purchase agreement (PPA) with Clean Power Indonesia to procure all electricity generated at a rate of USD 0.15/kWh and charge consumers at the National Electricity Rate of approximately USD 0.03/kWh. Bamboo is purchased from villagers as the main feedstock under a 20-year supply agreement for a linked price equal to 20 percent of the PLN electricity tariff paid to the project.

The project's total capital investment is USD 12.5 million, and operating expenses (including feedstock) are USD 0.12/kWh. As much as 96 percent of the investment was funded by a grant from the US Millennium Challenge Corporation, with the remaining investment coming from Clean Power Indonesia and its local government partner.

By including the PLN in the business model (Figure 137), the project developers are protected against the risk of grid arrival and can maintain financial sustainability with a tariff that is affordable for consumers (Alliance for Rural Electrification 2019).

and a recommendation from the governor or other official from the provincial government. The DGE will assign a technical team to assess the feasibility of the request to determine whether the requested permit in the business area will be granted.

Organizations the authors spoke with highlighted the fact that the licensing procedure is complicated. To date, no non-PLN entity has obtained a licence to sell electricity to end-users in a PLN business area.

Outside the PLN areas

In 2016, the ESDM issued a regulation that sought to accelerate electrification in rural areas (Minister of Energy and Mineral Resources, 2016). The minister determines a business area, consisting of multiple villages not served by the PLN. Developers can apply to serve the area. If successful, they may generate up to 50MW and sell electricity directly. If no private companies register an interest in serving the business area defined by the local government, then the local state-owned business is assigned to run the service (Figure 138).

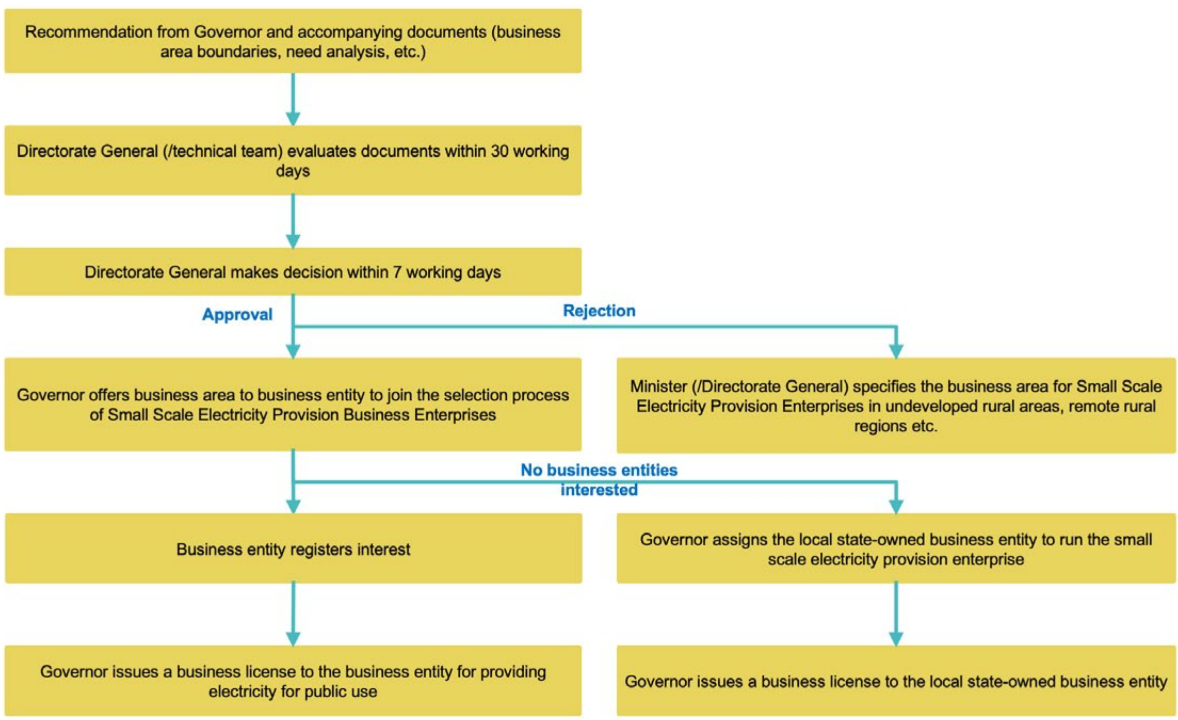
Foreign company ownership

The Indonesian government limits foreign ownership of businesses that build or operate generation plants of any size (Table 28). Power plants up to 1MW in size must be owned by domestic investors while power plants 1–10MW are open to foreign investment of up to 49 percent. Projects larger than 10MW may have foreign investment of up to 95 percent (or 100 percent under a public-private partnership arrangement). This bars any direct foreign ownership in mini-grids, which would typically have a capacity of less than 1MW.

There are also local content requirements that may further deter investors, even though it is unclear how the share of locally-manufactured content is measured or how effectively this will stop developers from importing foreign materials. The regulations are especially unclear for hybrid-generation projects such as solar-diesel, as there are different local content requirements for each generation source.

Figure 138

Indonesia's business licence application procedure



Source: The Ministry of Energy and Mineral Resources, 2016.

Table 28

Foreign company ownership allowed in the Indonesian power sector

Asset	Ownership rules
Power plant (<1MW)	Domestic ownership only
Small-scale power plant (1-10MW)	Maximum 49% foreign ownership
Power plant (>10MW)	Maximum 95% foreign ownership (100% for public-private partnerships during concession period)
Power transmission	Maximum 95% foreign ownership (100% for public-private partnerships during concession period)
Power distribution	Maximum 95% foreign ownership (100% for public-private partnerships during concession period)
Electric power installation operation and maintenance	Maximum 95% foreign ownership

Source: BloombergNEF, PR No. 44/2016.

Mini-grid tariffs

Grid connected mini-grids

In PLN areas, developers are required to charge a regulated tariff. For developers receiving a subsidy from the national government, the PLN's subsidized tariff of USD 0.03/kWh must be charged to residential consumers and a subsidy (that considers operational expenditure, losses, generation cost and expansion plans) is provided. If developers don't receive a subsidy, the minister or governor decides the tariff. However, it is unlikely that rural consumers would be willing or able to pay a cost-reflective tariff.

Off-grid mini-grids

Where the PLN is not present, tariffs are unregulated. The most common tariff structure is a flat rate, the level of which is agreed between the villagers and developer, typically ranging from IDR 10,000–55,000 (USD 0.73–3.91) per kWh. This wide range likely reflects the operation and maintenance, and transmission and distribution costs associated with complex geographies on remote islands. This might include the cost of transporting equipment to these remote locations that can take several weeks.

Arrival of the main grid

The PLN is obliged to purchase electricity generated from an IPP's mini-grid if the main grid arrives at the site, through a 20-year PPA. The PLN must purchase power in Indonesian rupiah, and can pay in US dollars only if an exemption is obtained from Bank Indonesia (Allen & Overy, 2017). The mini-grid is transferred to the PLN once the 20-year term is over.

The PLN is required to purchase electricity from renewable energy power plants of less than 10MW, which include renewable mini-grids. The tariff is set under two different scenarios:

- 85 percent of the regional cost of electricity generation if the regional cost of power exceeds the national average
- A negotiated rate if the regional cost is equal to or less than the national average.

As of 2018, there were no solar, solar hybrid or wind mini-grids connected to the main grid. However, there have been a number of outcomes since the main grid arrived at the 199 hydro-based mini-grids (Table 29).

Table 29

Outcomes of mini-grids in Indonesia upon arrival of the main grid

Outcome	Reason(s)	Number of projects
Mini-grid abandoned	Tariff higher than that of PLN Poor management of the system	140
Mini-grid operating in parallel to the main grid	Tariff cheaper than that of PLN Better quality service	50
All electricity sold to PLN		5
Excess electricity sold to PLN		4

Source: BloombergNEF, World Bank. **Note:** Green highlights favourable outcome.

Only nine (5 percent) of the 199 mini-grids were connected to the main grid successfully. Prior to May 2017, government-funded infrastructure could not generate private income. In addition to this, the feed-in tariffs were deemed too low in some cases.

Section 17
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Appendix A
Database

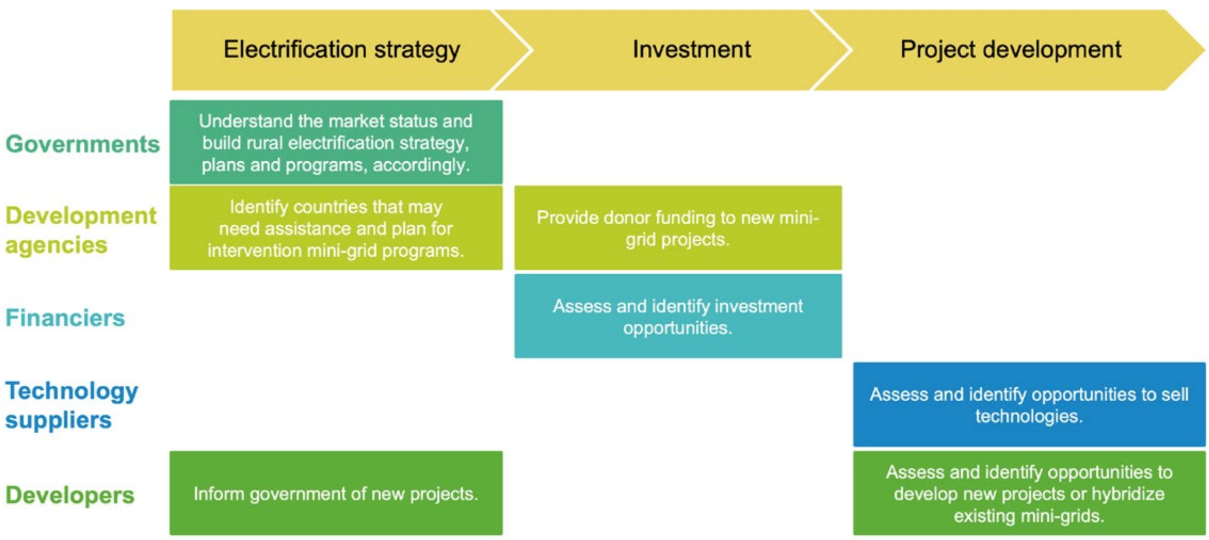
There is no open-source mini-grid database that provides comprehensive project-level data. If such a database existed, it would help stakeholders across the various stages of mini-grid development to address the electricity access challenge. The authors of this report collected data on over 7,000 projects, spanning 75 countries and representing a total of 3GW of generating capacity. This section highlights the approach taken to build the database, data sources, limitations, benefits to stakeholders, and recommendations.

Why build an open-source database?

An open-source mini-grid asset database would provide benefits for various types of stakeholders (Figure 139). Governments could then use the database to stay up-to-date on the status of the mini-grid market in their country, including where mini-grids are installed and the participants involved. The database would inform and enhance their rural electrification strategies, plans and programmes. Donor agencies could use the database to identify countries that may need their intervention, including financial and technical assistance. Financiers, technology vendors and developers could use the data to assess business opportunities for investments, to determine which technologies to develop and to decide where resources should be deployed. Governments would be made systematically aware of projects planned or under development, improving coordination.

Figure 139

Potential benefits of an open-source mini-grid database



Source: BloombergNEF.

Data collection approaches and primary data sources

The authors initially designed a database template that included fields such as:

- Location (country, state, and city)
- Ownership
- Operation status
- Technology (configuration, generation capacity and battery)
- Customer count.

Mini-grid asset data were then collected taking three different approaches (Figure 140). Existing datasets from BNEF, Carbon Trust, CLUB-ER, ADER Madagascar and country offices of the German Agency for International Development (GIZ) were standardized. Secondly, data were added from responses to a survey sent to over 50 key developers, including developers GIZ had worked with. Finally, data were extracted from developer websites, news articles, sector reports and academic research articles. Data were collected from October 2019 to mid-March 2020.

Projects submitted by developers may have been funded by development finance institutuons (DFIs) or other organizations that also submitted data to the authors.

After the data collection process ended, there was an effort to clean the database. Cross-checking of each country's generation capacity, and commissioning year, was implemented to identify and subsequently remove duplicate data. Projects with a commissioning year up to and including 2019 were assumed to be operating, resulting in the overall project status profile in Figure 141.

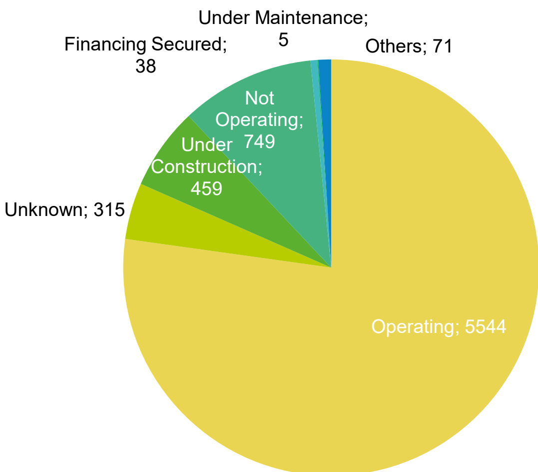
Figure 140

Approaches and primary data sources

Source: BloombergNEF.

Figure 141

Status of projects in the database



Source: BloombergNEF.

Scope

Any generation technologies used for mini-grids are within the scope of the database. While the database shows all the generation technologies incorporated into a given project, the authors categorized some technologies into broader groups for data-visualization purposes such as charts and figures throughout this report. This means that any generation technologies integrated with solar fall under the *solar hybrid* category. Table 30 shows how generation technologies in the database were subsequently reflected throughout this report.

The data collection efforts were aligned with the geographical scope of this report, namely Sub-Saharan Africa, emerging Asia and island nations. Mini-grids in high-income countries were deemed out of scope for this exercise, as these systems are generally focused on addressing resilience challenges and/or renewable energy integration as opposed to improving energy access. Some projects situated in emerging countries outside the scope of this report (e.g., Honduras) were also captured.

Comparison with other research

The World Bank Energy Sector Management Assistance Program (ESMAP) collected data on over 19,000 installed mini-grids in its report *Mini Grids for a Half a Billion People* – a much larger dataset than that of the 4,763 mini-grids collected through this study. (ESMAP, 2019) There are three main differences in the two datasets:

- **Geographical scope:** In ESMAP's report, China, Russia and the US are among the top 10 countries by the number of operating mini-grids. The 2,076 recorded projects equate to just over 10 percent of all the projects. In the database built in this research, projects in more developed economies including China, Russia and the US were excluded as these mini-grids are most likely used for purposes other than just energy access.

Table 30

Generation technology categories in this report

Technology categories	Technologies captured in the database
Solar PV	Solar PV
Hydro	Hydro
Diesel and/or HFO	Diesel
	Diesel + HFO
	HFO
Solar hybrid	Hybrid: Solar PV + Diesel
	Hybrid: Solar PV + Hydro
	Hybrid: Solar PV + Wind
Biomass	Biomass: Cogeneration
	Biomass: Gasification
	Biomass: Palm Oil
Wind	Wind
Other	Other
	Hybrid: Wind + Diesel
	Hybrid: Hydro + Diesel

Source: BloombergNEF.

Figure 142

Projects captured in the database by country

Source: BloombergNEF.

- **Technological scope:** In ESMAP's report, the vast majority of the installed mini-grids included are first and second generation mini-grids (e.g., diesel mini-grids, hydro mini-grids). Thousands of these mini-grids were not included in the database in this study, which focused more on the third generation systems (e.g., renewable hybrid systems). In general, the earlier mini-grid systems, which are often small, are not well publicized as build-out was undertaken by local communities or entrepreneurs. Across the board, third-generation systems are far better documented, given that there is more external involvement and they are in many ways more significant.
- **Limited data on projects in two countries:** Afghanistan (4,980) and Myanmar (3,988) account for almost a half of all the projects that ESMAP counted. However, the authors encountered challenges in accessing these data:
  - Afghanistan's Rural Energy Department under the Ministry of Energy and Water developed and initially publicized a database covering a total of 5,195 renewable energy projects, many of which can be categorized as solar mini-grids installed primarily by NGOs. However, the ministry has since removed the database from public record and despite several attempts, the authors were unable to obtain it from the government or any other source during the period of this research project.
  - Myanmar's project data were collected on the ground through interviews and surveys with local developers in the country. The authors did not take this approach, hence, the vast majority of the data in the country are not included in the database.

Other limitations

There are other limitations in the data collection process and they are worth considering in the development of the database in future:

- **Incomplete information** – Some projects were missing either a commissioning year or operational status. While the authors' mini-grid data accounted for 8GW of generation capacity, only 3GW was reflected in charts in the report. Some of these projects do not show simply because they are not operating. However, some projects did not report either generation capacity or a commissioning year, and therefore cannot be reflected in the time-series charts.
- **Lack of site coordinates** – Less than 1 percent of projects in the database have site longitude and latitude available. Ideally, project data

would be visualized on a map to show sites, which would allow stakeholders to better capture locations of the existing mini-grids. This would be useful for stakeholders' rural electrification plans.

Recommendation

The authors suggest that stakeholders continue to add new mini-grid data as well as update the existing records in the database for the benefit of the sector. The launched database is the initial version. While much effort was taken to reflect the sector in the database, some projects may not have been captured. By developing the database further, research organizations can use it to produce analysis to inform stakeholders of the latest market status. Stakeholders can use the database to support rural electrification planning, technical and financial assistance, and mini-grid businesses.

Appendix B
Assumptions for economic analysis

The authors analyzed the levelized cost of electricity (LCOE) for mini-grids observed today across the six case study countries using the HOMER Pro microgrid model. The authors collected data such as capex and opex from developers through interviews and from research literature. The collected data were aggregated to set the most representative-cost scenario, and input into the software. The modelling output is indicative of the economic performance of a mini-grid asset, and does not necessarily reflect the true economic performance that may be observed in reality. Table 31 and Table 32 show the cost and load profile inputs that were used in running HOMER Pro. The modelling assumed a project lifetime of 25 years.

Cost assumptions

Table 31

Project assumptions for case study countries

Country	Nigeria	Tanzania	Uganda	India (Bihar)	Indonesia	Philippines
Capex (/kW)	3,363	3,847	4,185	4,050	4,500	2,868
Opex ($/kW/year)	161	199	140	200	138	130
Diesel price ($/litre)	0.58	0.97	1.06	1.02	0.75	0.90
Grid power price ($/kWh)	0.080	0.110	0.206	0.085	0.078	0.176

Source: BloombergNEF. **Note:** Capex assumptions are for solar hybrid mini-grids.

Table 32

Load profile inputs

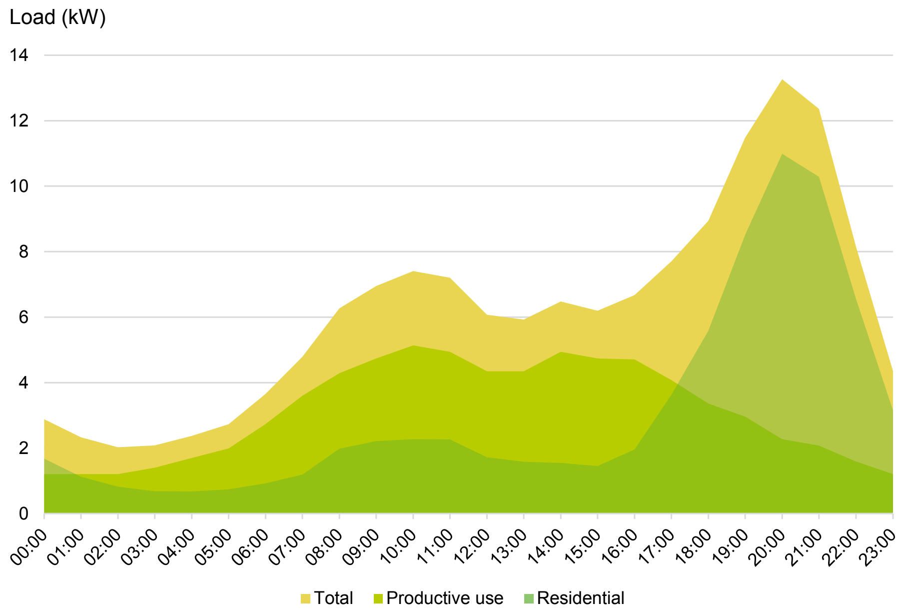
	Residential	Productive use
Residential inputs		
Number of households	250	N/A
High income households (%)	15%	N/A
Medium income households (%)	50%	N/A
Low income households (%)	35%	N/A
Productive use inputs (number of customers)		
Water pumping operations	N/A	2
Milling operations	N/A	2
Small shops	N/A	5
Schools	N/A	1
Clinics	N/A	1
Street lights	N/A	10
Shared inputs		
Total daily consumption (kWh)	74	75
Total annual consumption (kWh)	26,842	27,287

Source: BloombergNEF.

The authors used the Rural African Load Profile Tool designed by the National Renewable Energy Laboratory (NREL) to generate hourly load profiles (Figure 143). The economic analysis has two load profiles, residential and total, the latter being a total of the residential load and the productive-use load.

Figure 143

Mini-grid load profiles



Source: BloombergNEF, NREL.

Appendix C
Methodology for sizing addressable market

About demographic data

Data on many emerging markets are notoriously scarce, so reaching the estimated population breakdown for this report required a fair number of assumptions. The authors primarily relied on population forecasts, separate breakdowns for different income levels (as a proxy of affordability to pay for mini-grid electricity) and different population densities (as a proxy for locations where mini-grids are likely to be more suitable than grid extension or off-grid solar kits). Underlying data are from the World Bank. Data on electrification rates are taken from a range of different sources including Climatescope, the IEA and the World Bank.

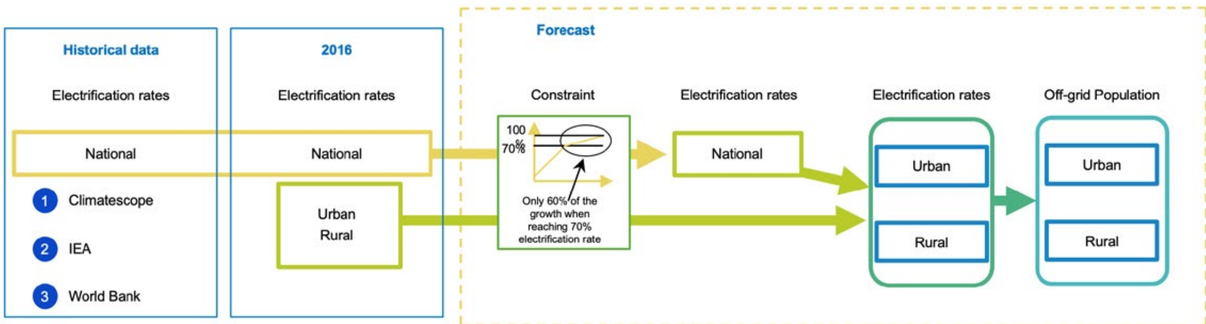
To arrive at an estimate, the authors made the following key assumptions and steps:

1. Urban and rural electrification rates are usually known. The World Bank also provides data on poverty rates defined as individuals living on less than USD 1.90 per day, as well as the population distribution for different income levels.
2. Population density was estimated based on the average density in rural areas for a given country. The authors identified four different density groups, from urban to low-density rural (defined as less than 250 people per square kilometre of land area). The authors then assumed that 60 percent of the population lives within the average density for that country, while 20 percent of the population lives within the higher density and 20 percent within the lower density.
3. Combining the data from the first two steps, the authors broke down each country's off-grid population into 14 different segments (Figure 145).

Historical data show a clear decrease in the percentage of the population living in poverty when GDP per capita rises (Figure 146). The authors assumed that when a country reaches USD 1,000 GDP per capita, no more than 40 percent of the population will live below the USD 1.90/day poverty line. In line with past trends this will slowly decline until 88 percent of the population is assumed to be above the international poverty line when a country's GDP exceeds USD 6,000 per person (Figure 146).

Figure 144

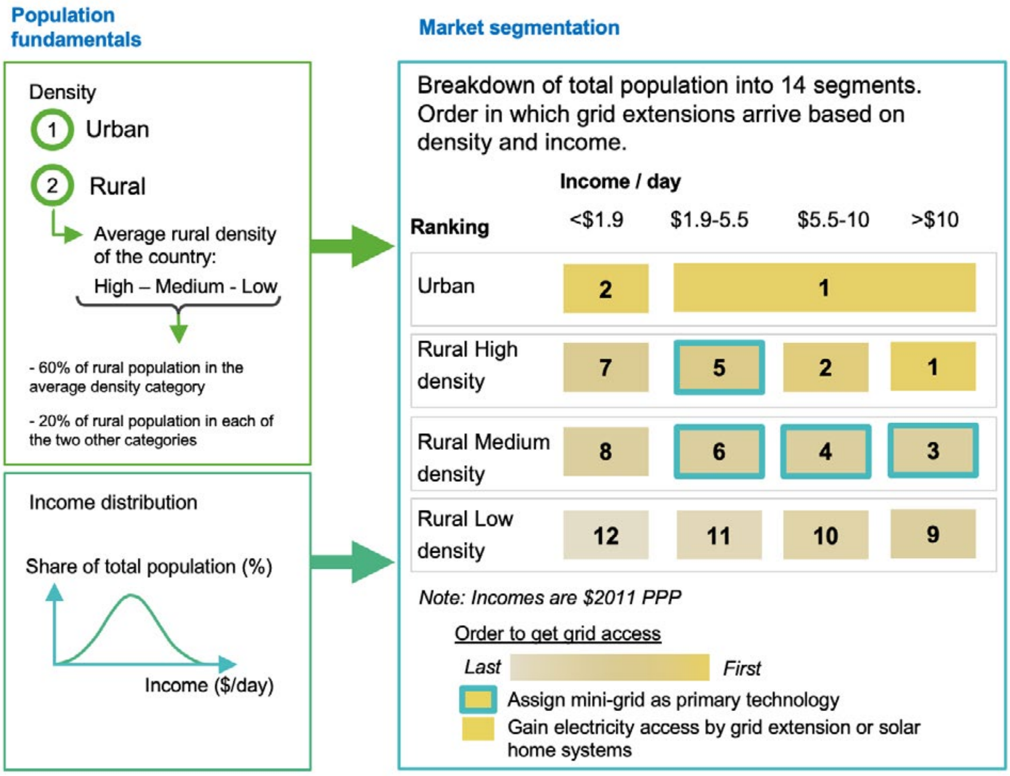
Global off-grid population forecast



Source: BloombergNEF.

Figure 145

Off-grid population breakdown



Source: BloombergNEF.

The authors combined the figures from Step 3 and Step 4 with data on expected population growth, urbanization and GDP growth to assess the number of people living in each segment and country by 2030.

Estimating addressable market size

The authors assigned the mini-grid as the primary technology for four market segments, based on the cost analysis (segments 3-6 in Figure 145). Other market segments are more likely to gain electricity access either from grid extension or solar home systems. The richest and most densely populated segments will benefit from continued expansion of the main grid.

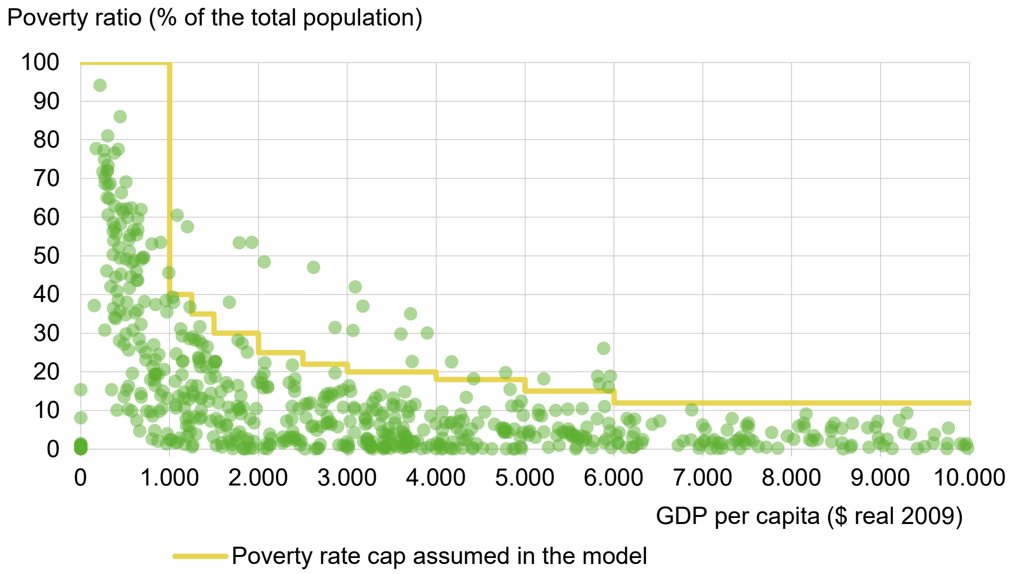
The addressable market size is the number of households that can be economically reached by mini-grids. The pace at which mini-grids are installed depends on the electricity access improvement in each country and assumes that that each country will reach universal access by 2030. Sizes of households differ by country.

Comparison of the market sizing of IEA and estimating addressable market size

A similarly comprehensive analysis of the pathway to reach universal access to electricity was undertaken by the IEA and the Energy Sector Management Assistance Program (ESMAP). The IEA conducted a geospatial analysis calculating the least-cost technology for every single settlement, based on population density and distance from the main grid, using satellite data and results from its World Energy Model. The methodology for this research is less granular and approximates the optimal technology solution for 14 representative population segments with different population densities and income levels in each of the countries studied. Not all the results in this research are directly comparable as the regions covered are different (i.e., Sub-Saharan Africa, Asia and island nations in this research versus global in the research by the IEA and ESMAP), but some figures are comparable.

Figure 146

National poverty rates and GDP per capita



Source: BloombergNEF, World Bank. **Note:** Data included are from 2000-2016. National poverty line is defined as people living on less than USD 1.9 a day (using 2011 purchasing power).

The capital expenditure per mini-grid connection in the analysis carried out for the IEA's World Economic Outlook and ESMAP's Mini Grid Outlook is around USD 2,700 and USD 2,175 respectively. Over the period studied, the mini-grid capital investment per connection increases from USD 914 in 2020 to USD 1,353 in 2030. This is due to increasing solar and storage penetration that typically has a higher capex relative to the lifetime cost compared to diesel generators. Overall, this results in an average capital cost of USD 1,146 per connection.

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