Conclusions

Subhes C. Bhattacharyya and Debajit Palit

Abstract This chapter summarises the main findings of the book and presents the concluding remarks. Various chapters of the book show that with proper technical design, appropriate choice of delivery options and a supporting environment, mini-grids can be an effective solution for enhancing electricity access in rural areas of developing countries. The experience from several successful examples of mini-grids in South Asia suggests that success in each case was achieved through a unique combination of critical factors. All successful cases have managed the technology well, ensured effective delivery and followed a business-like approach.

1 Summary of Findings

As part of the research project on Off-grid Access Systems in South Asia (OASYS-South Asia), a detailed investigation on the mini-grids as a viable option for electrification in South Asia was undertaken. In 13 chapters (excluding Introduction and the Conclusion) this book reports various dimensions of the study and provides the theoretical technological underpinning, practical design aspects, case studies and business-related considerations. In two parts, the book has strived to combine both the background knowledge required to appreciate the mini-grid based electrification in rural areas and in-depth research studies that demonstrate the integration of a multidimensional analytical framework into research. One of the main gaps in the literature relates to inadequacy of information about

S. C. Bhattacharyya (✉)
Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK
e-mail: subhesb@dmu.ac.uk; subhes_bhattacharyya@yahoo.com

D. Palit
The Energy and Resources Institute, New Delhi, India
e-mail: debajitp@teri.res.in

S. C. Bhattacharyya and D. Palit (eds.), *Mini-Grids for Rural Electrification of Developing Countries*, Green Energy and Technology,
DOI: 10.1007/978-3-319-04816-1_15,

successful mini-grid examples. This book bridges this gap through detailed case studies of examples from South Asia. Moreover, given the emphasis on productive use of electricity for rural livelihood generation, this book reports the step-by-step process that was followed to develop the demonstration project set up in a cluster of five villages in Dhenkanal district of Odisha (India), where lighting provision for residential use has been combined with livelihood generation activities and other support initiatives for social capital development. It thus contributes to the energy-plus agenda of energy access theme and demonstrates the delivery of an integrated activity that links rural electricity with rural development.

Establishing the link with the previous book published from this research project, "Suite of Off-Grid Options in South Asia" provided an overview of a suite of decentralised options available in South Asia to address the electricity access challenge. Although South Asia has gained some experience in decentralised options, the stand-alone solar home systems (SHS) received greater attention. But the limited service provided by the SHS makes it a temporary solution and the relatively high initial investment requirement limits the choice to the richer section of the population. There is some experience with mini-grids as well and alternative business models have been explored but the regulatory environment is not conducive yet to ensure long-term viability of the options.

The technical options for mini-grids in rural areas, covered in "Technical Aspects of Mini-Grids for Rural Electrification", demonstrate the near cost-effectiveness of a number of technologies for which the potential of renewable energy resources exists in delivering electricity in rural areas through mini-grids. The chapter explained how such potential can be harnessed through appropriate technologies. Referring to the debate on AC versus DC supply, the chapter suggests that, with technological improvements, the DC options should also be considered because appliances using DC supply are now not limited to basic applications such as lighting and mobile charging but are being extended to those requiring electric motors, which offer precise speed and torque control thereby resulting in energy saving. In rural areas, a DC system eliminates the conversion loss and reduces the capital investment requirement but the distance limitation with a 24 V supply system restricts its use to closely distributed households with limited demand. But in a hybrid system where loads and generating sources can be segregated in AC and DC, a dual bus system with a bi-directional converter can be used. As the applications increase, the costs will decline, making mini-grids even more cost-effective and a reliable option in the future.

"Smart Design of Stand-Alone Solar PV System for Off Grid Electrification Projects: Technical Aspects of Mini-Grids for Rural Electrification" supplements the technical discussion of "Technical Aspects of Mini-Grids for Rural Electrification" through a detailed presentation of solar PV mini-grid design in an intelligent way. The entire range of activities of a PV system design is covered with the objective of providing a reliable but affordable supply at a high efficiency. The smart use of load profiling, resource profiling and load categorisation suggested here can lead to cost saving through better capacity choices and management. Similarly, the balance of the systems such as batteries and inverters can also be better managed for cost saving through a smart configuration of the system. In addition, by providing for the grid connectivity option, the system can be protected from becoming a stranded asset in the future when the central grid is extended eventually. The step-by-step guideline provides the practical advice for potential users while the smart features make the contribution state-of-the-art.

The integrated framework presented in "Analytical Frameworks and an Integrated Approach for Mini-Grid-Based Electrification" goes beyond the conventional techno-economic analysis of mini-grids normally found in the academic literature. The detailed review of the literature shows that a plethora of analytical approaches has been applied to study rural electrification in general and mini-grid-based decentralised electrification in particular. Yet, the practice-based literature lacks academic rigour and the academically oriented studies are not always grounded in practical reality. Moreover, the frameworks tend to neglect the iterative process of project development and incorporation of feedback from the ground. The framework presented in this chapter remedies the above limitations and provides a sound yet practically grounded approach to analyse mini-grid-based electrification that has been applied in various case studies reported in the book.

The field-level analysis presented here confirms that the success of an off-grid project depends on factors beyond techno-economic considerations. The policy environment, social acceptance, linkages with income-generating activities and technological appropriateness play a defining role. Accordingly, the macro-economic policy instruments need to be aligned with the local context; the technology choice and scale of operation are determined by the nature of the local energy service, which in turn depends on the economic condition and social structure while influencing the financing options of the initiative. This emphasis on local context and the feedback from it plays an important role in creating a viable operation.

Although demand-side management is often discussed in relation to central grid systems, it has a vital role in small-scale decentralised systems where the resources are limited, demand diversity is less pronounced and supply has to be balanced with demand anyway. This assumes greater importance in systems where the energy source is variable in nature. This important issue is captured in "Demand Management for Off-Grid Electricity Networks", providing a review of alternative options for demand management in off-grid systems. It suggests that dynamic current limits such as those provided by an electronic trip are appropriate for generator-limited systems while an energy budgeting scheme is appropriate for a battery-limited system.

Electricity supply through mini-grids in rural areas represents a paradigm shift and the commercial aspects of such a business require a careful consideration. Creating a viable business is a challenging task in a difficult micro-environment exemplified by limited customer base, locational disadvantage, poor paying capacity and lack of skilled manpower. The macro-environment may not be supportive either, thereby creating impediments to any commercial viability. This may arise from lack of regulatory clarity about such business prospects, hurdles in accessing finance, short-term nature of funding and non-conducive policy environment. Accordingly, "Business Issues for Mini-Grid-Based Electrification in

Developing Countries" suggests that choosing an appropriate scale of the business in such a situation is clearly vital. If the rural area does not have a ready market, a limited supply for lighting only may be attempted. Where more productive uses exist or dormant demand exists, a more ambitious system (light-plus) can be considered. Where an anchor load is readily available, the supply viability can improve due to the contractual arrangement with the dominant buyer. However, in each case, there are specific challenges particularly in terms of funding, ensuring reliable supply and managing the business locally. The choice of technology, supply chain management and careful operation and maintenance of the system in rural areas is therefore important to economise on costs and investment needs. Moreover, appropriate charges for the supply and efficient collection arrangement are also essential to run a healthy business.

The range of case studies included in the second part shows the practical dimension of mini-grid-based electricity development in South Asia. As part of the OASYS South Asia project, a number of demonstration efforts are being undertaken. The implementation of such a project in a cluster of five villages in Dhenkanal district of Odisha is reported in "Approach for Designing Solar Photovoltaic-Based Mini-Grid Projects: A Case Study from India". This demonstration project showcases a small-scale lighting-plus system using solar PV as the source of electricity generation. The supply will be locally managed by the community with the support of an NGO. Three larger villages are connected with AC grids whereas two smaller ones are connected with DC grids, thereby demonstrating two distribution options in a single site. While the households in each case were provided with a connection of two LED lamps of 3 W each and a mobile charging connection, the project is also catering to commercial loads in the main village to support livelihood activities, community loads (e.g. street lights, water purifier and facilities in the community hall) and water pumping for agriculture. The implementation activity reinforces that in a community-based system, it is important to engage regularly with the community from the beginning of the work and take them into confidence. The remoteness of the site and limited infrastructure availability need to be considered in the planning process. The difficulties in transporting the equipment and materials, as well as finding suitable semi-skilled workers for various construction activities can lead to cost and time over-runs unless properly taken care of. The technology selection needs to consider ease of operation and maintenance while the system design should keep the reliability of supply and system operation in mind. Moreover, once electricity reaches through the mini-grid, users may like to demand more and some provision for additional demand as demand management is important as well.

Application of the integrated framework of analysis in two chapters ("Renewable Energy-Based Mini-Grid for Rural Electrification: Case Study of an Indian Village" and "From SHS to Mini-Grid-Based Off-Grid Electrification: A Case Study of Bangladesh") marks a departure from the conventional analysis. The analysis has paid greater attention to demand estimation and has used alternative demand scenarios, whereby plausible cases were developed to capture various possibilities. The analysis has relied on the simulation, optimisation and sensitivity analyses using HOMER to identify the appropriate technology combinations to meet the demand. The work then extends into the business-related analysis to see if a viable business can be identified. The iterative process of analysis is also captured here. Similarly, an application of multicriteria decision making for off-grid technology choice is presented in "Application of Multi-criteria Decision Aids for Selection of Off-Grid Renewable Energy Technology Solutions for Decentralised Electrification" taking the perspective of some stakeholders involved in off-grid electricity supply.

The case study on Solar PV mini-grids in the state of Chhattisgarh in India is another contribution to knowledge. Although the system has been working effectively for some years, it has not received due attention in the academic circle. Our detailed case study shows that a top-down approach can also deliver and replicate if the critical factors are well managed. Chhattisgarh has developed a successful delivery model through a dedicated agency involvement, appropriate technology choice, technology standardisation, appropriate financial support from the government, and a clear delivery model with focused duties and responsibilities. While the financial viability has not been the main aim here, nonetheless successful operation of a large number of mini-grids in difficult conditions is not a mean achievement.

The mini-hydro-based local grid system in Nepal on the other hand provides a contrasting picture. Availability of a cost-effective renewable resource alone does not ensure success of a mini-grid system. Although Nepal has made visible progress towards electricity access, it still faces weak institutions, unclear policies, limited access to funding and limited demand from productive activities. Although mini-hydro plants tend to produce cheaper electricity, it seems to be losing out to solar PV.

Finally, the analysis of the business potential of electrifying rural South Asia using rice husks as a source of energy, following the example of Husk Power Systems, reveals that a viable supply can be developed for various scales of operation. The cost of electricity using rice husk is likely to be lower than that achievable with solar PV but grid price parity may not be easily achievable without capital subsidy and/or debt capital at reduced interest rates. Yet, the business can operate successfully through a suitably designed tariff structure. Integration of productive demand and higher capacity utilisation improves the financial viability of the business. Economies of scale through a bigger plant size bring down the cost of supply and the supply can become very competitive but greater attention is required for distribution system design, plant operation and supply chain management.

The main message that emanates from the studies reported here is that mini-grids can effectively complement the grid extension in rural areas and through proper technology choice, system design, enabling business environment and support mechanism, rural electricity supply can be offered through various delivery options. There is scope for a range of entities to be involved in the process: the private sector can achieve financial viability by economising on costs, developing an innovative supply and designing a careful tariff structure; public sector operators or community organisations that may not be looking for profitability as such can take advantage of public funds and aim for operational success by recovering running costs and managing the system effectively. Different scales of operation are likely to be appropriate in different locations and possibilities of clustering systems to strengthen the local supply will also arise. However, in all cases, local context requires careful understanding, which then needs to be translated into a suitable technical design, supported by an appropriate delivery mechanism and a conducive business environment. Absence or hindrances to these critical elements often endanger the process, causing failures and loss of interest in servicing this bottom of the pyramid.

2 Policy Recommendations and Way Forward

The challenge of achieving universal electrification by 2030 as envisaged by the UN Secretary General's initiative on Sustainable Energy for All requires commensurate solution strategies. While electrification through mini-grids offers such a strategy, achieving significant electrification through this mode demands leapfrogging to the rapid deployment stage from the pilot/demonstration project stage in which mini-grids are found at the moment. Such a transformation requires major efforts in various areas, some of which are highlighted below:

(a) *Create a supportive environment*: In order to expand rural supply through mini-grids, a supportive environment is required. In the policy sphere, a clearly spelt out rural electrification policy is required with well-defined roles and responsibilities for various organisations, clearly demarcated role for decentralised options, integration of off-grid electrification with local development policies and a transparent monitoring and implementation mechanism.

(b) *Ensure regulatory certainty*: As noted in "Analytical Frameworks and an Integrated Approach for Mini-Grid-Based Electrification", regulatory uncertainty and vacuum can stifle growth of mini-grid projects and the current paradigm of ad hoc and piecemeal dispensation to regulation produces sub-optimal outcomes. The mini-grid deployment as a miniature version of the utility model may not be legally viable unless its regulatory arrangement and scope is properly defined. In addition, a clear understanding with the incumbent utility is required in respect of grid extension, as this threatens and deters new investment in mini-grids. Similarly, clear regulatory arrangements are required in respect of licence or permissions for doing business, tariff systems, connection to the grid, safety requirements and quality of supply.

(c) *Guarantee technology neutrality*: The local context of rural areas in terms of resource potential, demand profile and paying capacity has a deciding influence on the technical choice. It is therefore important to avoid any a priori technology bias in the decision-making process. This in turn requires that the policy or regulatory environment should ensure technology neutrality and allow the most appropriate option to be developed without any hindrance.

(d) *Develop appropriate funding arrangements*: Access to funding is one of the main bottlenecks in expanding the business. As discussed in "Approach for Designing Solar Photovoltaic-Based Mini-Grid Projects: A Case Study from India", limited access to capital, short debt tenure, small size of projects (which excludes large financial institutions' direct involvement in such activities), limited credit record of rural entities, limited guarantee for debts and high interest rates are some of the financial barriers faced by rural communities and investors. These challenges have to be overcome to promote mini-grid-based electrification. Governments need to develop appropriate credit lines, project appraisal capabilities and support systems through rural electrification agencies, rural banks and similar financial institutions. The arrangements have to ensure neutrality in terms of borrowing entity to allow rural community organisations, cooperatives and private entities to gain access to such funds as long as the business looks credible.

(e) *Support rural infrastructure development*: As mini-grid development entails developing local electricity generation and distribution, it forms part of the rural infrastructure development. The state has supported investments in such infrastructure projects everywhere in the world and the developing countries are no exception. Our earlier work has suggested that countries which have made significant progress towards universal electricity access have all supported this effort. Accordingly, financial support for rural generating capacity and network development is justified and required. Although 100 % grant funding may not be desirable, a significant support can reduce the cost of supply and make the service affordable to rural communities.

(f) *Build required capacity*: The mini utility model of electrification is a demanding business that requires a set of skills to manage the system and run the activities effectively. As these skills are unlikely to be readily available in rural areas and perhaps lacking in urban areas, it is important to build capacity in anticipation. These skills will include, among others, technical expertise in running and maintaining the systems, basic accounting and record-keeping skills, project design and implementation, regulatory skills and financial skills to deal with financial institutions. South–South cooperation in this respect can be considered and the best practices from successful examples can be used to replicate such models.

This book has made contribution in most of the above areas and we hope that the readers will benefit from the research presented here.

Any study of this nature faces certain constraints and this work is no exception. Accordingly, we suggest a few areas for further investigation. First, although we have provided some case studies from South Asia, we are aware of rapid development in mini-grid-based electrification elsewhere in the world. An extension of the work to cover such experience from the rest of the world will surely be a valuable work. Second, we have mainly focused on village level mini-grids and have not considered the issue of replication and scaling-up in detail. This is an area worth investigating. Third, related to the previous issue, is the possibility of integration of local grids in the future, with an eventual formation of a central grid that can be connected to the main grid. This shift from an isolated operation to a centralised operation deserves careful attention and advance planning to avoid costly refurbishment in the future. Fourth, we have not considered MW scale generation projects located in rural areas which may serve local population and export the balance power to the central grid. Some such projects exist or are being developed in some Asian and African countries. As they are generally grid connected, they are not off-grid as such and did not come under our scope. But such projects can offer important lessons, particularly in terms of business models. A future study could include them. In addition, although we have considered a few business models, there may be other mini-grid models successfully running in India, Sri Lanka, Bangladesh, Nepal or elsewhere. With the limited resources and time, it was not possible to undertake an exhaustive study of all operating mini-girds. There is surely some scope for additional work here.

Also, while we have covered smart design of solar PV plants and have provided case studies of solar and gasifier projects, we have not covered the hybrid systems to a great extent. Such projects are limited in practice and have not become very popular yet. However, the hybrid systems may play a greater role in the future and further work in this area is required.

Finally, the regulatory arrangements and models for mini-grids have not been well covered in this book, as this was covered in the previous book published by the project (see [1]). Yet, a specific study on business models and regulatory arrangements has some potential. We shall endeavour to cover some of the above aspects in our upcoming works.

Reference

1. Bhattacharyya SC (ed) (2013) Rural electrification through decentralized off-grid systems in developing countries. Springer, London