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Solar mini-grids and solar lantern renting: Drivers and barriers for sustainability and replication

A report for policy makers, practitioners and researchers written by Kirsten Ulsrud, Charles Muchunku, Debajit Palit, Henry Gichungi, Gathu Kirubi, Kristen Wanyama and Anjali Saini

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Chapter 1: Introduction

This report is written for policy makers, practitioners and researchers interested in lessons learned on success factors and barriers for solar mini-grids, solar lantern renting and other village-scale solar power supply. The report offers new knowledge on what it takes to provide electricity to people outside the reach of the conventional electricity-grids, including the urgent need for new policies and regulations for mini-grids.

The concept of mini-grids here includes micro-grids as defined by IRENA (2017, p.89): Mini-grids involve assets for electricity generation between 1 kilowatt (kW) and 10 megawatt (mW) and supply electricity through a distribution grid that operates in isolation from the national main grid.[1] Some reports distinguish between mini-grids and micro-grids, and mini-grids then have generation capacities from around 10 kW up to 10 MW, while "micro-grids" and "pico-grids" are mini-grids with generation capacity less than 10 kW.[2]

The report is based on two sources of knowledge and experience. The first is the long-term research project Solar xChange, bringing key results from three detailed case studies in India, Kenya and Senegal. The second source is panel discussions and presentations from a workshop on "Solar mini-grids and other decentralized models for increased access to electricity: Practical experiences and lessons on sustainability" that was held in cooperation with *Kenya Renewable Energy Association (KEREA) and Strathmore Energy Research Centre (SERC) from Strathmore University* on October 19, 2016 in Nairobi, Kenya. The workshop gathered a range of experts including several mini-grid companies, policy makers and researchers, in addition to the Solar xChange research team. The presenters as well as the audience brought a broad range of expertise and on-the-ground experience, from social science to engineering, business and policy-making.

Both the research results and the workshop discussions presented in this report were related to the following themes:

- The role of decentralized electricity models, and how they complement extension of the main grid
- Challenges and dilemmas for mini-grids and other village-level electricity models, and success factors for operational and economic sustainability
- The human and societal dimensions of technological systems
- Affordability for all – a huge challenge that requires new ways of thinking about energy and development
- Income generation by the use of electricity, and which social and technical innovations are needed
- Political aspects, and the policies and regulations necessary to speed up progress and ensure the economic sustainability, affordability, and reliability of electricity services

The first part of the report presents research findings from the Solar xChange project, some of which were also presented in the workshop. The second part provides key points and discussions from the workshop (chapters 3-6). The third part (chapter 7) provides a discussion on the future role of small-scale renewable mini-grids.

[1] See IRENA (2017), REthinking Energy 2017: Accelerating the global energy transformation. International Renewable Energy Agency. Abu Dhabi.
[2] IRENA 2016. Policies and regulations for private sector renewable energy mini-grids.

PART I: RESEARCH FINDINGS

Chapter 2: Research findings from the Solar xChange case studies in India, Kenya and Senegal

This chapter provides research results on village-scale solar power supply systems (mini-grids, energy centers, and solar lantern charging) based on case studies in India, Kenya and Senegal. The research was intended to increase the knowledge on how such electricity provision can be organized in order to function well in practice, be viable in the long run, be possible to scale up, and give affordable, reliable, and usable electricity services.

Analytical framework for the case studies

Village-level solar power supply was selected as the unit of analysis for this research because such models can be crucial to providing access to electricity for everyone. An advantage of these models is that investment in power generating equipment and maintenance is taken care of for the electricity users, in contrast to individually owned solar PV systems. However, it was acknowledged that different solutions can complement each other, including individual solar systems, village-level systems, and the national electricity grid.

The research was carried out through two research projects, Solar Transitions and Solar xChange, funded by the Research Council of Norway[3] and led by the University of Oslo. The research group was composed of social scientists and practitioners (including technical experts) from Norway, Kenya, India, and Austria.

Society and technology evolve in constant interaction and shape each other, and social science approaches are therefore important in research on the implementation and maintenance of energy technology. A delivery model for electricity supply is a system composed of both social and technical elements. At the national and international levels, the solar PV sector can be seen as a broad social and technological ("socio-technical") system consisting of various ways of using the technology, different companies, organizations, and government units, and institutions such as education opportunities, knowledge, and policies.

We chose to study specific examples of solar power provision at the village level, including mini-grids, to contribute to the understanding of how such decentralized electricity provision can succeed in practice. The research took into account how various dimensions influenced each other, including how the activities at the local level interacted with factors at the national and international levels. The data collection focused on six broad dimensions of mini-grid systems or other infrastructures or projects implemented at the village level:

[3] Project numbers 190138 and 217137.

1) The role of the national and international framework conditions, including both established and emerging energy systems
2) The role of the local social and cultural context, including social practices
3) The role of the social and technical design of the electricity system, and the implementation process, including the type of project implementers involved (and how the project implementers accounted for dimensions 1 and 2)
4) The actual functioning of the system, analyzing operational and economic sustainability
5) The kind of electricity access achieved and by whom (including the genders of the people involved), where, when, and why, including the suitability of the electricity services, the electricity tiers achieved, income generation, affordability, and reliability
6) Replication and upscaling, by whom, where, and how

In the following, we present certain results from three of our case studies: Chhattisgarh in India, Kitui in Kenya, and Thies in Senegal. For a detailed and systematic presentation of the results within the different dimensions mentioned above, see Ulsrud (2015), Ulsrud et al. (2015), and forthcoming publications from our team. Here, we present a summary of the cases and the findings without explicitly referring to these dimensions, but these factors were a critical foundation for the data collection and analysis.

The case study on mini-grids in Chhattisgarh State in India

We studied the work of the state government in Chhattisgarh, India in the implementation and operation of 1400 mini-grids during the last 10–11 years. The project implementer was the Chhattisgarh Renewable Energy Development Agency (CREDA), which was also responsible for the operation, maintenance, and expansion of the mini-grids. CREDA and the mini-grid program were created by a handful of committed and enthusiastic individuals who are still in charge. The grids were built in poor and remote villages, spread over many districts and regions. The areas were hilly and forested, and the state government had determined that grid extension would not be feasible, so decentralized solutions were required. People in these areas had no previous experience with electricity. At the time of our fieldwork (2015), mini-grids were used for lighting, phone charging, TV, radio, etc., and the electricity was supplied in the evening.

CREDA attempted to provide electricity services and conditions for subscription that suited the people in this social and cultural context at the same time as they developed electricity services as a top-down, large-scale activity. This required standardization and streamlining of the electricity systems, including the operation and maintenance of the local mini-grids. CREDA instituted a governmental organizational structure with offices at three administrative levels. The districts were the lowest level, with district engineers who followed up with operation and maintenance.

In addition to these government structures, CREDA hired private sector companies with expertise in electrical engineering as service providers for operation and maintenance. These companies provided "cluster technicians," who could cover 10–12 villages in a cluster by using a motorbike, giving support to local operators and committees.

The roles and commitment of both the district engineers and the cluster technicians were important to the functioning of the mini-grids, including maintenance. Broad and equitable access to basic electricity services had been achieved, as every household in the village was connected, and the tariff was very low or zero. The state government paid for operation and maintenance, through a revenue stream from a state tax on power generation based on coal. The mini-grids were functioning well in some places, while a few had been closed down (after grid electricity reached some of the villages), and others gave very short and unreliable supply. Demand for electricity in the villages had increased beyond the design capacity of the initial power plants, which was a general problem, if also a positive sign of people's appreciation of the access to electricity. This was due to the use of TVs and other appliances that the mini-grids were not designed for, which shortened the hours of supply and led to frequent power outages. CREDA is working on the financing and implementation of capacity enhancement, but it may take time to achieve this in all 1400 villages.

This case study shows that governments may have special opportunities for implementation, operation and upscaling of off-grid electricity provision. Government financing not only of the capital costs but also of certain operation and maintenance costs is an option if the government has a stable stream of income that can sustain the activity. This can enhance affordability through low tariffs. The example also suggests that a strong point of governments is that they can build the new administrative structures needed for upscaling. At the same time, such large scale activities as CREDA's work makes it a substantial task to ensure operational sustainability in every village. A well-designed cooperation with private sector companies can be important for operation and maintenance, in addition to supply and installation of equipment. Another lesson that can be drawn from this example is that the consumption of electricity can increase rapidly even for people who get access for the first time, if the electricity is supplied at a low or nearly zero price. Our research also shows that both the expectations of increased use of electricity and people's mind-sets can change quickly, decreasing the satisfaction with services that initially were experienced as good. User satisfaction is therefore a moving target.[4]

The action research and case study on a solar energy center and charging stations in Kitui County in Kenya

This case study was done through action research, combining social science based research methods with the development of a practical pilot project based on the research results. The initial plan was to implement the first solar mini-grid in Kenya, but the plan changed significantly during the process due to characteristics of the local social and cultural context. Instead of selecting a place that suited for a mini-grid model, our team deliberately selected a place where the settlement pattern was very dispersed and not suitable for a mini-grid. Such a settlement pattern is typical for Kenya (and also for Sub-Saharan Africa in general). The plan shifted to developing a village-level power supply suitable for the settlement pattern, and the portable lantern rental method observed in India became a source of learning. The team combined research in the village (on social

[4] People will be likely to wish to move upwards from basic electricity services (i.e., low tiers according to the SE4All multitier framework) to higher levels of consumption (higher tiers), and an inability to do so, including lack of affordability, is likely to reduce their satisfaction with what is available to them.

practices, norms, energy expenditure, and needs) with close cooperation with the community, and developed detailed ideas for a socio-technical design. This design was influenced by local ideas for staffing, ownership and the construction of a house, as well as the constraints of the technology, available funding, and future costs of battery replacement.

The result (a socio-technical design) was called an energy center model. It was based on a 2.1kW solar system and a house with four rooms where various electricity services would be delivered. The main services were the rental of portable lanterns, phone charging, IT, TV and DVD; hair-cutting was also added later. The research team tried to create an economically sustainable model that would be replicable for others, such as businesses, NGOs, and governments. Grant funding provided the capital investment, while the revenue from the sale of electricity services was intended to cover operation and maintenance costs. One adaptation to incorporate suggestions from the local community was that people from the village would be trained as staff (for business management, technical tasks, and IT services), instead of hiring outside people with higher qualifications. A young woman became manager of the energy center, and she solved some of the initial problems, such as delays in delivering the lanterns for charging. Subunits called "agents" were gradually started in 10 additional villages, offering lantern rental, phone charging, and sale of lanterns.

Data on the functioning of the system and its causes have been collected and analyzed continuously from the March 2012 initiation of the project. The operation of the Center and agents has mostly functioned well (i.e., it can be seen as operationally sustainable), and follow-up training, advice, and gradual adjustments have played a role in this. Another important factor has been the way in which the local staff and board selects and trains new staff members. They have chosen to hire and train young, unemployed women with a secondary school education and a committed attitude. Economic sustainability is below the original goal, due to unexpectedly lower use of the services and higher expenses for the operation of the energy center. One important cause of less use of the services is the low income and deep poverty of the majority of the population in the 11 villages now served with portable lanterns, as shown by our surveys. (For elaboration on the challenges met and gradual improvements, see Ulsrud et al. 2015.) One reason that the Center employed excess staff is probably that there is a strong need for jobs; one salaried person can support an extended family economically. Despite the shortcomings in economic performance, the Center has still covered its operation and maintenance expenditures during its 5 years of operation.

About 200 lanterns are currently rented out to households, small businesses, schools, and clinics. The portion of households and businesses (the potential users in each village) actually using the services ranges from about 6 to 30%, with the lowest portions in the places with the shortest time since implementation. People in these villages live up to 10 km from the village markets, so it is not realistic for everyone to be able to rent the lanterns. A larger portion of the population is using the lanterns within a radius of 2–4 km from the market, but accurate figures are not available. The number of users is high compared to the people who had their own solar home system when the project started. The number of people who own a solar lantern or solar home system has also increased. Some bought them at the energy center, and many people learned about solar energy through the center. The IT and TV services were highlighted as important by households, businesses, schoolteachers and village leaders, but these are not economically sustainable (they are subsidized by lantern rentals and phone charging).

Interviews with the users of portable lanterns show that the lanterns are moved around inside different buildings, including homes and small businesses, and used at night when on the farm, walking along the road, taking care of children, and going to the toilet. Different family members use the lanterns (women, men, and children). The lumen level of the lanterns (the brightness of the light) has been good due to selecting good quality lanterns for the project.

Replication of the model can be economically sustainable if the focus is placed on the services with the highest demand (lantern rental and phone charging), which reduces the number of services provided. Costs can be minimized through measures such as shrinking the size of the battery bank (reducing the costs of battery replacement) or the number of staff. It is also important to find ways of ensuring accurate revenue collection from subcenters/agents. Such solutions have been developed in further trial projects and implemented as part of an ongoing project by the government of Kenya. *The government project scales up the portable lantern rental through solar charging stations in different counties in Kenya. This project is described in the presentation below by Chief Engineer Henry Kapsowe of Kenya Power.*

Some lessons learned from the Kitui example include the following:

- Rental of portable lanterns and provision of other basic electricity services can make an important difference for people and is suitable in areas where mini-grids are not feasible.
- The implementation of a village-level electricity system is a process of innovation, not necessarily on technical solutions but on a range of other aspects.
- There are important dilemmas between social sustainability and economic sustainability, because a diversity of services at low prices is important for people's benefit but expensive to sustain.
- Close cooperation with village communities requires commitment and a humble attitude; it has challenges but can lead to comprehensive learning processes for both parties.

The case study on mini-grids in the Thies region in Senegal

In Senegal, we studied a project, consisting of six mini-grids in the Thies region that was implemented and owned by a private sector company. The company raised funding for the power plants and the implementation process and received donor grants for the power plant houses and grids (the fixed assets). The model could therefore be an example for how governments could be involved in public-private partnerships with such a division of the investment costs. The company would take care of the rest, and it planned to recover its investment costs, including operation, maintenance, future expansion, and debt financing. The tariff level was set in order to reflect these costs.

The company's motivation was idealistic, in combination with the business vision. The entrepreneurs developed an innovative socio-technical design, including devices and rules for metering, prepayment, allocation of electricity, and systematic expansion. These solutions addressed several typical problems in previous mini-grids, such as customers failing to pay, unmetered supply, overload of the battery banks, and deep discharging of batteries. The customers could choose between different levels of power capacity, and these had different connection fees and monthly tariffs. This helped with affordability. The prepaid electricity was provided in weekly amounts, and the electricity would switch off when it was used up.

The settlements in the villages were dense, making them suitable for mini-grids. They were relatively wealthy compared with the villages studied in Kitui in Kenya, so even the cheapest option in the Thies case supported several lights and phone charging, in contrast with the single, portable lanterns used in Kitui. Broad access to basic electricity services had been achieved in the six villages in Thies, since very few people were not connected, but a majority of the households could not afford enough power to be able to watch TV or similar activities.

The operation and maintenance seemed to function well, in large part because of the company's willingness to follow up on the power supply and solve problems that people encountered. This was mostly handled by the company staff. Good-quality equipment was also important for performance. The electricity supply was mostly reliable. The customers experienced automatic disconnection in their houses because they either connected bigger loads than they had subscribed for or used up the agreed number of kWh before the week was over. (This automatic disconnection was a function of the meter to balance the power system and avoid blackouts.)

The system was both advanced and innovative but also a bit challenging for the customers to use correctly. The families were also large (polygamous), so it could be difficult for them to control and coordinate the use of electricity in several rooms and buildings when all of them shared a single connection.

The users were still satisfied in many ways, and they praised the access to electricity. They complained about the costs, however, and we found four main reasons for this: they compared the tariff paid in the villages served by mini-grids with the tariff in areas connected to the main grid, where the national utility (Senelec) distributed electricity at a lower price; they contended with economic struggles and low income; they had some frustration about the payment system and uncertainty about when the prepaid electricity would be used up; and, finally, complaints were probably greater than normal due to our research team's presence and our questions about people's views on the electricity supply.

The company had planned to scale up to a total number of 30 mini-grids and secured the financing for this. However, they had to cancel the whole plan because the government could not accept the electricity tariffs that the company needed and so did not give licenses for mini-grids beyond the pilot. This was due to the government's intent to develop regulations for a uniform electricity tariff. The government was working on a plan for cross-subsidization to areas where the uniform tariff would not cover the actual costs of supplying electricity, but this work was going slowly. As a result of the lack of licenses, the investors withdrew from the project, and this made the company unable to scale up in Senegal. Unclear, unsuitable, and absent regulations became a stumbling block for the company's contribution to electricity provision in the country, although the policy framework had looked promising. The company finally had to give up their work in Senegal after 5–6 years of committed effort.

This case suggests that mini-grids implemented by the private sector have the potential for important contributions to providing electricity access that reaches almost everyone in each rural community and functions in practice over time. At the same time, the case also demonstrates some of the main difficulties that private sector companies have met with in this market. These are related to policies and regulations and their effects on the chances to operate in economically sustainable ways, as well as the costs. In order to survive economically, the mini-grid companies have to either charge cost-reflective tariffs or receive reliable and long-term support for their operations. Both options have challenges.

First, cost-reflective tariffs for mini-grids tend to be higher than national utility tariffs, in part because the national utility tariffs usually do not reflect all the costs that go into installation and operation of electricity supply, in addition to administration of the electricity sector. However, although there could be good reasons for cost-reflective tariffs in private-sector-led mini-grids, it can be politically difficult for a government to accept it; that means admitting that people in remote areas served by mini-grids have to pay more per unit of electricity than people on the national electricity grids. Another argument is that cost-reflective tariffs should not be a problem because the electricity from the mini-grids would be the cheapest option available in the areas where these are implemented, and many people in such areas are already used to paying higher prices for much poorer energy services.

Second, it can be difficult for a government to provide reliable and long-term economic support for the private sector's operation of mini-grids, although it might be possible in some countries. For example, an established system for cross-subsidization for electricity provision in remote areas, as in Kenya, could be extended to privately operated mini-grids, although this would be much more complex. Private sector mini-grid developers tend to see such dependence on ongoing support as risky and unreliable. The Senegalese case illustrates how crucial the national policies and regulations are to the opportunities for private sector actors to provide electricity through mini-grids in remote areas.

The mini-grid company that we focused on in the case study in Senegal is currently implementing mini-grids in some other African countries where the regulatory framework is better, but they still face uncertainty due to the political nature of the kinds of issues mentioned above. It is difficult to anticipate which steps the governments will take in the years to come. Innovation in policies and regulations for the private sector and different arrangements for private sector involvement are important to exploit the potential of mini-grids for rural electrification. For further discussion of the roles of the private and public sectors in this field, see the two panel discussions described below, especially the one in section 5.

A lesson learned on how to provide broad access to electricity services is that affordability is enhanced if customers are allowed to stop making payments (and discontinue the electricity, which is prepaid) when they have economic problems. Such flexibility might reduce revenue slightly, but it is helpful for customers with low and fluctuating incomes.

The case study on mini-grids in Senegal also supports the importance of further cost reductions, and other improvements through social, economic, organizational, and technical innovation, for the achievement of electricity access for everyone.

Conclusions

The intent of this research has been to increase the knowledge on how mini-grids and other village-level electricity systems can be designed, implemented, and operated in ways that make them function well in the long run and that can be expanded and scaled up. We have also tried to understand how these types of socio-technical systems can provide electricity services that are affordable, reliable, and useful for the majority of the population in each village that relies on them. The research also identified problems and barriers related to implementation and sustainable management and suggested some potential solutions. In addition to the conclusions mentioned under the three case studies, certain more general conclusions are presented here.

The cases show the importance of learning through practical experience *after* implementation of the electricity systems, not merely through planning in advance. Many energy projects break down because of the lack of such follow-up and the absence of willingness and resources to make improvements over time based on lessons learned. Project implementers have to spend time in the remote villages, observe how people relate to the electricity systems, and be committed to listening to people's reactions and ways of perceiving various characteristics of the systems. This includes the perspectives of those who are not able to connect. Only then will it be possible to understand how the electricity system fits into the local social and cultural context and how it can be improved. In addition, financers and policy makers can achieve better results if they acknowledge that the implementation of innovative socio-technical solutions always has some unexpected outcomes that must be considered and that comprehensive learning takes place during the process, not least during the upscaling. Upscaling is a learning situation where plans have to be changed on the fly, and it is a gradual process of system innovation. The process is influenced by different social contexts in different geographical areas. There are also large areas where neither conventional electricity grids nor mini-/micro-grids are suitable. Rental of portable lanterns is a model that can provide good-quality lighting in such areas. According to this research, a rental model can offer additional and more affordable lighting compared to individually owned equipment and represent a stepping stone to the further use of solar PV systems.

Our research also shows that flexibility in the ways in which the electricity services are provided is important for affordability and practical usability of the services. Different options for subscription, such as in the Senegalese case, can make it possible for people with extremely low income to have at least some basic electricity supply. Another useful example of flexibility is offering people the opportunity to vary their usage, and therefore their spending on electricity, over time. In the Kitui case, for instance, people were free to take breaks from renting the lanterns. A further example of flexibility observed in the case studies was the use of portable devices, like the Kitui portable lanterns. The portability of the lights was much appreciated and also aided affordability and access, because the lantern technology itself therefore provided flexibility in when and where to use it, for what, and by which family members. This also shows the importance of designing the details of the electricity provision in ways that fit with people's practical needs, livelihoods, and various other characteristics of different social and cultural contexts. For further analysis, see forthcoming publications by Ulsrud and co-authors.

PART II: WORKSHOP SESSIONS

Chapter 3: Social and technological innovation by the government of Kenya

Chief Eng. Henry Kapsowe, Kenya Power. Comments by Solar xChange team member Eng. Henry Gichungi.

a) Rental of portable lanterns for basic access to lighting
Engineer Henry Kapsowe first described a project currently under implementation by Kenya Power involving the rental of portable lanterns. Eight hundred and forty solar charging stations are being implemented in thirteen counties[5] in Kenya where the government has found that off-grid solutions are necessary. Twenty-four thousand lanterns will be rented out. The customers rent the lanterns for a few days at a time and bring them back for charging. A local shop owner operates the charging station and receives a commission on the revenue from the lantern rental. The funding of the activity comes from Nordic Development Fund (NDF).

Engineer Henry Gichungi provided comments based on his involvement as an advisor for the project on behalf of the Solar xChange project and as a former Kenya Power official (deputy director for off-grid power stations) who secured the funding for the project. He answered a range of questions from the audience, and the information he provided is summarized here. Sinotec supplies and installs the charging equipment and does the initial training of the operators. The lanterns are manufactured by Omni-voltaic, have a two-year warranty period, and have a lumen level of 100 lumens on medium mode and 200 lumens on the highest mode. The size of the solar systems used for charging is 100W. The payment model is rent to own at 10 Ksh per day; if customers do not have the 10 Ksh, they keep the lantern without using it until they get the money. When the total amount paid reaches Ksh 5600, the customer will be given a solar panel so as to own the lantern. Esunpower makes the computer software used for money collection, and Sinotec developed the software (Solkit) for payment on the charging system. Kenya Power is recruiting an operator who will operate and maintain the lantern rental service and be paid by NDF for two years.

[5] Marsabit, Isiolo, Baringo, Homa Bay, Lamu, Garissa, Wajir, Mandera, Turkana, Tana River, Meru, Embu and Samburu.

b) Hybridization of the isolated diesel-operated grids in Kenya

In the second part of his presentation, Engineer Kapsowe of Kenya Power presented the ongoing activity on hybrid power generation for isolated grids/large mini-grids operated by Kenya Power, which has 20 such grids operating in remote counties. Three additional grids have been constructed but not yet commissioned. Diesel generators are the main technology, but solar PV technology is installed as a complement. The solar capacity ranges from 10 to 300 kilowatts (kW). Wind generators are installed in two plants. The installation of the renewable power generation is financed by the government of Kenya and international loans, repaid through the resulting savings on diesel fuel for the power plants.

Chapter 4: Panel discussion: Success factors and challenges for village-level solar power supply models and their upscaling

- Introduction by moderator *Debajit Palit,* The Energy and Resources Institute (TERI)
- New experience from Senegal, Tanzania, and Nigeria. *Siv. Eng. Jakob Schmidt-Reindahl*, Inensus
- An advisor's experience: *Florian Simonsen,* Project Advisor, GIZ ProSolar
- An academic perspective: *Dr. Oliver Johnson,* Senior Research Fellow Energy & Climate Change Programme Leader Africa Centre Deputy Director, Stockholm Environment Institute (SEI)
- The experience of the United Nations Office for Project Services (UNOPS): *Thushanti Selvarajah*, Project Manager, UNOPS
- Panel discussion and questions from the audience.

Debajit Palit from TERI, member of the Solar xChange project, introduced the panel discussion by referring to International Energy Agency (IEA) reports stating that 70% of the additional electricity connections from now to 2030 will be through off-grid means, with 40% by mini-grids alone. He added that, at the same time, many country governments continue to emphasize grid extension. One example is Tanzania, where mini-grids were being implemented by private sector developers in line with the policy developed for the purpose. However, the president has reportedly said recently that he plans to cover the entire country with grid extension in the next five years. Users might favor the grid, and one of the reasons is a lower tariff (5–6 US cents/kWh for grid versus >40 US cents/kWh for mini-grids). So far, mini-grids have mostly been accomplished with little organization, implemented on a local scale by relatively small entities or NGOs/research institutes. Scale has probably not been reached by any organization because of low volume and associated high transaction costs, and this also maintains a high tariff.

Palit also suggested that traditionally too much stress had been placed on technology innovations — with too little focus on policy and institutional and financing innovations. This includes the limited ability of small project developers to absorb the large amount of financing available from various donors/venture funds. Recently, IRENA and REN 21 have been attempting to address the knowledge issues by documenting policies and cases and what can and should be done to scale up private sector mini-grids. Some countries have also developed a policy framework. Nevertheless, Palit said that we don't see much scaling up and that large players are also absent in this space.

The panel participants brought up a wide range of factors that they found played a role in mini- and micro-grid development and potential upscaling. Lack of a proper or conducive policy and regulatory framework was pointed out as the major challenge hindering the development of projects, especially for private sector developers. Aside from the issue of uniform tariffs, the licensing procedure is lengthy and costly. Although many mini-grids are implemented by donors, there is lack of coordination among the various entities. Some developers do not have a long-term strategy for the plants, which disregards the sustainability aspect of the projects. By contrast, fully subsidized projects spoil the market for private mini-grids. Another challenge is the lack of legal protection for operators from the risk of the main grid reaching the sites. The governments also come up with unrealistic strategic plans, and this makes it more difficult for private developers to get investors and financing for such projects. There is even the pressure of fulfilling short-term government targets against the company's long-term plans.

Mini-grid development by the private sector faces competition from technology developments. Innovation, such as for PAYG and battery technology, has created new markets and therefore additional competition from cheaper sources of energy (e.g., solar home systems and pico-solar).

The perception that solar energy supply is usually a temporary solution until the main grid reaches these locations makes it difficult to get people to invest. While one of the reasons for this perception is pricing (as discussed above), another could be the fact that many solar projects tend to meet only basic energy requirements with little consideration of how to achieve higher levels of service at an affordable price. It is also difficult to convince donors to provide funds for the project's lifetime to ensure adequate monitoring and maintenance. The government therefore needs to take up this role. Poor installation and sizing of some plants make them operational only for a short period. This further cultivates a negative perception of mini-grids. Institutional buildings can be incubators for technology if well installed and well maintained, and this can improve the perception of mini-grids. It is also difficult to implement mini-grids in areas with widely dispersed population, as it increases the costs.

The government should create a conducive environment for the private sector to scale up by streamlining administrative processes, providing a regulatory framework, and financing mechanisms with clear objectives. Coordination is important in order to avoid competition from fully subsidized projects.

It is also important to redesign business models based on the lessons learned from the pilot projects. Another question is the channels through which to disseminate the lessons and information from the pilot mini-grids. Some key lessons were learned about scaling up:

- Proper site selection — far from the grid
- Customer base — willing buyers of the power supply

- Awareness creation and agreement on the tariff rates with the community before implementation
- Consideration of the lengthy and costly licensing procedure in the planning stage
- Acknowledgment that anchor clients are important, as they provide regular revenues, but that it is risky to depend too much on them
- Awareness of the importance of an operator to the sustainability and operation of the business because of ensuring new connections
- Correct sizing of the project, including the initial load assessment (i.e., proper assessment of the demand for power and also the willingness to pay)
- Recognition of the gender dynamics of the project in the design (i.e., taking into account participation in the design and operation of the project and differentiation of the type of services and use of electricity)
- Accounting for the local social and cultural context in the design. Taking into consideration the income activities of the community will ensure that most households pay their electricity bills to avoid disconnection.

Chapter 5: Panel discussion: Policies, regulations, and financing for the upscaling of mini-grids and the moral dilemma of cost-reflective tariffs

- Introduction by moderator *Charles Muchunku*, member of the Solar xChange team
- The Kenyan Energy Regulatory Commission's work on regulations for mini- and micro-grids, *Caroline Kimathi*
- *Eng. Henry Gichungi,* consultant on the Kenyan off-grid solar access program, discussing the World Bank's new support for off-grid power supply in Kenya
- A practitioners' perspective 1: *Jakob Schmidt-Reindahl*, Inensus
- A practitioner's perspective 2: *Johannes Holst,* PowerGen
- Panel discussion, including questions and comments from the audience.

The discussion focused on two questions:

- Complementarity between private and public sector mini-grid (or micro-grid) initiatives. Are there examples of this in practice? How could this be best structured?
- Financing of private mini-grids. How are private mini-grids currently being financed (through debt, equity or grant, or a mix of these)? What is the ideal financing model?

When it comes to implementing mini-grids, the public and private sectors have different and complementary strengths. The government/electrification authorities can mobilize large amounts of public funding (e.g., through levies, grants, or government borrowing) to implement mini-grids at scale (in terms of number and size of the systems). In addition, this is considered a social investment; governments are not looking for a financial return. By contrast, the private sector's strength lies in speed, efficiency, cost effectiveness, and the ability and flexibility to innovate (i.e. quickly adopt or adapt new technologies as they emerge). One could therefore expect that the most effective mini-grid models would be based on well-designed public-private partnerships.

The panelists mentioned the following ways for the public and private sector to collaborate:

- Interconnection of private mini-grids with the main grid should be possible if or when the main grid is extended. In this way, private developers could continue to serve their customers (with cheaper main grid power) and would also have the opportunity to sell renewable energy (RE) power to the grid operator. As private mini-grid developers cannot compete with prices offered by the main grid, extension of the main grid is currently considered a business risk rather than an opportunity.
- Private mini-grid developers should be compensated in the event of the main grid being extended or the government implementing a mini-grid to serve the same customers.
- An off-grid power purchase agreement model (the private sector focuses on generation, while the public utility, which can manage and extend electricity cross-subsidies, focuses on distribution) should be offered. This way, private investors are guaranteed a return on investment, while mini-grid customers can benefit from electricity cross-subsidies.
- The government should undertake national studies to identify potential mini-grid sites and provide a clear plan on where and when it will implement mini-grids or extend the grid and which sites will be available for the private sector.

It was acknowledged that grant funding still had a key role to play in the issue of financing of private mini-grids; it is still not possible for developers to finance mini-grids purely on equity and debt. However, considering that the sources of grant funding are varied and that a significant effort is required to source such funding, it will be difficult to generate a reliable and sustainable source of grant funds. Governments could be considered a sustainable source of grant funding, since this is how they fund electrification. There was debate as to whether the role of electrification authorities/agencies was to implement mini-grids or to facilitate their implementation (through public utilities or the private sector). It was argued that the private sector has demonstrated its ability to provide electricity services at a much lower per consumer capital expenditure (i.e., investment cost per connection) and more reliably than electrification agencies and public utilities, respectively, justifying that it should also be considered for government funding.

Chapter 6: The importance of gender sensitivity in efforts for off- and on-grid electrification

Led by Dir. Anjali Saini, Seacrester Consulting, Nairobi, Research partner, the EFEWEE project and the Solar xChange project

Anjali Saini described the research project "Exploring Factors That Enhance (and restrict) Women's Empowerment Through Electrification" (EFEWEE). She mentioned that several members of the Solar xChange project also participate in EFEWEE. She explained that the project investigates the impacts of electricity on a range of dimensions of women's empowerment (including material, social, and human resources and influence over decisions). The project also investigates factors that play a role in such empowerment, including the type of electricity system (on-grid, off-grid, and different characteristics of these) and the characteristics of the local social and cultural context.

A question was asked to the audience: "What does gender and electrification mean to you?" to start a discussion. One of the workshop participants answered "nothing!" and sparked a lively discussion. Additional questions were also put to the audience: What is empowerment? Does it matter for women's empowerment through electricity to have women involved in electricity supply? Does it matter if gender is taken into account during planning and implementation?

The participants pointed out various factors to consider regarding electrification and gender, including the following. The implementer (who decides how electricity should be installed) should consider gender roles (allocation of resources). Gender should also be considered when doing the wiring of the house; for instance, who decides where to put the socket and how to use the electricity, e.g. does someone need electricity in the kitchen? One comment referred to a mini-grid project where women participated and yet there were few extended effects on women's position in the wider community. A response to this was that in another case, an energy center project where a woman became a manager, several young women were later employed and trained by the initial staff members. This led to a change in the perceptions of the community members about what women can do.

It was argued that women and empowerment go hand-in-hand with the policies that articulate gender and how they translate into practice. Other comments included that some of the factors that affect gender relations include norms, physical infrastructure, power relations, and uses of electricity. Further arguments were that gender is about equality in power relations; empowered women are able make decisions, acquire skills, and take control of their lives. Electrification is a push factor to achieve equality.

PART III: REFLECTIONS

Chapter 7: Reflections on the future role of small-scale renewable and hybrid mini-grids

These reflections focus especially on small-scale renewable and hybrid mini-grids implemented in order to electrify rural communities. Such mini-grids have very different characteristics and require different types of knowledge, policies, and support mechanisms than other off-grid solar PV models. The workshop described above gathered an audience with diverse experience on such mini-grids, and this led to up-to-date and detailed discussions on factors that currently influence the progress of such delivery models. These discussions, as well as the research results described earlier in this report, showed that it is still difficult to implement mini-grids in an economically self-sustaining and scalable way, due to political, regulatory, and economic barriers.

At the same time, research shows that there have been great improvements in technical solutions, business models, organizational arrangements, and practical solutions for renewable mini-grid systems. Current mini-grid models appear to function much better and have lower investment costs than before. Mini-grid systems also appear to have some fruitful social characteristics according to our various case studies. For instance, they tend to provide more affordable access to electricity to a larger portion of people in each community than other off-grid solutions and main grids. They tend to achieve quick electrification of whole villages or large portions of each village, as in the examples we have studied in Senegal and India. They seem to give people a better impression/awareness of what electricity can do for them than small, individual solar systems, and they have the potential for higher service levels (tiers). Mini-grid systems do have advantages when it comes to facilitating income generation and productive activities. However, this is a slower and more difficult process than what is acknowledged in the literature on energy and economic development. Increased production in rural areas meets with a range of constraints (e.g., access to markets) in addition to those related to electricity supply. The nature of such constraints, how and why they occur, and how they can be overcome are important topics for further social science research.

Despite such achievements and positive characteristics of renewable and hybrid mini-grids, there are significant remaining challenges for private and public sector actors in this realm, including the complexity of implementing, operating, and scaling up such decentralized infrastructures. This creates some skepticism about mini-grids, driving some people to conclude that the mini-grid model does not work. Some also claim that it might not even be needed, arguing that pico-solar lighting products and solar home systems can cover all needs in the areas where national main grids are unfeasible.

Others have a more optimistic view, expecting that renewable mini-grids implemented by governments, the private sector, and others will be important to rural electricity access in the future. From this point of view, the task is to continue to work on improvements and learn more about how and by whom mini-grids should be supported, implemented, operated, maintained, and scaled up.

Two reports from IRENA represent a relatively optimistic view. These are "Rethinking Energy 2017: Accelerating the global energy transformation"[6] and "Renewable mini-grids."[7] These reports identify ongoing and promising innovations likely to change the way mini-grids are performing, both economically and practically. However, they also point out that many issues remain to be addressed in order to achieve commercially viable renewable mini-grids that are not supported by cross-subsidies or grants.

On the issue of cross-subsidies and grants, the dependence on such support is often seen as a weakness of mini-grids. This view might be questioned, based on the fact that the populations they serve are economically deprived. Support to small-scale mini-grids in such areas, through government units, companies, or other mini-grid operators, can be justified as an indirect support to people who need electricity and live in poverty. Support to renewable mini-grids also furthers social and technical innovation on decentralized power provision. It is necessary to improve the support mechanisms to make them fair, systematic, broadly available, transparent, and stable.

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[6] IRENA (2017), *REthinking Energy 2017: Accelerating the global energy transformation.* International Renewable Energy Agency. Abu Dhabi.

[7] IRENA (2016), Innovation Outlook: Renewable Mini-grids, International Renewable Energy Agency, Abu Dhabi.

For private sector companies, unstable and unreliable support mechanisms create uncertainty and risk. In Senegal, for instance, where cross-subsidization is suggested by the government but not yet established, there is tremendous uncertainty as to how it will work. It is therefore not tempting for the private sector to start projects that depend on this. In contrast to the situation in Senegal, cross-subsidization is well established and well functioning in Kenya but does not apply to private sector actors. In Kenya, therefore, it could be possible to try out a similar system of support to the private sector.

To claim that renewable mini-grids and other village-level systems have failed is probably to ignore the power of innovation, as shown by historical experience on transitions to novel socio-technical systems. It is unlikely that social and technological innovations in mini-grids have come to an end. The innovation processes include a range of aspects and take place in different places and at different societal levels. Such "system innovation" is moving forward due to the efforts of various types of actors, including governments, companies, donors, technical experts, social scientists, and people using the electricity. According to many experts, mini-grids are still at an early stage of their development.

There are nevertheless many open questions in this field, including political and ideological issues with the role of governments, the private sector, donors, and researchers in the future. A large support program (KOSAP) that includes mini-grids is under development in Kenya, carried out by the World Bank and the government of Kenya. This program has the potential to advance further learning and innovation on mini-grids for electricity access. It may build on the experiences and research findings available so far on what can be learned from previous efforts.

There is little doubt that different types of electricity models can fruitfully complement each other and that the creation of a diverse electricity sector can be productive. Different models have different advantages and disadvantages for different social groups. In other words, there is no one-size-fits-all solution. Instead of seeing the models as competing, it is more helpful to focus on how the different models can be improved, widely implemented, and combined. New types of delivery models will probably also be developed. It is not possible to know today where ongoing innovation processes will lead us in the future or what future energy systems will look like, because innovation is a not a process that follows a straight line (as convincingly shown in social studies of technology). There is an inherent uncertainty in all innovation and most efforts must confront difficulties and even failure. These are inevitable characteristics of innovation processes, leading to vigorous learning and the development of new ideas and solutions.

Different types of models will certainly fit in different local and national contexts, because of not only different social and cultural features, economic conditions, and settlement patterns but also different political ideologies, governance systems, government revenue streams, and characteristics of existing energy sectors. It is very likely that the suite of delivery models, including stand-alone systems, mini-grids, solar lantern rental systems, and conventional grid extension, are needed on a large scale.








About the Solar xChange project

The research project "Solar xChange: A comparative study of socio-technical innovations and sustainability factors for upscaling of village-scale solar power supply models in developing countries" is led by the department of Sociology and Human Geography at the University of Oslo. The project has research partners (social scientists and practitioners) from Kenya, India, and Norway. The main objective is to assess experiences with different models for village-scale solar power supply systems in the Global South, explore their role in adaptation to climate change, draw lessons for their wider dissemination, provide new real-world examples, and initiate upscaling processes and knowledge exchange. The project team aims to actively transfer, translate, and build on insights between the investigated cases, actors, and countries and then apply the knowledge in pilot projects.