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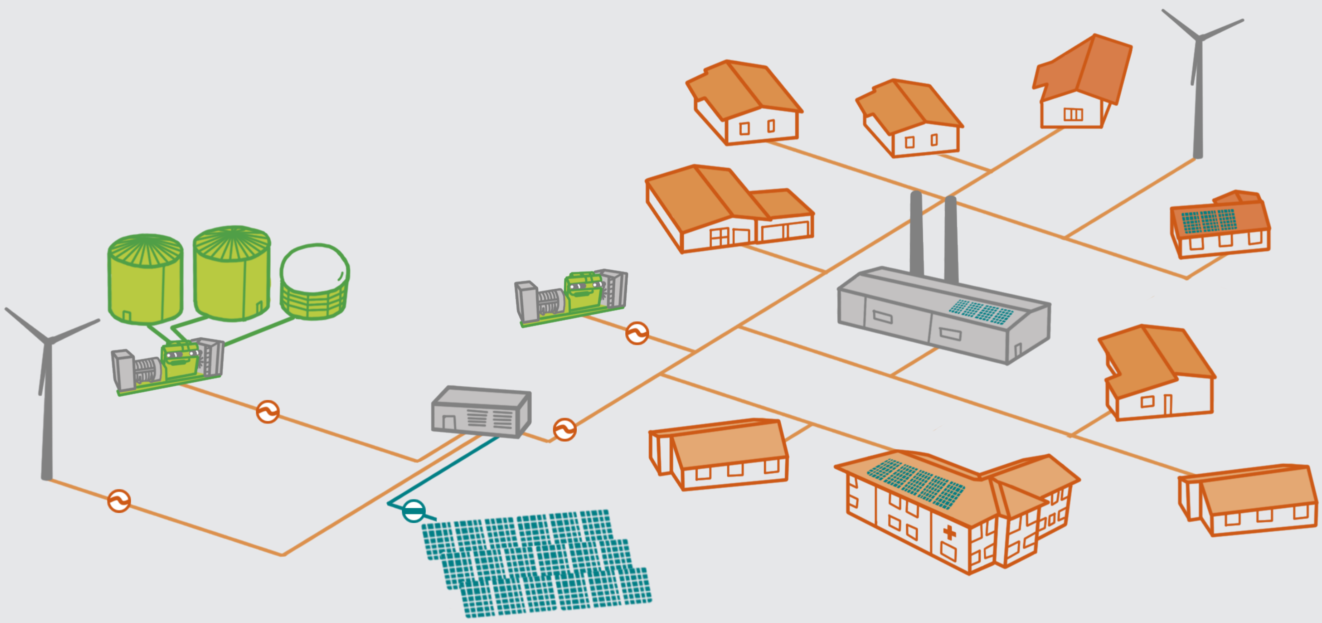
Climate Change & Environment

Mini-grids



Key Messages

Access to electricity is an important factor in economic and social development in rural areas and can have a positive impact on education, income and health. But more than a billion people predominantly in rural areas of developing countries still live without access to electricity. Through its Sustainable Development Goals, the United Nations wants to change this situation and provide universal access to electricity by 2030.

Given the expense of providing grid electricity to all rural areas, mini-grids will play an important role in reaching this target. Technological innovations that allow developing countries to develop a decentralized grid architecture to electrify remote regions are available. Renewable electricity can largely replace diesel generators in existing mini-grids turning them into green mini-grids. New green mini-grids can entirely avoid the use of fossil fuels, and can thereby help reduce and avoid CO_2 emissions significantly.

But for mini-grids to develop their full potential for development, a range of economic, technical, and social challenges must be addressed. Development cooperation will play an important role in this context: To reduce the burden on national development budgets, new business models need to be developed to attract private investment in mini-grids; national authorities need to be supported to prepare the legal frameworks for the construction and operation of mini-grids; village communities and entrepreneurs need to be supported to better utilize the available power from mini-grids; and service networks for maintaining and repairing mini-grids need to be established to guarantee a sustainable and reliable electricity supply.

Context

Why this nexus brief

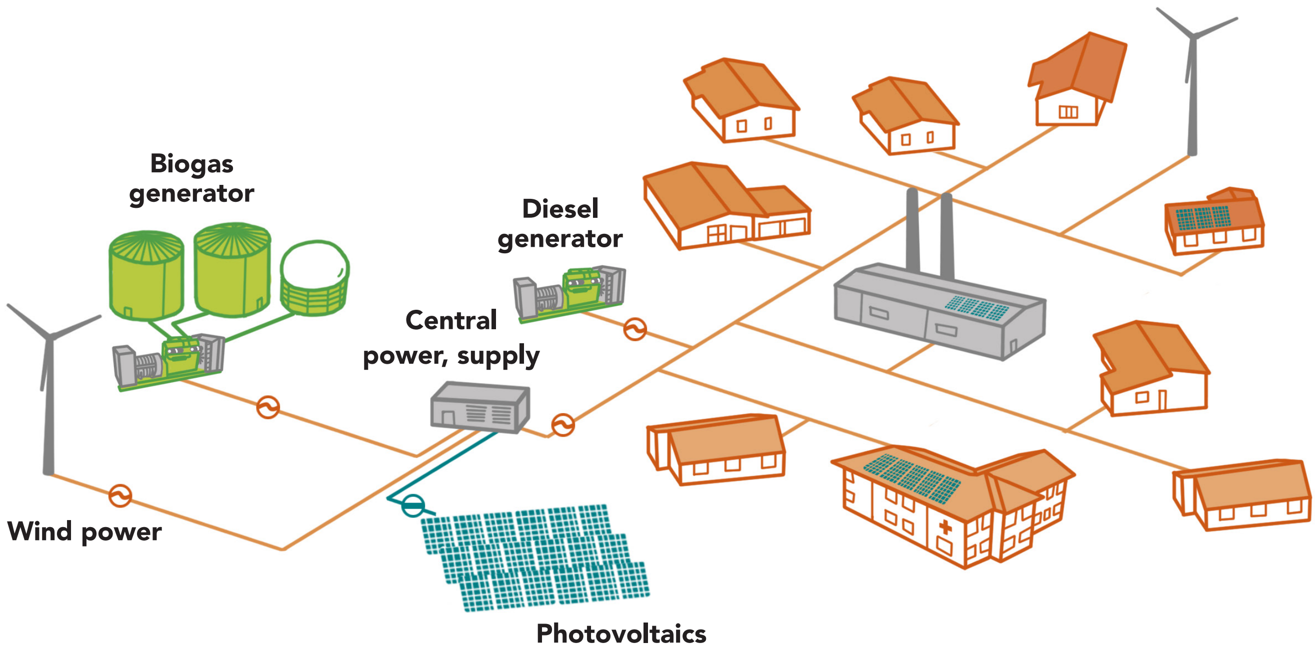
This nexus brief focuses on rural electrification through mini-grids and their importance for the nexus of sustainable development, poverty alleviation, and climate change. Mini-grids will play an important role in achieving universal access to electricity but new business models, regulatory frameworks, and service networks are needed to address various technical, economic, and social challenges.

Green Mini-grids in the context of climate change and sustainable development

Access to electricity is widely recognized as a crucial element in economic development. Health and education are negatively impacted when electricity is not available, when medicines and vaccines cannot be refrigerated, and there is no lighting for evening studies. Access to clean water and food security is improved when there is electricity for pumps and irrigation. Additional income-generating activities become feasible when power is available for milling, cold storage, small-scale manufacturing, services, and information and communications technology. Currently, more than 1 billion people, predominantly rural dwellers, do not have access to electricity. Sustainable Development Goal 7 tries to remedy this situation by targeting universal access to affordable, reliable, and modern energy services by 2030 (https://sustainabledevelopment.un.org/).

Figure 1: Scheme of a hybrid mini-grid

Source: BINE Information Service, 2011:2



Definition of a mini-grid

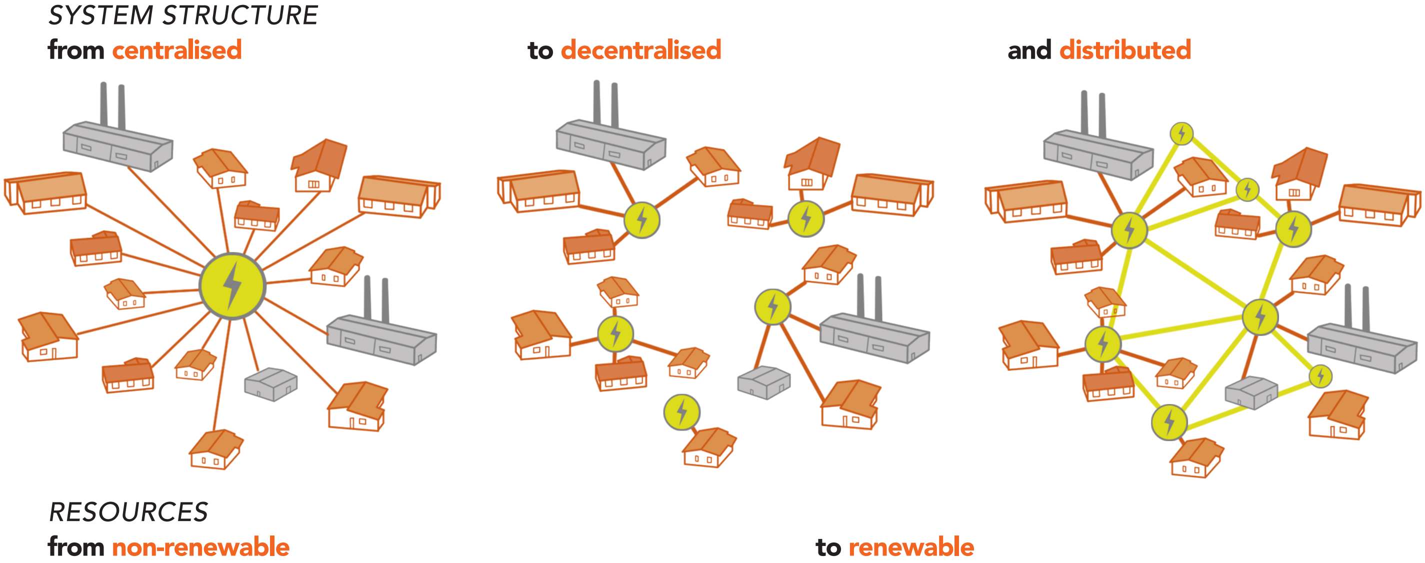
A mini-grid is a set of small-scale electricity generators and possibly energy storage systems interconnected to a distribution network that supplies electricity to a small, localized group of customers and operates independently from the national transmission grid (SE4All, 2017). In this publication, we mainly refer to village mini-grids powered by a single generator with a capacity of 10kW to 200kW. Smaller mini-grids are sometimes referred as "micro-grids" or "nano-grids". Mini-grids powered by renewable energy are also called "green mini-grids".

The options for providing access to electricity in rural areas include extension of the national grid, mini-grids, and stand-alone systems. In the past, most national governments in developing countries have prioritized the grid extension approach for rural electrification. Progress often remained very slow, however, and in some countries of sub-Saharan Africa the rate of electrification was lower than population growth (RECP, 2014:25). Mini-grids are therefore seeing a surge in interest by national governments and private developers as a less expensive and faster electrification approach. Stand-alone systems are suitable for remote areas with very low potential demand and scattered loads.

Mini-grids in sub-Saharan Africa, the Caribbean, and Pacific islands were mostly operated by diesel generators, as this is the least capital-intensive form of electrification. The downside of these diesel mini-grids is the high cost of diesel fuel. One result of the high operating costs is that green mini-grids, which are mainly powered by renewable energy, have become an increasingly important topic in international discussions over the past 15 years. The rise in diesel fuel prices has weighed heavily on the financial budgets of governments, which therefore sought ways to reduce costs. Thanks to the accelerated price decline of photovoltaics and other renewable energy sources in recent years, feeding electricity from renewable energy sources into these mini-grids has become possible. Combining conventional and renewable energy is also called hybridization of mini-grids. IRENA (2016:3) estimates that there is a potential of 50 to 250 gigawatts of diesel mini-grids that can be hybridized with renewables. This is equivalent to the capacity of 50 to 250 nuclear power plants. Green mini-grids thereby not only reduce operational costs but also contribute to significantly reduced CO_2 emissions.

Figure 2: From centralized to distributed power grid architecture

Source: Bacchetti et al., 2016



Mini-grids as a part of the future power grid architecture

The development of green mini-grid technology is also influenced by developments in Organisation for Economic Co-operation and Development (OECD) countries. The continuing growth in decentralized power generation plants from photovoltaics, wind, and biomass, will require a fundamental adjustment of the power grid architecture. The traditional grid architecture pursued worldwide over the past one hundred years was based on larger centralized conventional power generators. The future power grid may resemble a mesh of distributed storage, generation, and consumption nodes rather than its current mono-directional architecture (Figure 2). Such a distributed system structure will resemble a mesh of interconnected mini-grids. Interconnection is beneficial for system stability but theoretically these mini-grid subsystems could work autonomously once smart grid and storage technologies become mature and affordable.

Facts & Figures

1.2 billion people are without access to modern energy services

Globally, 84 percent of the population had access to electricity in 2014, while nearly 1.2 billion people were still excluded from electricity services. Sustainable Development Goal 7 focuses on universal access to affordable, reliable, and modern energy services by 2030 (United Nations, 2015). In recent years, Asia – where 79 per cent of the rural people have access to electricity compared to 96 per cent in urban areas – has made the most progress towards this goal. In contrast, the number of people without access to electricity in Africa has risen during the past five years. Only 28 per cent of the people in rural Africa and 71 per cent in urban areas have access to electricity. The situation is worst in sub-Saharan Africa where the rural electrification rate remains below 10 per cent in 22 countries (Figures from Table 1: IEA, 2016).

Most African governments in the region have developed national electrification strategies recommending both national grid extension and decentralized electrification through mini-grids and isolated off-grid solutions. There are no official figures on how many people currently obtain their electricity from a mini-grid connection, but considering the sheer size of the task at hand, the number of existing mini-grids is definitely small.

Additional USD 641 billion needed to achieve universal access to electricity

An estimated additional USD 32 billion would be needed annually to achieve the universal electricity access target by 2030, and even though the required investment is significant, it is only around 3 per cent of annual global investment in energy infrastructure

Table 1: Electricity access in 2014 – Regional aggregates

Source: IEA, 2016

Region	Population without electricity (millions)	Electrification rate (%)	Urban electrification rate (%)	Rural electrification rate (%)
Developing countries	**1,185**	**79**	**92**	**67**
Africa	**634**	**45**	**71**	**28**
North Africa	1	99	100	99
Sub-Saharan Africa	632	35	63	19
Developing Asia	**512**	**86**	**96**	**79**
China	0	100	100	100
India	244	81	96	74
Latin America	**22**	**95**	**98**	**85**
Middle East	**18**	**92**	**98**	**78**
Transition economies & OECD	**1**	**100**	**100**	**100**
WORLD	**1,186**	**84**	**95**	**71**

Table 2: Additional investment required to achieve universal access to electricity in the Energy for All Case (in billions of 2010 dollars)

Source: IEA, 2011:22

	2010–2020	2021–2030	Total
Africa	**119**	**271**	**390**
Sub-Saharan Africa	118	271	389
Developing Asia	**119**	**122**	**241**
India	62	73	135
Rest of developing Asia	58	49	107
Latin America	**3**	**3**	**6**
Developing countries*	**243**	**398**	**641**
WORLD	**243**	**398**	**641**

* Developing countries total includes Middle East countries

(IEA, 2011:20ff). The International Energy Agency estimates that 45 per cent of additional connections will be achieved through national grid extensions, 35 per cent by mini-grid solutions, and the remaining 20 per cent by stand-alone off-grid solutions. The investment in mini-grids totals USD 12 billion annually in this scenario, which would allow the connection of 19 million additional people annually. Ninety per cent of these new mini-grids are expected to be green.

Technical challenges of mini-grids

The key challenge in operating any power grid is to maintain a stable and reliable electricity supply. In the absence of large electricity storage devices, the supply has to be exactly balanced with actual consumption to maintain a stable frequency and voltage. This task is easiest to achieve when a grid is supplied with energy from hydropower turbines or combustion engines. These are called dispatchable energy sources, which means that their power output can easily be adjusted to match the actual power demand.

As long as there is only one generator, the task of controlling the mini-grid is easily mastered and can also be done by semi-skilled workers. If multiple generators are feeding into a mini-grid the task is more complicated because the alternating current of the two generators needs to be synchronized. This usually requires a communication channel between the generators and sophisticated electronic controllers that increase the cost of the system.

The challenges become even bigger if different types of generators are feeding a mini-grid, in particular in the case of renewables such as wind and photovoltaics. These are non-dispatchable energy sources and their power output fluctuates strongly with changing weather conditions. When the share of renewables surpasses 20 per cent, specific design and operational measures must be taken.

Economic challenges of mini-grids

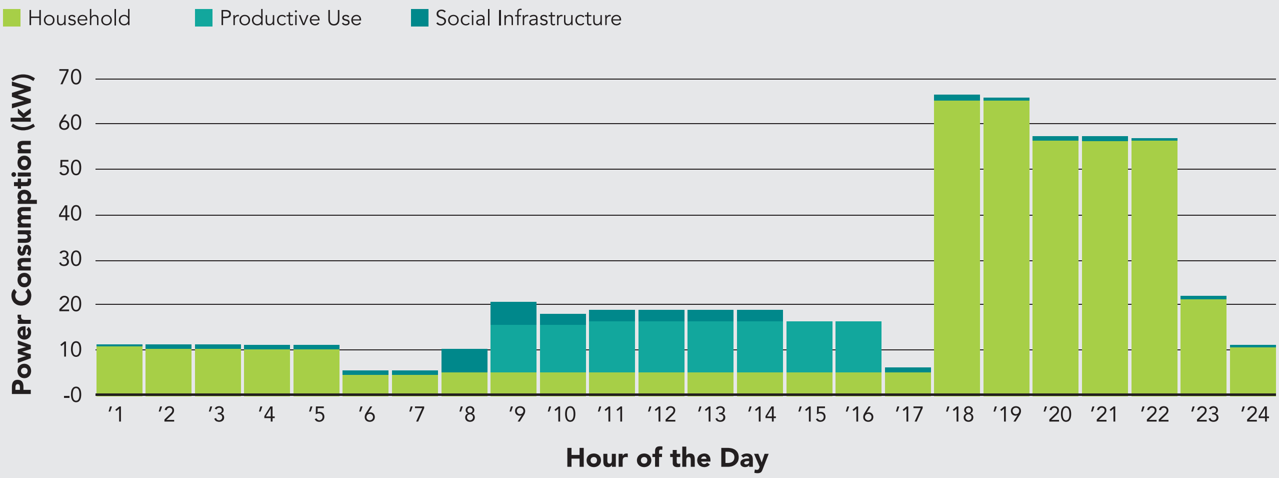
Isolated mini-grids often suffer from low load factors (i.e., the percentage of energy generated during a time period that can actually be sold). Where electricity is used only for lighting and operating a couple of TVs, the load factor can be less than 25 per cent. Figure 3 shows a theoretical load profile for an Indonesian village of 350 households with established economic activities beyond agriculture (Blum et al., 2013:8).

The load profile shows a pronounced evening peak. But during the day the electricity demand is rather low despite some economic activities. The resulting revenue is correspondingly low and will hardly be enough to cover regular operation and maintenance costs or to amortize the investment. Such mini-grids cannot be operated on a sustainable basis without relatively high-cost covering tariffs and investment subsidies. Where villagers cannot afford such high tariffs there is a high risk that systems will sooner or later fall into disrepair.

Because of these low-yield prospects, it is difficult to find private investors for isolated mini-grids. Increasing the attractiveness of such mini-grids requires additional productive uses that create additional load (and revenues) during the daytime.

Figure 3: Typical load profile of an isolated mini-grid

Source: Blum et al., 2013:8



Experience shows, however, that it is not easy to realize such productive uses. The mere availability of electricity is not a sufficient condition.

Social challenges of mini-grids

The construction of a mini-grid in remote villages is a massive intervention in the usual living conditions and can trigger conflicts, particularly where community ownership and operation is the preferred model. Elements of this model can cause the emergence of personal conflicts and power struggles for resources, and can negatively affect the operation of a mini-grid:

- The staff associated with a mini-grid management committee will get access to resources (work, wages, and power), and the most influential people may be selected over the most appropriate
- If the available capacity of the mini-grid is not sufficient to electrify all households, the unconnected people may feel treated unfairly, and may sabotage the mini-grid infrastructure
- In some societies operators feel unable to take sanctions against villagers in the event of electricity theft or non-payment of bills, and this approach can have a negative impact on the sustainable operation and safety of the electricity supply
- The lack of independent monitoring of operators can lead to inappropriate expenditures and subsequent shortfalls for legitimate expenses such as maintenance and repair
- If the land ownership at the location of mini-grid infrastructure is not clear, compensation claims may arise later

Possible business models to operate mini-grids

Apart from community ownership, mini-grids can basically be either owned or operated by the public sector, the private sector, or some combination. Table 3 provides an overview of different business models.[1] The main reason to involve the private sector is to leverage the limited public funds available for infrastructure development. The ambitious objective of universal electricity access cannot be achieved by public funds only, so the fully public models will not be a solution. But neither will the fully private model be a solution because of the economic challenges described above. Between these two poles there are mixed models with better chances of success.

The Public Private Partnership (PPP) Model

The government or a public utility plan and construct a mini-grid project including the power generators. The operation of the project is outsourced to a private sector company responsible for the generation, distribution, and retailing of electricity. The PPP model may be useful in cases of the privatization of the operation and maintenance of existing mini-grids. A private operator may work for less than the public utilities' own cost, thus reducing the pressure on their budget. For the construction of new mini-grids, however, this model appears to be less appealing since there is no leverage of private investment by public funds.

The Power Purchasing Agreement (PPA) Model

In many developing countries, national utilities have constructed isolated mini-grids to serve communities that were not likely to be reached by the national utility's main grid. Diesel generators, which required

Table 3: Mini-grid business models

Business Model	Generation/Distribution/Retailing
Fully public	Government builds infrastructure
	Operation and maintenance by public utility
Fully private	Ownership of assets and operation and maintenance by vertically integrated private firm or two or more private firms
Public Private Partnership Model (PPP, mixed model)	Ownership of infrastructure with public sector but operation and maintenance outsourced to private sector either through concession or a fee-based management contract
Power Purchase Agreement Model (PPA, mixed model)	Generation: Private sector builds and owns the generation part and sells power wholesale under PPA with the utility
	Distribution/retail: Public utility owns the distribution grid and manages the retailing of the electricity

1 The models and their elements are a synthesis of different studies: Tenenbaum et al., 2014; RECP, 2013 + 2014; ECA, 2014; Meier, 2012 + 2015.

the smallest up-front capital investment, served these isolated mini-grids. Once the mini-grids became operational, the national utility was usually forced to sell electricity to the customers at the national retail tariff, even though its production costs at these locations were likely to be several times higher than the tariff. As renewable energy has become more economical, private power producers have started to approach the national utility with offers to replace the national utility's diesel fuel with lower cost renewable sources. The private sector finds this particularly attractive where the regulator sets a feed-in tariff at a level close to the utility's relatively high cost for operating the diesel generators – also called an avoided cost tariff.

The PPA model could also be a solution for new mini-grid projects because it includes incentives for all stakeholders:

- The public sector does not need to pay for the power generation infrastructure but only for the grid infrastructure – thus achieving leverage on its own funds
- The private sector investor is paid an economically attractive feed-in tariff and is not exposed to the risks related to the retailing of electricity
- The villagers are treated equally as grid-connected clients and can benefit from cross-subsidized national tariffs

The type of model chosen always depends on the current regulatory framework and political considerations. In countries where there is no policy of uniform national tariffs, for example, the private power producers may also be allowed to charge cost-covering retail tariffs. This may be considered unfair for the remote communities, but it may be fairer compared to not providing them with any electricity services at all.

Key Issues

Key issue 1: Sustainable operation is a challenge in many mini-grids

The focus of mini-grid deployment has often been on technical planning and physical construction, but questions related to the long-term operation of mini-grids has been neglected to a certain extent. Systematic maintenance and repair services are often not available in remote villages and load management and limitations to load growth are not sufficiently understood by operators. The economic challenges prevent mini-grid committees from becoming financially healthy organizations. A recent study in Northern Pakistan found that "…nearly three quarters of the plants examined showed weaknesses and faults, ranging from minor deficiencies, through severely reduced capacity, to total breakdown" (GIZ, 2013:10).

The reasons for these problems are not technical in nature, but due to the lack of a clear organizational scheme for the operation and maintenance of the mini-grids. Community operation of mini-grids can only lead to sustainable operation with adequate after-sales support. It may be the easiest business model to implement as it requires no specific regulatory framework and does not burden governmental budgets beyond the initial investment. But where long-term and regular support of communities cannot be guaranteed, new business models based on public-private partnership might be introduced. Such models require some form of public subsidies and a regulatory framework needs to be put in place, but the additional efforts will be rewarded with more sustainable and reliable electricity supply in remote regions.

Key issue 2: Increased private sector involvement is needed to achieve development goals

Given the huge investment needed to achieve the universal access target, the energy sector needs substantial private capital to complement scarce public resources. Private investment in mini-grids remains rare, however, as it is still difficult to generate adequate margins with mini-grids. So far, profit-oriented companies can only be found as providers of engineering, procurement (of the power system), installation, and commissioning services, and as consultancy firms.

Private developers and operators will only consider entering the mini-grid business in countries where this activity can be profitable, or at least cost covering in the case of social businesses, NGOs and cooperatives (RECP, 2014). But the costs of generation and distribution of electricity in mini-grids are higher than on the national grid. Thus, in order to attract private investment, a mini-grid system must be able to achieve higher revenues (either through adequate feed-in-tariffs or consumer tariffs) compared to a conventontial grid system.

Key issue 3: Regulatory frameworks are absent or inappropriate

Mobilizing the private sector to operate mini-grids is key to a larger mini-grid roll-out, especially in smaller villages. According to RECP (2014), a country becomes suitable for mini-grid roll-outs as soon as it fulfills the following three prerequisites:

1. It must be legal to operate a mini- or micro-utility, and licences should be easily obtained
2. Micro-utilities must be allowed to charge tariffs that allow "risk equivalent" margins
3. Ministries and authorities must disclose to potential investors those villages and towns listed for mini-grid electrification that will not be connected to the main grid within a guaranteed period of time, and must implement a clear, reliable long-term scheme for when the national grid does arrive

In many developing countries, particularly in Africa, mini-grids can only be operated informally on the notoriously difficult community operation model. Such informality prevents mini-grid operators from acquiring finance. Thus, countries that do not allow legal private mini-grid operations will see only a limited number of mini-grids being established.

Other countries are following a decentralized approach and have unbundled their electricity sector, allowing competition in electricity generation and/or distribution, subject to strict control by the regulatory authority. These schemes are in principle appropriate for private mini-grid operation, but other practical issues have to be overcome for a larger mini-grid roll-out – complex and time-consuming licensing and tariff setting processes, for example, or prohibitively high fees for the various licences, permits, and approvals.

Key issue 4: Mini-grids need to be extendable to address growth in demand

The peak load demand in a mini-grid is often underestimated. The pace of load development is difficult to predict, but a generator can reach its capacity because of rapid growth in demand just a few months after a plant commissioning. Cases like this call for load management measures such as load shedding during peak hours. Consumers do not easily accept such measures. After all, they paid a connection fee and expect to have permanent, not occasional, electric service. An even more severe problem is that additional people are refused a connection because of the lack capacity to serve peak demand.

In light of these potential problems, the design of mini-grids needs to address the possibilities for extending the capacity of power plants – a real challenge given the limited natural energy resources available. The emergence of affordable batteries will offer new solutions to this problem. In the past, the systems were oversized in relation to the average load with the objective of matching the evening demand peak as closely as possible. The integration of batteries into the mini-grid design allows for the downsizing of the capacity of the power generators to a level that is sufficient to recharge the batteries. The batteries will then be used to provide peak power – the technical term for this is "peak-shaving". The sizing of power generators correlates directly with the investment capital needed. The capital saved in downsizing can thus be invested in batteries. The decoupling of the available energy potential and peak load demand is particularly attractive in micro hydropower plants. The available hydropower potential can be developed in steps that allow the synchronizing of capacity increases with the growth in electricity demand.

Key issue 5: Technical innovations enlarge the potential of mini-grids

Developing countries can benefit from rapid technological developments in OECD countries by seizing opportunities to leapfrog certain stages of technological development. Developing countries skipped the stage of fixed line telephone networks, for example, and went directly to modern microwave based transmission networks. Similarly, in the energy sector, countries will be able to skip the phase of centralized power grids and jump directly to a decentralized or distributed power grid architecture. Complementary innovations that are in the pipeline will allow mini-grids to become greener and more stable, and to increase modularity and ease of use (IRENA, 2016).

In particular, storage technologies are expected to play a growing role in improving the flexibility of power systems and in the market penetration of electric vehicles, heating and cooling systems, and mini-grid installations. New battery types will create further competition to drive down prices to below USD 50/kWh by 2035. The Internet of things technologies will continue to enable more intelligent use of electricity.

Integrating these technologies in mini-grids can make the grids more cost efficient and beneficial for the local communities, thus enlarging their potential and importance for developing regions.

Relevance for Development Cooperation

The Swiss development cooperation, NGOs, and the private sector have been involved in rural electrification since the early days of development cooperation. Initially, the focus was on developing appropriate micro hydropower technologies and transferring these technologies to local workshops and technicians in the partner countries. Mini-grids for power distribution were always an integral part of these projects.[1] Thanks to the efforts of Swiss organizations, many small enterprises in developing countries independently contribute to the expansion of access to electricity in their own countries. In Indonesia, Nepal, and Pakistan alone, several thousand micro hydropower plants based on Swiss technology transfer are currently in operation. Over the past two decades, the newer renewable technologies (photovoltaic, wind, biomass) have gained increasing attention. The Swiss government supports innovative projects in these fields through its Interdepartmental REPIC[2] Platform, among other efforts.

Although much has been achieved, the limitations of local capacities are also being realized in practice, as the description of challenges and key issues demonstrate. This means that the tasks of development cooperation are far from being completed. On the contrary, in order to achieve the ambitious targets in the areas of access to electricity, climate change, and environmentally sustainable development, the activities must be further intensified. Possible areas for future development cooperation include the following:

The capacities of existing mini-grids are mostly underutilized, except for the evening peak. The communities lack of ideas, knowledge, and capabilities on how to better utilize the available power. Development cooperation should develop and implement approaches to facilitate the better utilization power for productive and consumptive purposes.

After the commissioning of mini-grids, the rural communities were often left without access to adequate after-sales services for operation, maintenance, and repair. Development cooperation should facilitate the establishment of such service structures. The REPIC support for the establishment of a service network in Pakistan (see box) provides a useful model.

Finding local engineers that can solve a particular technical problem is no longer a key issue, but finding local entrepreneurs dedicated to rural electrification and willing to initiate and invest in energy infrastructure projects is still difficult. Development cooperation could help develop the required incentive systems. A possible way to address this challenge could be to promote the captive electricity generation by local entrepreneurs as a business model. A local company may be supported to set up and operate a mini-grid and to use the electricity during the day for productive purposes. After the working hours, the company becomes an electricity service company supplying power to the neighboring villagers. Remote ice factories, agricultural mills, and sawmills are already operating such mini-grids in Asia and Africa.

Development cooperation could also make an important contribution by supporting national or regional authorities in the creation of legal frameworks for the construction and operation of mini-grids. In many places, unclear legal frameworks and responsibilities lead to problems. In Switzerland, power plants in rural areas are important for rural development. The regulations regarding resource rights, ownership, operating permits, licensing, and other matters are in place and could be models to be transferred to developing countries.

1 The technical expertise is well documented in the MHPG Series published in the 1990s (see http://skat.ch/publications/publications-energy-climate).

2 REPIC is the interdepartmental platform for the promotion of renewable energy, energy and resource efficiency in international cooperation.

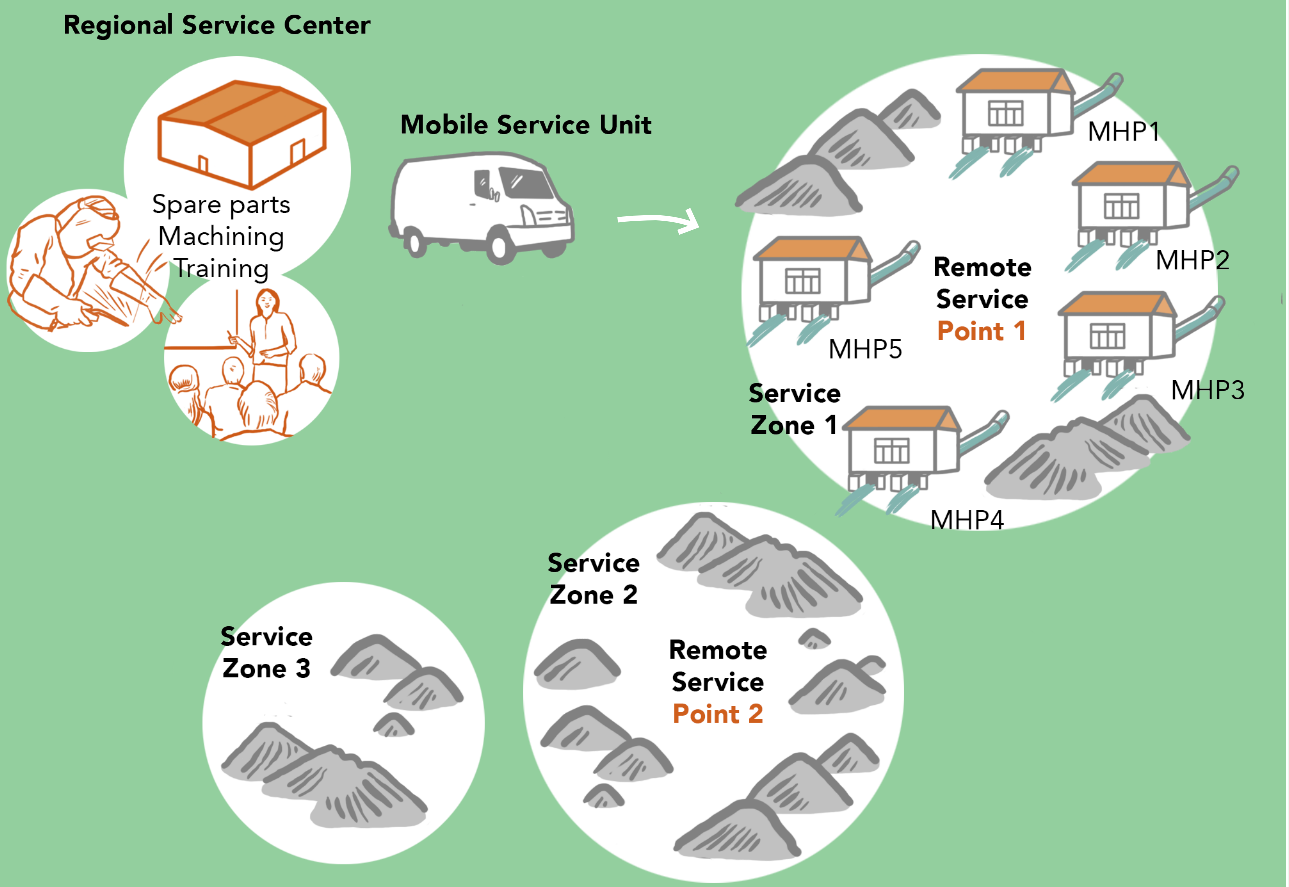
Operation and maintenance network for mini-grids in Pakistan

REPIC supported the establishment of an operation and maintenance network for mini-grids in Chitral, Northern Pakistan. In this remote district, there are hundreds of mini-grids, mainly powered by micro hydropower. The Micro-hydro Resource and Service Center operates a network of remote service points throughout the district. The network guarantees a fast response to village operators faced with technical problems.

The regional service center, located in Chitral, consists of a workshop and welding facility needed for major repairs and overhauls of micro hydropower equipment. The service center also hosts training facilities and a spare parts shop. For on-site repairs, the service center is equipped with a mobile service unit.

The service network helps improve the sustainable operation of local mini-grids. To be able to provide its services on a long-term basis, the service network itself needs to be sustainable. Therefore, the communities have to pay for these services without subsidies from the government or donor agencies. The communities are willing to pay because the prices charged by the service center are still lower than the costs of solving the problems on their own.

Figure 4: Private sector operated micro-hydropower service network in Chitral Pakistan
Source: GFA Entec



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