PART II: MINI-GRIDS – SERVING "THE MISSING MIDDLE"

Conventionally, extending the national electricity grid has been seen as the way to provide access. Other options have been regarded as inadequate or interim measures[82]. However, there are several reasons why relying on the grid to provide access is not always the best approach. The rate of grid-based electrification is slow, off-grid options are cheaper in rural and remote areas, and off-grid technology is advancing rapidly.

Off-grid solar household systems and mini-grids can be used to provide energy services across the full range of levels of access, reflecting different households' needs and incomes **(Figure 15)**.

FIGURE 15: TIERS - OFF-GRID SYSTEMS MEET MANY LEVELS OF ENERGY NEED

	TIER ○	TIER ●	TIER ● ●	TIER ● ● ●	TIER ● ● ● ●	TIER ● ● ● ● ●
ENERGY SERVICES		Task lighting and phone charging	General lighting, television and fan	Tier 2 and any medium-powered appliances	Tier 3 and any high-powered appliances	Tier 4 and any very high-powered appliances
CAPACITY		Up to 12 Wh	Up to 200 Wh	Up to 1 kWh	Up to 3.4 kWh	Up to 8.2 kWh
SOLAR PRODUCT	LIGHT ONLY	LIGHT ONLY	SMALL SHS	LARGE SHS	LARGE SHS	LARGE SHS
		LIGHT & CHARGER				
MINI GRID			MINI GRIDS	MINI GRIDS	MINI GRIDS	MINI GRIDS

Many efforts to bring power to Africans who do not have sufficient access are focused on large-scale grid-power development projects and small off-grid solutions, leaving a sizable "missing middle" in the dark. While rural electrification constitutes a top priority for most African governments, little has been done to try to meet the power needs of the missing middle.

Mini-grids – which can be grid-connected or independent – lie in the middle, between off-grid systems and grid connections. They comprise an electricity generator and a distribution network that supplies several users, such as households and businesses. The International Energy Agency (IEA) estimates[83] that 140 million people in Africa will gain access to electricity through mini-grids. This would require the installation of 4,000 to 8,000 mini-grids a year for the next 25 years, a number that far exceeds all current estimates of mini-grid investments in Africa[84]. While initiatives to promote off-grid household systems and investment in centralized grids have taken off, the promotion of mini-grids appears to lag.

Mini-grids offer a number of advantages over grid extension and off-grid household systems. They allow flexibility in design and scale, as well as in business or operational model. They can provide electricity in rural and remote areas, where populations are dispersed and per capita electricity consumption is low, at much lower cost than grid extension[85]. In terms of tiers of access, mini-grids can provide up to tiers 4 and 5 **(Figure 15)**, though most[86] deliver tiers 2 and 3. They require smaller capital investment than grid expansion, making it easier to secure finance. Mini-grids can provide electricity in remote areas for productive uses such as farm machinery, which usually require more power than an off-grid household system can provide. They also allow economies of scale to be exploited where houses, businesses and public services in remote areas are physically close to one another.

Despite these advantages, mini-grids are expanding in Africa at a slower rate than in other regions and more slowly than off-grid household systems. There are several reasons for this limited progress. Proven commercial business models are lacking, as are adequate and appropriate forms of financing and implementation capacity[87]. In addition, policy frameworks for mini-grids are inadequate and uncertain, and many developers and operators lack the requisite experience and knowledge of mini-grids[88].

> **MINI-GRIDS OFFER A NUMBER OF ADVANTAGES OVER GRID EXTENSION AND OFF-GRID HOUSEHOLD SYSTEMS.**

On the positive side, the context is rapidly changing for both solar household systems and mini-grids. Opportunities are increasing because policymakers are paying greater attention to electricity access and because more funding is available from development finance institutions and donors. Off-grid electricity is becoming more attractive worldwide because of falling costs of renewable-energy options, more efficient technologies for generation and electrical appliances, and innovations in the use of digital technology for the management of electricity services. Africa has the potential to be at the forefront of this off-grid electricity transformation.

There is no universally accepted definition of a mini-grid, except that it is a system that combines generation capacity and a distribution network. Sustainable Energy for All (SE4All) uses a definition that embraces a variety of systems or models, mainly to distinguish them from stand-alone household systems and extensions of the main grid. This definition includes mini-grids that are unconnected to the main grid (i.e. off-grid) and systems that are connected but able to operate independently. In the current report, mini-grids that are unconnected to the main grid are called isolated mini-grids[89].

The range and variety of mini-grids have given rise to a number of different categorizations, usually based on the capacity of the system. For example, the International Renewable Energy Agency (IRENA) has proposed[90] that they be called pico-, nano-, micro- and mini-grids according to capacity (under 1kW, under 5kW, under 100kW and under 100MW, respectively). The UK Department for International Development (DFID)[91] has suggested the following categorization, combining criteria on capacity and whether they are isolated or connected to the national grid:

Grid-connect/proximate – (> 1MW)
Isolated – (100kW – 1MW)
Very small isolated (micro) – (< 100kW)

The great majority of mini-grids in Africa fall in the capacity range between a few kilowatts and 10-15MW; some are isolated, some are connected to the main grid.

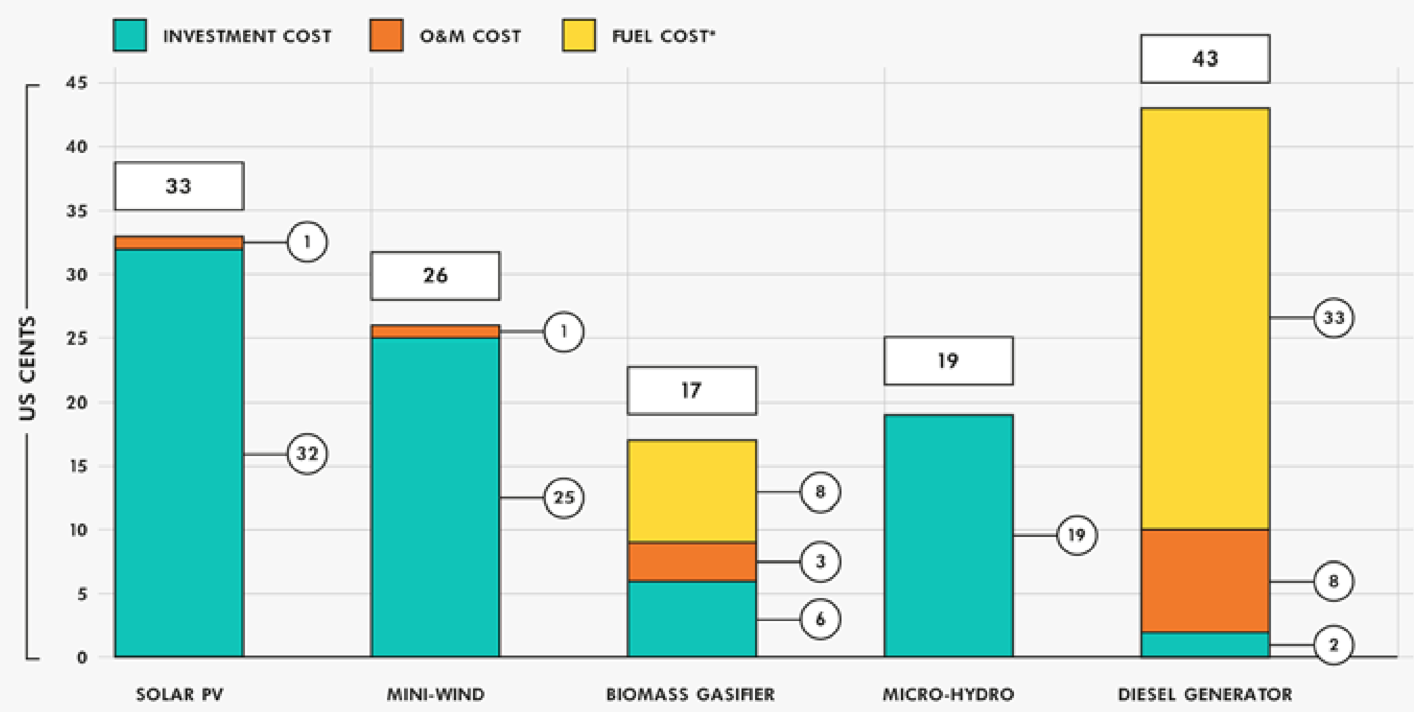
Around 5 million households worldwide are supplied by mini-grids using renewable energy sources[92]. The installed capacity of mini-grids globally includes 75GW of hydropower, 23GW of diesel generators and several thousand solar-powered systems.

Mini-grids have been installed in almost every African country, although detailed information is often unavailable, including whether the programmes are still operating. In some countries, including Mali, Senegal and Tanzania, mini-grids are already an established part of the delivery of electricity services and integral to efforts to extend access to electricity. The total installed capacity of mini-grids in Africa is currently around 1.2GW, or 0.7 per cent of the continent's on-grid installed capacity in 2012[93].

Existing mini-grids in Africa are mostly diesel or hydropower systems, though the number of solar PV and hybrid systems is growing. The International Energy Agency has estimated that almost one-third of the mini-grids needed to provide off-grid access to electricity in Africa will be diesel or petrol-fuelled systems, with the other two-thirds relying on renewable energy sources. Solar PV mini-grids will grow rapidly and will have the largest share (37 per cent) by 2040, followed by hydropower (20 per cent), wind (8 per cent) and bioenergy (3 per cent)[94].

Mini-grids that use diesel or petrol generators have the advantage of low capital costs. This makes them an attractive option where incomes are low and the cost of finance is high. They have the added advantage that the technology is widespread, making repairs and maintenance easier. Diesel generators, however, depend on a regular supply of fuel, which can be interrupted in remote areas and is subject to price fluctuation. Fuel accounts for most of the cost of electricity from diesel generators **(Figure 16)**.

FIGURE 16: GLOBAL COST OF ELECTRICITY GENERATED BY MINI-GRID SYSTEMS



Source: Clean Energy Ministerial (2014)
Note: * Dependent upon the price of diesel

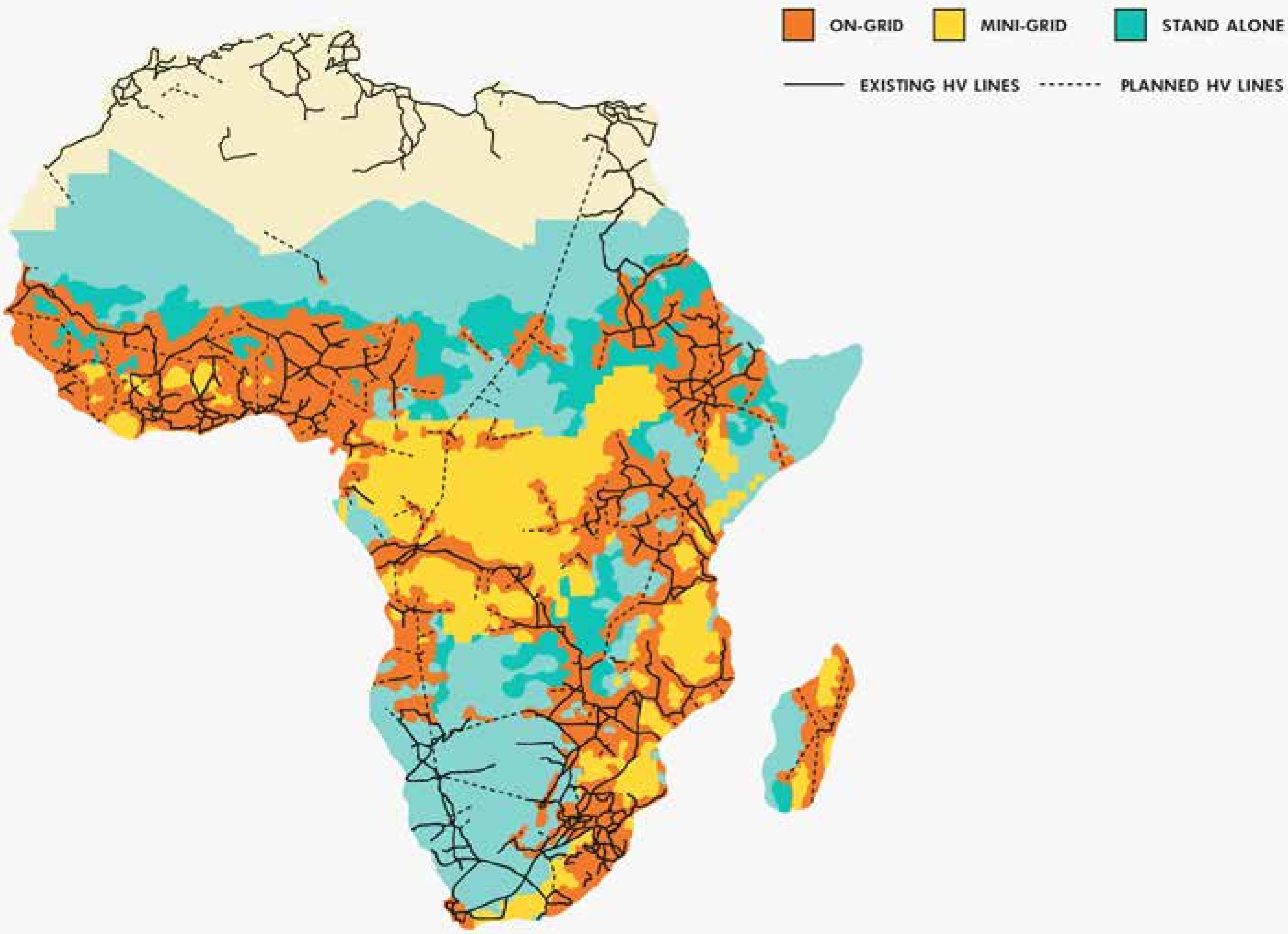
Figure 16 also shows that, on average, renewable energy mini-grids produce electricity at: US$0.19-0.33 per kilowatt-hour (kWh) which is lower cost than diesel systems which produce at US$0.43/kWh (depending on the price of diesel). The cost of electricity supplied by renewable-energy mini-grids is determined by the initial investment cost, with the exception of biomass-fuelled systems. The higher investment cost and longer payback period presents a challenge for the financing of renewable energy systems (see below).

Though most renewable energy mini-grids do not face the risk of interrupted fuel supply or fuel-cost increases, their effective generation capacity may vary according to weather and season. Electricity storage, in batteries, is one way to overcome this variability, particularly for solar and wind systems. Another way is to combine different sources of energy in "hybrid" schemes, commonly solar or wind combined with diesel; hybrid solar-wind and solar-biomass systems can also be found. Hybrid renewable-diesel systems are more economic than diesel only[95,96].

The potential of isolated mini-grids to increase access to electricity has been assessed in several modelling studies, based largely on cost comparisons[97]. The most recent of these is the model developed by the United Nations Department of Economic and Social Affairs[98], which provides a graphic description of where mini-grids (or grid extension, or stand-alone systems) are likely to be the least-cost electrification option under different sets of assumptions **(Figure 17)**.

FIGURE 17: THE MINI-GRID POTENTIAL

Areas best suited to grid, mini-grid and stand-alone systems, Sub-Saharan Africa



Source: UNDESA (2016)

MINI-GRID MODELS

Four kinds of model for the operation of mini-grids are usually distinguished: utility, private, community and public-private. Each has its own advantages and disadvantages **(Table 4)**.

Utility model

In the utility model, a large or medium-sized state-owned or private utility company is responsible for the installation and operation of mini-grids[99]. The utility operates the mini-grid in the same way as the main grid, generating electricity and distributing it to consumers. When the tariffs for consumers are the same as on the main grid, the utility cross-subsidizes the tariff for those connected to the mini-grid (because the unit cost of electricity from mini-grids is higher). The mini-grid investment is likely to be financed by the government, as utilities tend to operate mini-grids only at government instigation and not to regard them as core business or an important source of revenue.

The Tsumkwe mini-grid in Namibia is an example of a utility model mini-grid. This PV-diesel hybrid mini-grid, with a capacity of 202kW, supplies power to 3,000 residents of the Tsumkwe settlement area, as well as 35 commercial and public-service customers. The mini-grid was financed by public and donor finance, and is owned by the regional government, Otjozondjupa Regional Council, and operated on their behalf by the Ministry of Public Works. The regional government manages revenue collection and finances fuel purchases[100].

Private model

In the private model, a private company develops, installs and operates the mini-grid, generating electricity and selling it to connected customers[101]. This is distinguished from the utility model because the company tends to be small or medium-sized and does not also operate the main grid. Finance for the investment may come from a variety of sources, including grants, commercial or concessional loans, and equity. Most privately operated mini-grids have received some form of public support, but purely private mini-grids do exist, such as those operated by American company Powerhive and German company Inensus[102].

Powerhive has been granted a concession to generate and distribute electricity in Kisii and Nyamira, Kenya. The company currently operates four solar PV mini-grids, supplying over 1,500 customers in Kenya. These mini-grids use information technologies to manage the mini-grid management and collect payments. The company used project finance for the first mini-grids, and has recently secured US$11 million in equity finance and US$20 million in venture-capital finance to extend its electricity services to 90,000 people[103].

Community model

When the community served by a mini-grid owns and operates it, the design and installation has often been done by a third party, contracted by the community or on its behalf by an non-governmental organization (NGO) or development agency. Rural communities rarely have the expertise to plan and build mini-grids themselves. The investment finance is generally from grants, supplemented by a cash or in-kind contribution from the community. The operation of a community mini-grid, including revenue collection, is usually managed directly by a village committee formed for this purpose or by a cooperative, but in some cases is contracted to an entrepreneur[104].

Four hydropower mini-grids in Kenya, at Thima, Kathamba, Tungu Kabiri and Kipini, illustrate the community model. In each case the community is responsible for the operation and maintenance of the system, from generation to transmission and revenue collection. The community schemes have elected management committees for this purpose. Kathamba, Thima and Kipini supply mainly households (55, 115 and 120 households, respectively)[105], while Tungu Kabiri serves small businesses.

Community-owned mini-grids are generally initiated by the communities themselves. The initial capital is usually raised through contributions from community members interested in the project. In the case of Tungu Kabiri, 200 members of the community each bought a US$50 share in the company specially formed to own and operate the plant. The schemes also received donor support, in the form of technical support (Kathamba and Tungu Kabiri), equipment (Kipini) and applications for grant funding (Kipini and Tungu Kabiri).

Inadequate power supply has been a challenge for these community-owned mini-grids. This has been managed partly by limiting the hours of service and by varying tariffs for different levels of consumption. The community schemes in Kenya, however, demonstrate that communities can organize themselves to build and operate mini-grids and that they are willing to invest their own time and money to ensure a supply of electricity.

Public-private model

The public-private model can exploit the advantages of the other models and minimize their risks by dividing ownership and operation of a mini-grid among different public and private organizations (as is increasingly being done with national power systems). For instance, generation might be the responsibility of a private company, under a concession from the utility, and distribution of the electricity might be the responsibility of a community organization, which contracts a private business to provide technical support. There are numerous variations of the public-private model, but all require contractual arrangements between the different organizations involved.

Senegal, for example, has boosted rural electrification through a model in which the government retains ownership of the mini-grid and a private company is awarded a 15-year concession to operate and maintain it. This approach, under the Renewable Energy for Senegal (ERSEN) Off-grid Solar Energy Programme, has been followed for 18 mini-grids powered by solar PV and diesel generators. These supply electricity to over 38,000 households, 88 schools and 88 clinics, as well as businesses and public buildings[106].

The Dutch-German Partnership Energising Development (EnDev) and the European Union have provided 80 per cent of the investment cost, with 10 per cent coming from the private operators and 10 per cent from the communities served. Tariffs, which cover operation and maintenance costs, are negotiated by the private operator and vary among schemes. Community involvement has been organized through representative project-management committees in each location.

TABLE 4: ADVANTAGES AND DISADVANTAGES OF MINI-GRID MODELS

	Advantages	Disadvantages
Utility model	• Utilities have experience in electricity generation and distribution, as well as administrative processes • Utilities are likely to have access to policymakers and public and donor funds, and require little additional regulation • Implementation of uniform tariffs across the electricity sector is straightforward • The model enables economies of scale for spare parts and maintenance	• Utilities lack incentives for a decentralized approach and may not give priority to mini-grids in rural areas • Power utilities are often inefficient, financially precarious and subject to political interference and corruption • Utilities may not have capacity for the complexity of planning, implementing and operating multiple mini grids • Utilities may be unresponsive to local circumstances and unable to innovate • The model may only be able to attract public finance
Private model	• Companies may have good technical competence, ability to manage risks and capacity to offer efficient operation and management • There is an incentive to pursue financial sustainability when driven by market dynamics rather than government subsidies • Private companies can better quantify project benefits (and costs) and thus improve pricing and tariff collection • Decentralized implementation and management reduces risk and administrative capacity requirements • Companies can attract private investment and make efficient use of limited capital	• Upfront financial support may be required to ensure that mini-grids are financially attractive • The African private sector lacks experience and technical capacity • Tariffs are needed to cover costs • Companies need to manage relations with communities served • The model requires a stable policy and regulatory framework that is well defined and supportive
Community model	• The model enables community buy-in and increases ownership among electricity consumers, which can improve operation and maintenance • There is a higher chance that the system is appropriate to the community's circumstances and priorities • The model supports community self-sufficiency and empowers local people • Management can be pragmatic and more efficient than large, distant, bureaucratic utilities	• Communities may lack the necessary technical and business skills • Local governance of mini-grids needs to be clear and well managed • Community decision-making can slow implementation and be affected by conflicting social interests
Public-private model	• The model combines the advantages of the other models and may mitigate their challenges and increase opportunities for mini-grids • Responsibilities can be configured to maximize advantages (e.g. if the utility is the distributor, uniform tariffs across the sector can be more easily applied; if the private sector is involved, private investment may be facilitated)	• Differences in the management systems of each entity can increase transaction costs • A strong framework is required to balance the interests of different actors and establish the interface between them

Sources: GVEP (2011b), Seguin (2014), RECP (2013)

Mini-grids in Africa are generally conceived as a means to supply electricity in areas remote from the main grid. The models described above all apply to such isolated mini-grids. In practice, mini-grids may be connected to the national grid from the start of their operation or later. Taking this option into account, four kinds of scheme can be distinguished:

- Isolated small power producer selling directly to retail customers (this is the conventional mini-grid)
- Small power producer connected to the national grid, selling directly to local retail customers and selling surplus power to the grid (or drawing power from it)
- Small power producer connected to the national grid and selling wholesale to the utility or electricity wholesaler (i.e. the conventional independent power producer, IPP)
- Small power distributor, purchasing electricity from the grid and retailing it to localized customers.

Given the challenges facing the power sector in most African countries, all of these models could be considered in the development of electricity systems. By allowing diversity in the way electricity is generated and distributed, African countries could leapfrog to a new model for the sector, as argued by Jim Rogers, the former chief executive of Duke Energy, one of the world's largest utility companies. The new model "is one in which power is no longer solely delivered through a complex and expensive grid of base load generation and fixed wires, but through a mix of renewable technologies that are more affordable, smaller and decentralized"[107].

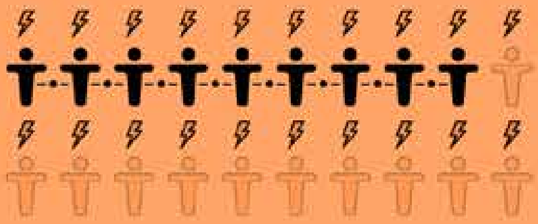
Mini-grid experience in Asia and North America offers African governments and their partners some valuable lessons, notably about finance, regulations and innovation **(Box 3)**. **(See infographic: Mini-Grids: Africa versus Asia)**

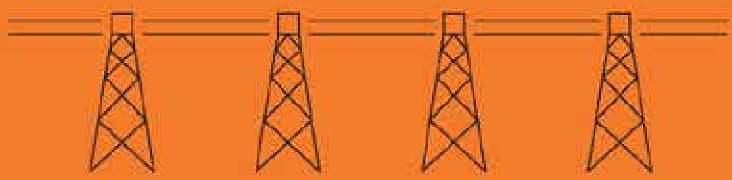
MINI-GRIDS: AFRICA VERSUS ASIA

OVERVIEW

1.2 billion people (17% of the global population) live without electricity. The vast majority are in Sub-Saharan Africa (53%) and the Asia-Pacific region (43%).

315 million Africans in rural areas will gain access to electricity by 2040, 45% of them from mini-grid systems





HYBRID SYSTEMS

Small-scale hydropower is the largest source of electricity generation for mini-grids in countries such as Nepal, with diesel coming in second.

Many small islands, for example in Indonesia, the Philippines and China, rely on diesel generation for electricity. Mali uses diesel more than any other African country, with 200 mostly small mini-grids in operation.

These diesel-powered mini-grids are undergoing hybridization to integrate renewables.

↓ SUCCESS STORIES: AFRICA

MOROCCO

Morocco is an African leader in electrification using village-scale mini-grids. By 2010, 3,663 villages had been electrified with solar energy.

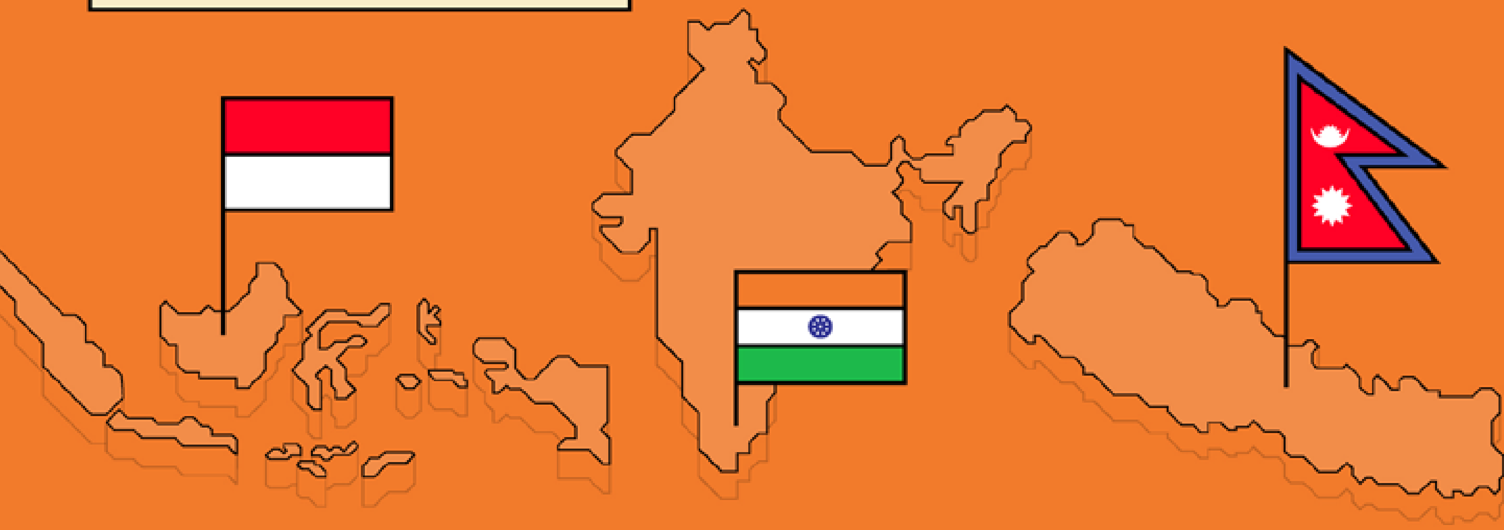
MALI

Access to electricity in Mali's rural areas jumped from 1% in 2006 to 17% in 2012. Mali has the largest number of solar **PV/diesel hybrid mini-grids** in Africa.

SENEGAL

Senegal has installed 35 hybrid mini-grids (solar PV and diesel) and plans 41 more. It is one of Africa's most active proponents of **hybrid mini-grids.**

↓ SUCCESS STORIES: ASIA



INDONESIA

In 2015, more than 600 micro-hydro plants were providing off-grid electricity to rural areas of Indonesia.

INDIA

In early 2016, the state of Uttar Pradesh offered incentives for mini-grids. By the end of 2016, 500 solar mini-grids were to be installed.

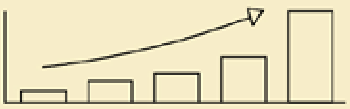
NEPAL

In Nepal, around 1,300 micro-hydro plants and 1,600 pico-hydro systems were in operation in 2015.

TYPES OF TECHNOLOGY USED IN MINI-GRIDS IN BOTH AFRICA AND ASIA: SOLAR, HYDRO, BATTERY, DIESEL, BIOGAS

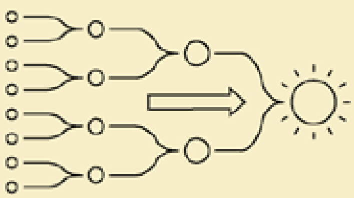
SUCCESS FACTORS

HOW TO PROMOTE MINI-GRIDS

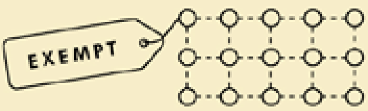


Foster a stable, long-term policy environment to boost investors' confidence.

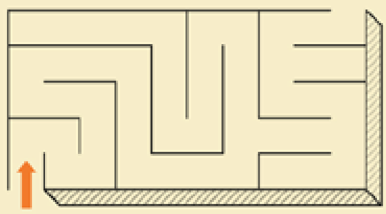
Set clear guidelines, requirements and tariffs through robust, transparent policies and regulations.



Make it easy for mini-grid developers to obtain permits, finance and other necessities.



Exempt very small mini-grids from some regulations.



CHALLENGES FACING MINI-GRID DEVELOPMENT

- Many mini-grids have so far relied on subsidies, which may not continue.
- Higher tariffs
- Lack of a clear framework for mini-grid policies and plans.
- Delays and bureaucracy
- Lack of business focus
- Limited private sector involvement

BOX 3: AFRICA CAN LEARN FROM MINI-GRID EXPERIENCE IN ASIA AND AMERICA

In 2015, North America and Asia had the two largest shares of the world's installed micro-grid capacity, and over half of that (54 per cent) was off-grid[108]. Africa and the Middle East together accounted for only 1 per cent of the market.

Asia: Favourable policy and regulation is vital

Rural electrification in Asia has been pursued mainly through grid extension, as in Africa[109]. Where this approach is too expensive, off-grid electricity systems have been promoted, in some places for more than three decades [110]. Most of these mini-grids are based on either solar PV or micro-hydropower. Diesel systems are also found, notably in the Philippines[111].

Most mini-grids in Asia provide limited electricity services for household use, and are difficult to establish and sustain. To be successful, models need to combine public and private finance, and aggregate investments at a scale that reduces the transaction costs and operation and maintenance (O&M) costs for each scheme. Mini-grid programmes should be able to adapt to a variety of environmental and social contexts.

In South Asia, mini-grids have mainly followed a community model and been financed by grants[112]. But many community mini-grid projects in South Asia have struggled to become financially viable. They have been more successful when they have promoted productive uses of the electricity and enabled consumers to purchase appliances.

A review of seven micro-grids (six in Asia and one in Haiti) identified seven key considerations for mini-grid development: tariff design, tariff-collection mechanisms, maintenance and contractor performance, theft management, demand growth, load limits, and local training and institutionalization[113]. Experience in Asia also shows that all mini-grid models require favourable government policy and regulations, including capital subsidies, in order to be viable.

One key question for developers is what will happen if the main grid is extended to a mini-grid location. The publication of grid-extension plans and a clear policy for the future of mini-grids when the main grid arrives would help reduce the risk of uncertainty for investors.

Tariff regulations are another area of concern for mini-grid developers. Mini-grid programmes that rely on revenue from consumers to cover costs (capital and operating and maintenance costs) need tariffs that reflect these costs. If regulations do not allow these tariffs there should be subsidies for the producers or the consumers.

North America: Resilience, renewables and innovation

The first electricity-generation and distribution systems in the United States, introduced in the 1880s, were mini-grids; these were interconnected later. In recent years, there has been a return to such systems, now usually called micro-grids. Most have a capacity of 1MW or less. They are usually connected to the main grid, but can operate separately when necessary. Aggregate installed capacity is expected to exceed 1.8GW by the end of 2017[114] and 2.8GW by 2020[115].

One reason for this return to small networks is the need to increase the resilience of the electricity supply. On an extensive main grid supplied by large generation plants, power cuts can affect a very large number of businesses and households[116] and it can be difficult to restore services quickly. Micro-grids can continue to supply consumers when the main grid suffers interruptions.

Micro-grid investment has also increased because there is greater interest in exploiting renewable energy resources for lower-cost distributed generation. In 2014, 90 per cent of micro-grid installed capacity was based on fossil fuels. By 2020, the share of renewables is expected to reach 26 per cent[117].

Growth in micro-grid investment has been facilitated by public finance, directly in the form of grants and indirectly through tax breaks[118]. This has enabled innovation in the use of digital technologies to manage generation and distribution.

Recent experience of mini-grids in the United States offers two lessons for Africa. First, early adoption of technical innovations, particularly of digital management tools (for generation, distribution and revenue collection), could enable mini-grid business models to be more efficient and financially viable. Second, new technologies and approaches are introducing new organizational models for electricity systems that may prove more efficient and resilient than the conventional utility-based approach.

ACCELERATING MINI-GRID DEVELOPMENT

System management

Managing demand

In all African countries, the power sector faces the challenge of reliably balancing electricity supply with demand; failure leads to power crises, as Nigeria and Ghana are experiencing. In most countries there is both unmet demand and rapidly growing demand from existing consumers. Mini-grid operators need to be able to match the supply of electricity with demand during the day, as consumers vary their consumption. They also need enough overall demand to ensure that the system is financially viable. In addition, renewable energy mini-grids need to manage generation from solar PV, wind and hydropower, which varies with the weather or the season.

Operators can manage demand in several ways. They can promote energy-efficient appliances and lighting, such as light-emitting diode lamps (LEDs); they can restrict the use of electricity by individual consumers; and, where regulations permit, they can vary the tariff. Technologies such as electricity storage (batteries), current limiters, load controllers and meters can help to manage demand.

Recent innovations with digital technologies, similar to those used in micro-grids in the United States, are also being tried in Africa, increasing the spread of "smart micro-grids". Smart meters offer the potential to measure consumption, facilitate payments and automatically manage a mini-grid's overall load.

In Kenya, for example, the automatic system deployed by Powerhive at Kisii includes distributed meters that use wireless communication to transmit electricity-consumption data and customers' credit balances (on prepaid accounts) to the company[119]. The SharedSolar systems installed in Millennium Villages in Mali and Uganda also combine prepaid metering with central monitoring and control, with up to 10 households connected to each meter. Customers have a daily consumption limit and a maximum power limit, and purchase credit by SMS message[120].

When most of a mini-grid's customers are households, electricity consumption reaches a peak in the evening when people have stopped work for the day. This means that for a large part of the day the mini-grid's installed capacity is under-utilized and the unit cost of electricity consumed is higher. The load factor – the proportion of electricity generated that is consumed – can affect the viability of a mini-grid. Many schemes are designed with an "anchor load", such as a school, health centre, commercial business, manufacturing enterprise or mobile-phone mast that can consume a significant and stable proportion of the power generated. In the planning and design of mini-grids, the capacity of the scheme also needs to take account of expected increases in demand (load factor) over the life of the plant.

Tariffs and revenue collection

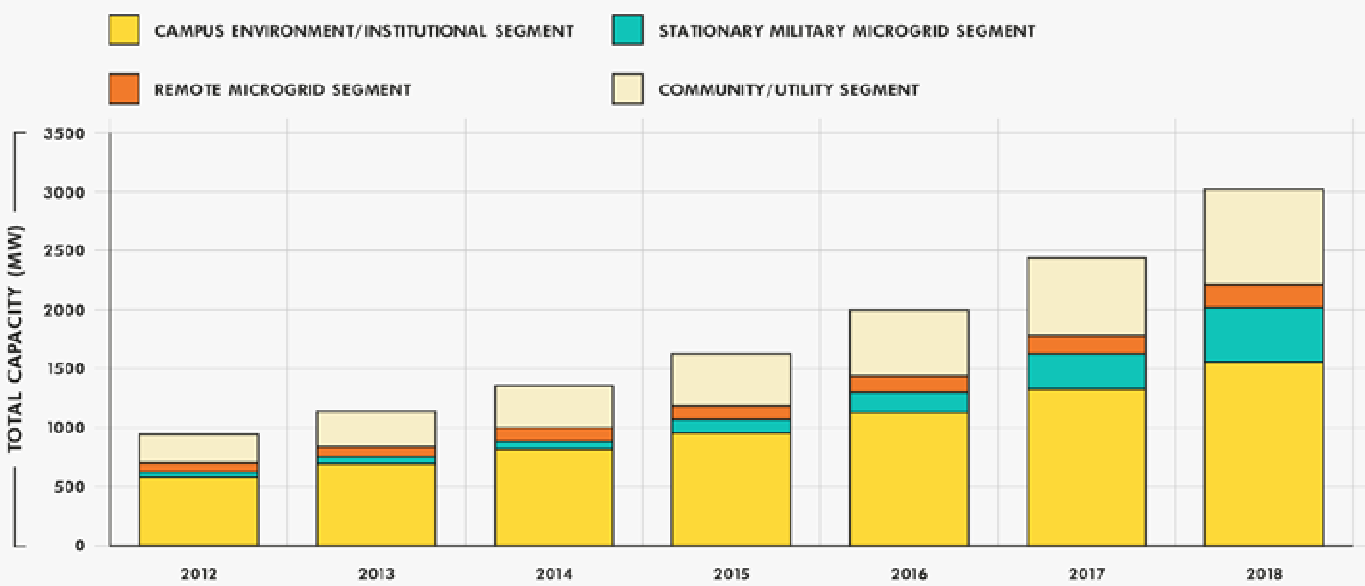
The financial viability of mini-grids depends on their ability to collect enough revenue to cover at least their operating and maintenance costs. A grant or subsidy may provide the initial capital for utility and community-operated schemes, so that they only need to cover operating and maintenance costs. By comparison, private, commercial schemes may also need to recover financing costs and to ensure a profit for the equity-holders.

Mini-grids that provide an alternative to grid extension are likely to be located in rural and remote areas where population density and per capita incomes are low, reducing the prospects for collecting revenue. This disincentive for commercial investment in mini-grids can be mitigated by an anchor load, but often public finance will be necessary for the initial investment.

In addition, although the total cost of extending the grid to a particular location may be higher than the cost of installing a mini-grid there, the unit cost of electricity (e.g. in dollars per kilowatt hour) on the main grid is usually lower **(Figure 18)**. This indicates that the consumer tariff on the mini-grid should be higher than the tariff on the main grid, if tariffs are to cover costs. Government regulations, however, may determine what can be charged (see below).

FIGURE 18: THE COST OF ELECTRICITY IS LOWER ON-GRID THAN OFF-GRID

Levelized costs of on-grid and off-grid electricity in Sub-Saharan Africa, 2012



Source: IEA (2014)

Tariffs do not necessarily have to be based on units of electricity (kWh). In some cases, the tariff is based on the power consumption (in Watts) of consumers, setting a monthly charge and a maximum power limit. Alternatively, tariffs can be applied on a fee-for service basis, using units of service, such as hours of lighting or the avoided cost of kerosene. Variations include flat-rate tariffs, time-based tariffs (e.g. higher rates during peak hours) and tariffs set by customer category (i.e. residential, commercial, industrial). Advanced metering, digital technologies and mobile communications can facilitate setting tariffs and managing payments.

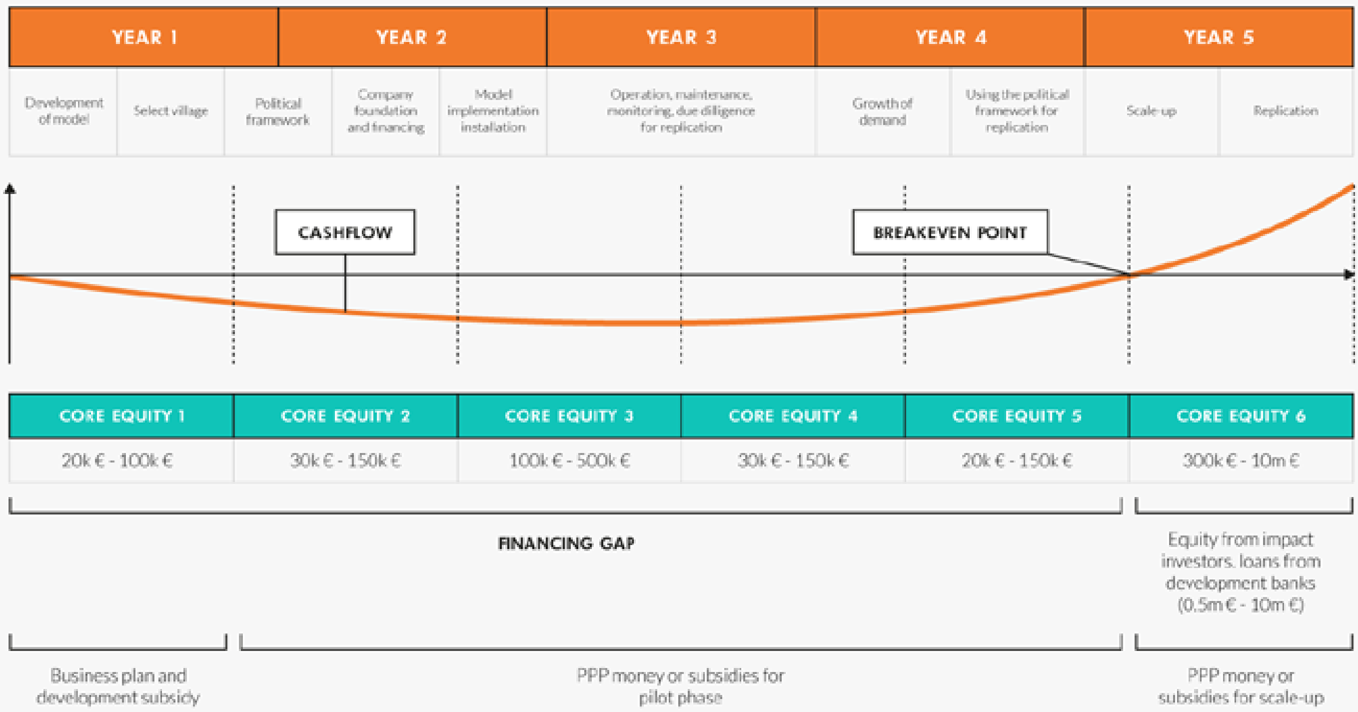
Financing mini-grids

Financing the operation of mini-grids is largely a question of setting tariffs that reflect costs and collecting revenue efficiently, as described above. This section focuses on financing the up-front costs of mini-grids from public and private sources. Initial financing is a particular constraint on developing mini-grids that use renewable sources **(Figure 19)**.

The capital cost of mini-grids varies according to the capacity of the system to be installed, the size of the distribution network, the source of energy for generating electricity and the specific location. This leads to variation in estimates of the total investment required for mini-grids in Africa, as well as in the costs for individual countries. The International Energy Agency, for instance, estimates[121] that over US$300 billion globally would need to be invested in mini-grids to achieve objectives for access to electricity. Its estimate of total off-grid investments in Africa[122] to 2040 is US$61.5 billion, but more would be required to achieve universal access to electricity.

FIGURE 19: THE RENEWABLE MINI-GRIDS INVESTMENT CHALLENGE

Early year cash flow for a renewable mini-grid



Source: RECP (2013)

Where will this initial finance come from? In practice a combination of public finance (from governments and donors) and private finance (equity and debt) will be required to overcome the risks and transaction costs [123], and to reach the scale of investment needed to ensure access to electricity in rural areas. Based on its experience in East Africa, Energy 4 Impact (formerly known as GVEP International) suggests that local commercial banks would provide only 60-70 per cent of the total investment cost. Grants, equity and in-kind community contributions would have to make up the balance.

Most public finance for mini-grids has been provided by international donors, through government and non-governmental organizations. Utilities and rural electrification agencies have been reluctant to finance mini-grids because they are not perceived as core business and may not provide substantial revenues. But the availability of donor finance for mini-grids is increasing, particularly for renewable energy mini-grids, for example from the Solar Energy Finance Association, UK Department for International Development (DFID) and the Africa-European Union Renewable Energy Cooperation Programme (RECP).

Private investors perceive mini-grids as a high risk. In rural or remote areas, infrastructure and the business environment may be under-developed, and markets are constrained by low incomes. Few developers or businesses have experience of investing in or operating mini-grids.

Diesel-fuelled mini-grids pose risks of variations in the fuel price and interruption to supply. The high initial investment cost of renewable energy mini-grids requires a long pay-back period, posing a market or demand risk from changes in demand or the arrival of the main grid. Political risks from changes in the policy and regulatory environment can be mitigated by a strong sustained policy framework, and good design and management.

Because of regulatory weaknesses (see next section) and because they are unable to exploit the economies of scale of national grids, mini-grids can have high transaction costs[124]: project design and development, licensing, due diligence, even financing costs – which are necessary irrespective of the size of a system – can be disproportionate to a mini-grid's overall investment cost.

Transaction costs can be reduced by aggregating mini-grid projects into larger programmes for financing. Several developers are taking this approach, including Inensus, Africa Power, Synchronicity and African Solar Designs. At the same time, development finance institutions such as the African Development Bank, Islamic Development Bank and Department for International Development are looking at mechanisms for investing into portfolios of mini-grid projects. Providing grants or concessional loans for the early stages of mini-grid development, complemented by equity investment (including from the communities to be served), would address the transaction-cost barrier and make mini-grids more attractive to private investors[125].