Policy briefing

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The history of mini-grid development in developing countries

Improving access to modern energy services in rural areas in developing countries remains a major development priority. While many countries continue to pursue ambitious and often challenging grid connection programmes, there is increasing interest in decentralized generation and distribution through mini-grids.

These are defined here as a power source of <3MW (diesel, hydro, biomass, hybrid) supplying a local distribution grid connected to domestic, business and institutional customers in the locality. This brief summarises some of the main approaches to mini-grid development, the requirements for successful implementation and key challenges to their development, particularly in Africa. Country examples are referred to where available. *Leo Peskett*

Key Points

- Mini-grids can be designed using a range of technical and institutional/financial approaches. Hybrid mini-grids using multiple generation technologies can improve reliability of supply, although there may be trade-offs with management complexity.
- Mini-grids provide potential opportunities over grid-connected electrification, such as enhanced reliability of supply, lower costs in remote locations and better environmental performance.
- Mini-grid schemes need to overcome significant challenges in their development. Technical challenges include poor matching to local context and poor maintenance. Asia has been relatively successful in mini-grid development, while the challenges are greatest in Africa.
- Successful mini-grid development requires:
  - Design based on detailed analysis of local context including natural resources, supply chains, energy demand and current/future energy policies.
  - A favourable policy environment which may involve changes to national laws which favour grid electrification.
  - In community schemes sufficient time is required during project design to establish clear governance structures and to build community trust. Mini-grid schemes need to be linked into wider rural development strategies in order to match demand.
  - Securing sustainable finance to cover upfront costs. Ideally, at least the operation and maintenance costs must pay for themselves (through tariffs) in the long run for schemes to be feasible.

Introduction: The evolution of mini-grids in rural electrification

Centralized power generation has been the dominant approach to electrification in developed countries over the last century since the development of improved generation technologies such as large-scale steam turbines, the introduction of transformers and high voltage lines using alternating current (REEEP, undated).

A similar centralized approach has been followed in many developing countries. In post WW2 Africa, for example, centralised electricity generation was seen as a precondition for development, with the delivery of electricity and infrastructure paving the way for economic growth.

This approach overlooked constraints such as a dispersed population, low purchasing power and limited potential for load growth (Kirubi et al., 2008).

Since the 1980s the approach has evolved, supported by studies that have consistently shown that electricity in itself cannot bring rural development, and that inequity in access is prevalent where supply had been achieved.

Despite success in increasing rural energy access in some developing countries (e.g. Costa Rica, Thailand and Tunisia - Barnes, 2005), rural energy access remains a major challenge in many countries, with more than 1.5 billion people worldwide without access to electricity. Around 80% of these people live in rural areas and a large proportion are in Africa. By 2030, the number of people without electricity is likely to remain similar to the present day due to population growth (IEA, 2009).

Interest in decentralized or off-grid energy generation has grown over the last twenty years as developing countries continue to grapple with the challenge of increasing rural energy access.

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Support to off-grid electrification by the World Bank, for example, has grown from only two projects prior to 1995, to 31 since then (IEG, 2008). Mini-grid generation technologies have become cheaper (including dramatic cost reductions for some renewable technologies) and have increased in reliability, resulting in lower capital, operation, and management costs. In some areas this has made them more cost effective than on-grid, or completely off-grid technologies (IEG, 2008). A shift in donor and government policies towards a 'pro-poor' and environmentally friendly focus, has also helped to increase interest.

Over the same period advances have been made in the way that mini-grid development has been approached. The original technocratic focus has changed towards one more focussed on "end users their needs and involvement, capacity building, markets, policies, financing, and allocation of responsibilities. This new approach does not lead to any master plan, but helps formulate solutions adapted to local conditions and national frameworks."(USAID/ARE, 2011). Many studies find this to be a key factor of success in schemes, as outlined in later sections of this paper.

Mini-grids can include single generation technologies or a hybrid system that includes two or more technologies.

Approaches to mini-grid development

A large range of approaches to mini-grid development exist today. These can be classified in terms of the technologies involved and the institutional and financial arrangements. Mini-grids can include single generation technologies, such as diesel, solar photovoltaic, wind, hydropower or biomass power generation, or a hybrid system that includes two or more technologies. Hybrid systems have generated most interest because they mix 'dispatchable' power sources (e.g. diesel generation which can be delivered on demand) with 'non-dispatchable' power sources, so increasing reliability and load matching.

Institutional and financial structures for mini-grids are more diverse. Mini-grids may be owned and managed by the state, private sector or communities. Often a combination of different actors is involved, owning or managing different parts of the system, such as the production, distribution and demand management systems. Different financial models may also be applied in order to cover upfront capital costs and the ongoing operation and maintenance costs.

Four approaches can be distinguished based on the institutions and financing systems (World Bank, 2008a; USAID/ARE, 2011):

- ***Community based model***. In this case, the community becomes the owner and operator of the system and provides maintenance, tariff collection, and management services. For example, in Sri Lanka, the Off-grid Services Delivery Project has micro-hydro systems, which are owned and operated by community-based cooperative societies, while the government keeps some control over technical specifications and safety in its role as a provider of subsidies (USAID/ARE, 2011). Community based systems tend to be more common in developing countries where the private sector or utilities remain limited.
- ***Private sector operator***: In private sector led systems, a private actor establishes the mini-grid system, although there may be many different forms depending on whether the ownership of the mini-grid is retained or transferred to another actor, the types of contracts (e.g. with a utility or with end users), and the types of subsidies used. Box 2 provides examples of private sector models used in developing countries.
- ***Utility-based approach***: In this approach, a utility company is responsible for all or part of the electricity system. The company may be a national public institution, investor owned or a cooperative. The utility-based approach is the most common for rural electrification in developing countries.
- ***Hybrid business model***: This approach combines different aspects of the approaches above in order to maximise effectiveness and efficiency. Hybrid business models are very diverse and may involve different entities owning and operating different parts of the system. For example, a utility or a private company could implement and own a renewable energy mini-grid power system, while a community-based organization manages it on a daily basis and a private company provides the technical back-up and management advice.

Opportunities and challenges of mini-grid implementation in developing countries

Mini-grid approaches present a number of new opportunities for rural electrification, but experience indicates that in many contexts there are still considerable challenges to be overcome if they are to be scaled up.

Opportunities

Mini-grid systems can help to increase the reliability of electricity supply. Their smaller scale and enhanced local level ownership of physical infrastructure or management systems can help to reduce problems such as power theft. These are common problems with more centralized on-grid approaches, where management is further from the customer base. Reliability of supply is generally greater from hybrid mini-grid systems, compared to single technology approaches. This is because they can ensure the availability of power when one of the generation components experiences intermittence. This can also help to lower net costs over the lifetime of projects.

Mini-grids can help to improve environmental performance in terms of energy efficiency and carbon emissions. Hybrid mini-grid systems, for example, often incorporate a 75-99% renewable supply (USAID/ARE, 2011). Of the renewable energy technologies, economic assessments indicate that biomass, biogas, geothermal, wind and micro-hydro systems costing US¢6-15/kWh are the potential least-cost generation options for mini-grids in developing countries, assuming sufficient renewable energy resources are available (*ESMAP, 2007*).

Biogas digesters and biomass gasifiers are particularly promising from this economic perspective, given their high capacity factors and availability in size ranges matched to mini-grid loads. Geothermal also appears economical for countries with geothermal resources, although it is mainly limited to larger grid connected systems (*ESMAP 2007*). These positive economic assessments do not generally reflect the implementation challenges, such as finding suitable supplies of sustainable feedstocks for biomass generation or financing the large capital costs of geothermal - challenges that have limited the growth of such approaches.

Mini-grids present opportunities for countries where government grid systems are not well developed, and where there is a vibrant private sector (Box 1). They are also adaptable, in that different systems can be linked up and/or connected to grids as they expand.

Box 1: Mini-grid development in Somaliland and Puntland

In Somaliland and Puntland, private sector players supply more than 90% of power in urban and peri-urban areas using local private mini-grids. They have invested in diesel-based systems of between 500 kVA to 5000 kVA installed capacity per enterprise. These enterprises are normally zoned with each operator building, owning and operating the generation, transmission, distribution, maintenance and collecting tariffs.

Through the private sector led mini grids, more than 68% of urban/peri urban areas have access to electricity, though at a high cost (US$ 1.2) per kWh. The mini grids provide a basis through which a country distribution system could be interconnected and linked to the national grid so that power can be wheeled and sold across the network.

Mini-grid systems are also becoming more economically attractive as the cost of renewable technologies decreases and fuel prices rise. Schemes still require subsidies, but these are often a smaller percentage of investments than on-grid subsidies (*World Bank, 2008*).

Challenges

Despite the opportunities, penetration of mini-grid systems remains low in most developing countries. Their development has been greatest in Asia.

China has an estimated 60,000 schemes and Nepal, India, Vietnam, and Sri Lanka, each have 100–1000 mini-grids (*Martinot et al., 2002*[1]). The majority of schemes use diesel or hydro power generation and they are government run (*Palit and Chaurey, 2011*).

Mini-grids can help to improve environmental performance in terms of energy efficiency and carbon emissions.

[1] Figures are authors' estimates based on tabulations of country-level statistics from sources cited in the text and other sources. Very few of these indicators are summarized well in a single source.

Technological failures may arise in scheme implementation. Common reasons include:

- A lack of maintenance or the use of poor quality or untested technologies. Insufficient funding to sustain maintenance over the project lifetime and a lack of local skills available for maintenance have also contributed to these problems (IEG, 2008).
- Insufficient primary energy resources. For example, in bio gasification projects there are challenges in finding sustainable sources of biomass and operating effective supply chains for biomass feedstocks. Many schemes remain at the pilot stages (e.g. Zambia). Similar challenges can affect diesel powered mini-grids in remote locations where infrastructure is not adequate.
- Poor assessment (often compounded by a lack of data - ESMAP, 2000) of local physical parameters affecting power output and economics, including:
  - Population density within the location of the mini-grid, which influences load factors and the overall economics of mini-grid systems.
  - Type of terrain – mountainous terrain can result in higher costs for infrastructure, fuel costs (for diesel systems) and the operation of financing systems (e.g. fee collection).
  - Seasonal resource fluctuations – solar insolation (normally sufficient in tropical countries); wind speed fluctuations; and river flows.
  - Future policies: For example, a 2004 study in South Africa found that mini-grids were not viable because of lack of suitable sites and an ambitious national rapid rural electrification programme (e7, 2004).
- Development of schemes without attention to developing supplementary programmes dealing with issues such as access to markets, SME development and working with local financing institutions, has contributed to a lack of demand and an inability to sustain schemes.

Mini-grid development can be hampered by policy and regulatory barriers.

Building sustainable financing structures can be challenging, despite a growing understanding of financial barriers in project development and an increasing number of financial tools. While they may be more economically attractive than grid connection in remote areas, mini-grid systems can have high upfront costs. This is particularly the case for certain renewable generation technologies, compared to more conventional options such as diesel.

It is well recognised that financing schemes need to be designed to pay for themselves in order to be sustainable by establishing realistic tariffs for consumers, despite the potential equity implications. In practice, these have been difficult to get right and have been subject to high risks. For example, consumers may fail to understand or respect the financing agreements that have been established, which may be exacerbated by inappropriate implementation of the fee-for service business model (*Gboney, 2009*).

Mini-grids in many countries have been publically financed through grants or subsidies in order to cover upfront capital costs and sometimes ongoing costs, but these can prevent the development of sustainable local electricity markets if they are not carefully designed *(ESMAP, 2000; Barnes and Foley, 2004*). Another approach has been through supporting micro-finance schemes. However, these are limited mainly by a lack of coordination between the energy and micro-finance sectors and high perceived investment risks within local financial institutions (*Winiecki et al., 2008*).

Mini-grid development can be hampered by policy and regulatory barriers. These may be linked to high level political priorities, such as policies favouring extended grid connection in urban and peri-urban areas (some schemes have simply failed because they have been superseded by connection to the national grid – Graecen, undated), corruption and/or political lobbying by more powerful energy companies, or simply a lack of understanding among policy makers.

Investment barriers have also been created by complicated or out of date energy regulations, such as those relating to the process of tariff setting. For example, KfW has been using a negative concession system to identify providers (i.e. lowest price for a preset number of connections) in countries such as Senegal and Mali and to increase efficiencies in delivery. In practice, however, this has led to very long and complex procedures with high transaction costs that are unattractive to investors (*USAID/ARE, 2011*).

The development and operation of mini-grids requires expertise in assessing local conditions, installing generation equipment and grid systems, the maintenance of these systems and financial management. These requirements are greater in hybrid systems because they involve more diverse generation technologies and more complex management systems. A lack of local expertise may be a risk to their long-term sustainability (e.g. TramaTechnoAmbiental case study cited in USAID/ARE, 2011).

While mini-grid schemes have helped to increase access to electricity in rural areas at significant scale in some countries (e.g. Sri Lanka - World Bank, 2008), poorer members of communities may remain without access. Evidence surrounding these impacts of mini-grid systems on poverty reduction is limited. However, evidence from rural electrification programmes indicates that they have often failed to improve access for poor people. Often they cannot afford to pay fees and tariff structures can also result in them paying more. For example, if minimum monthly payments are required, people may face higher costs through payments for reconnection or find it hard to make payments due to fluctuating income throughout the year (*IEG, 2008*).

In schemes which target poorer people, elite capture in management systems can result in inequities in supply.

These opportunities and challenges are likely to vary between the different business model approaches outlined in section 1. Table 1 below summarises some of the advantages and disadvantages.

The potential for mini-grid development in Africa

Africa faces significant challenges in terms of scaling up mini-grid development. Many of these are due to wider systemic challenges that affect all electrification programmes. The power sector in Sub-Saharan Africa is characterized by sub-optimal development of energy resources, high costs, under-pricing, and large inefficiencies in performance linked to governance constraints and a distorted set of incentives.

Extending access to electricity is particularly challenging in low-income countries with low electrification rates (below 50%) because they do not have a critical mass of taxpayers and consumers that can make electrification financially sustainable (*World Bank, 2010*).

A lack of local expertise may be a risk to the long-term sustainability of a mini-grid.

Table 1: Advantages and disadvantages of different mini-grid business models. Sources: World Bank, 2008a; USAID/ARE, 2011

Model	Advantages	Disadvantages
Community	• Increase ownership which improves maintenance • Can be more efficient than bureaucratic utilities	• Communities may lack technical and business skills (e.g. design and installation; tariff setting), leading to higher costs to bring these in • Governance of systems needs to be well managed.
Private	• Greater efficiency • May have capacity to offer better operation and management services • May be better able to navigate political interference	• Lack upfront financial support in most cases • Often difficult to find enough experienced companies, so often schemes are run by smaller companies with less capacity
Utility	• Responsibility lies with an experienced organisation • Often good links to policy so have better access to legal systems • Their scale means that they may have better access to spare parts and maintenance	• Liberalisation means that they are market driven, so may not prioritise decentralised systems in rural areas • Often inefficient and bankrupt • Often driven by political agendas
Hybrid	• Combine the advantages of the models above, such as the technical expertise of a utility and the financial expertise of the private sector	• Differences in the management systems of each entity can increase transaction costs

The situation is made worse by poorly performing utilities and regressive pricing policies subsidizing those who can afford to pay cost-reflective tariffs (Foster and Briceño-Garmendia, 2010). As the World Bank (2010) notes "the consequence is a perverse situation, in which higher-income consumers receive benefits they do not need (through subsidized rates and/or unbilled consumption), leaving few or no resources to expand access." These economic factors apply to both grid-connected and mini-grid systems.

Some of the financing approaches that have worked on other continents and that may help to overcome the economic barriers are harder to implement in many African countries. This is due to a number of factors:

The most successful mini-grid schemes developed were designed taking into account local economic, social and environmental conditions.

- Generally poorer economic forecasts of projects in areas of low population density and low income, making the implementation of cost-reflective pricing more difficult and reducing incentives for private investment.
- Risk averse lending institutions which may be more reluctant to get involved in financing mini-grid schemes. Only 5-8 of the 20-30 micro-finance institutions worldwide that offer specialized energy loans have a presence in Sub-Saharan Africa (UNIDO/REEEP, 2008).
- Low efficiency linked to poor performance of utilities, power theft and poorly managed community schemes. In Sub-Saharan Africa technical and nontechnical losses are, on average, very high (30 to 35 percent). This means that a greater focus is needed on enhancing the technical, commercial and financial performance of utilities and implementing a well-designed tariff system, even if this does not increase access in the early years (World Bank, 2010).
- Lack of liquidity in utility companies

These issues mean that in Africa there is likely to be a greater role for sustained and well coordinated donor finance compared to other regions.

Economic barriers are compounded by inadequate legislation in many countries. Most African countries now have rural electrification plans but many of them still favour grid-connection. Where they refer to decentralised energy systems, they often lack detail (e.g. in relation to plans for grid extension), which prevents proper planning for mini-grids. Detail on renewable power generation technologies is also lacking, which acts as a disincentive for project developers.

For example, regulations linked to hydropower in many African countries do not include clear rules on access to water and associated payments (Jonker-Kluhne, 2011).

Regulations may also affect the costs of technology – in many African countries the costs of importing technologies can be prohibitively high. For example, solar PV systems may be three times more expensive in Ghana than in Bangladesh, and small hydro twice as expensive in some African countries than in Sri Lanka because of import duties (REN 21, 2010, cited in USAID/ARE, 2011). Again, there is a risk of over generalization as some countries (Kenya and Tanzania) have exempted certain off-grid technologies from import duties in order to promote investment (World Bank, 2008b).

Levels of expertise surrounding mini-grid development and operation tend to be lower in Africa. Most of the gaps are linked to power generation and site selection, as distribution system development requires similar skills to grid-based systems. Expertise in financial management for the diverse range of approaches to mini-grid development is also lacking among developers as well as in financial institutions used to dealing with more conventional schemes. These issues have been found to be major barriers in African rural electrification schemes (Khennas and Barnett, 2000), although they may be overcome through sustained support.

Requirements for developing successful mini-grids

The most successful mini-grid schemes have been developed where their design has carefully considered local economic, social and environmental conditions; where sustainable financial models have been developed; and where the national policy and regulatory context is sensitive to the requirements of building mini-grids. Many of these factors are very context specific (ESMAP, 2007; IEG, 2008; World Bank, 2010).

Site selection based on detailed situation analysis is important in order to ensure that mini-grids are not developed so close to grid systems that they are quickly superseded or so far that they are difficult to operate and manage under certain arrangements.

Detailed site analysis also helps with appropriate technology selection that will give some estimate of projected output. For renewables this includes an understanding of hydrology, wind speeds and solar insolation, depending on the technology. For diesel generation, a clear understanding of current and future fuel availability and price at the location are important. Even where appropriate sites are identified, it is usually important to develop mini-grids alongside other initiatives that may help to increase demand and people's ability to pay (Kirubi et al., 2008). This can be achieved through approaches that either include such activities in their design or opportunistically take advantage of existing development programmes (de Gouvello, 2008).

Gaining a good understanding of demand through field studies and demand analysis is another pre-requisite for designing sustainable systems that are economically viable. For example, Kirubi et al. (2008) found in the case of a project in Kenya that for micro-grids with a load factor of 43% the level of external subsidy was at most 31% of operating costs, compared to subsidy levels of 60–80% for micro-grids with a load factor of 20–25%. However, future demand growth also needs to be kept in mind, for example through over-sizing some components. (USAID/ARE, 2011).

Schemes need to be supported by a range of local services to facilitate maintenance and sustain local expertise, and they have generally been more successful where these exist or are promoted through separate or linked development programmes. Training programmes need to be provided for key operational staff involved in maintenance. Increasing local understanding of the technical aspects of schemes, and the rules and regulations surrounding aspects such as fee payments, can help to reduce conflict and problems such as electricity theft. The presence of companies at the local level that can provide energy products, services, and replacement parts is also important for integrating mini-grids into a more sustainable local infrastructure (World Bank, 2008b).

It is also important to support institutions at the national level in order to increase awareness of mini-grid potential within government and legislative processes. For private sector led schemes, a well organized private sector can be important and strong industry associations can help contribute to this.

For example, in Mauritius, the involvement of the private-sector sugar industry in advocating for the continued support of a cogeneration program was found to be a key element of the programme's success (USAID/ARE, 2011).

In community schemes sufficient time is required during project design to establish clear governance structures and to build community trust. Extensive consultation with communities is required alongside the incorporation of existing local community structures into scheme management. In some cases, failing to include local leaders has been perceived as a threat to their position in the village, resulting in improper maintenance and even the disconnection of the system (USAID/ARE, 2011). Even well designed schemes need to include provisions for dealing with unforeseen risks, such as dispute resolution procedures and some form of independent monitoring (e.g. of payment systems) (World Bank, 2008a).

Securing sustainable financing is one of the main keys to success. Successful schemes have secured sufficient upfront funding to carry out detailed design and the construction of high quality infrastructure, and have developed financing models that at least cover operation and management costs over the project lifetime (usually 20-30 years). This can be a complex process and success is dependent on both the decisions of the operator and the external environment. For operators, key success factors in financial mechanisms include:

- Using cost-reflective pricing, based on realistic economic assessments linked to the business model (Kirubi et al., 2008). In private sector schemes, this means that tariffs are required that result in returns throughout the project lifetime. Tariffs spelled out in PPAs must be flexible, revisable, and take into account changes in the marginal cost of generation in order to reflect either estimated long-term or short-term avoided cost for the utility.

- Splitting responsibilities for the operation of schemes (e.g. generation, distribution and fee collection) between different actors has also been found to be effective in some schemes because it can increase ownership and enhance independence.

- Payment collection mechanisms need to be well designed, clearly defined, well publicized and with clear record keeping. Different collection mechanisms can be used (e.g. metering; pre-agreed payments etc.) each with advantages and disadvantages.

Securing sustainable financing is one of the main keys to success.

Successful schemes have secured sufficient upfront funding to carry out detailed design and the construction of high quality infrastructure.

Box 2: Private finance for mini-grids

In Nepal, mini-grid development linked to small hydro schemes has been relatively successful and rural entrepreneurs have driven it. This has been attributed to (Martinot et al., 2002):

- The availability of credit from a public-sector agricultural development bank.
- Simplified licensing procedures to reduce transaction costs.
- Unrestricted power tariffs, private financing from commercial banks.
- Capital cost subsidies from the government.
- Technical assistance by bilateral donors and NGOs leading to technology development and manufacturing within Nepal's industrial base.

Another example of private sector based mini-grids is in the Philippines (USAID/ARE, 2011), where distribution utilities and electricity cooperatives have been required to outsource power generation – a service which is being provided by private companies (the National Power Corporation Small Power Utilities Group NPC SPG programme). The project has made an effort to promote off-grid islands in the Philippines as a new business opportunity.

A competitive bidding process for 15 year concessions is used to select the lowest cost generation options. Two subsidies have been created – one linked to generation and the other an output based aid subsidy covering the difference between generation costs and prices paid by the end users. Both of these have been designed to be phased out over time. The scheme has resulted in reduced prices and lower subsidy requirements compared to previous schemes.

Factors in the success of the scheme include technological neutrality in order to increase flexibility for private companies; a financial structure that serves consumers as well as the needs of private providers; and extensive education and communication programmes. While the scheme appears to have been successful, it is relatively young and therefore difficult to establish whether it will be sustainable in the long term.

For policy makers, legislators, donors and other actors influencing the external financing environment, some of the key factors for success include:

- Supporting local financial institutions. This may be achieved through approaches to reducing perceived risks of lenders, such as credit enhancement through partial risk guarantees provided by donors (World Bank, 2008b) or supporting partnerships between financial institutions and energy companies (Winiecki et al., 2008). Providing training to local financial institutions in order to increase their understanding of projects is also important.
- Government or donor led initiatives to incentivize private sector participation while limiting market distortions. These may include output-based aid subsidies, advanced market commitments and long-term concessions. Contractual length also needs to be considered - licenses given by governments that are too short risk disincentivising private investment because they do not allow sufficient cost recovery.
- Where subsidies are provided, schemes need to include provisions for dealing with their phase out. Subsidies ideally need to be designed to support market development, rather than hardware, and to subsidise access (e.g. upfront connection fees for consumers) rather than operating costs (ESMAP, 2000).
- Reducing transaction costs, for example through the standardization of administrative procedures needed for establishing tariffs, or the legal procedures for approval of schemes (Gboney, 2009; World Bank, 2008a).

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