Renewable Energy based Mini-grids for Enhancing Electricity Access: Experiences and Lessons from India

Debajit Palit[1], and Gopal K. Sarangi[2]

***Abstract* - Conventional grid extension has been the predominant mode of electrification in India. However, renewable energy based mini-grids have also been used for providing electricity access in remote areas, forested habitations, and islands. This paper, based on extensive literature review, interview with key stakeholders, and field visits to selected sites, captures the nuances of renewable energy based mini-grid developments in India. It also shares the experiences and lessons from the mini-grid programs by comprehensively analyzing multiple dimensions such as coverage and trend, technical designs, institutional arrangements, financial mechanism, tariffs, and operation and maintenance aspects. Finally, the paper suggests takeaway points for improving the rural electricity access level through renewable energy based mini-grids to compliment the grid electrification efforts in India.**

Key words – Distributed power generation, Electricity access, Micro-grids, Mini-grid, Renewable energy, Rural electrification

I. INTRODUCTION

Conventional grid extension has been the predominant mode of electrification in India covering almost 95 percent of the inhabited villages. However, statistics from the Census of India 2011 indicate that almost 77 million households in India were living without electricity in that year (Fig 1) [1]. Despite efforts by the federal and different provincial Governments to improve the state of electricity access, household electrification level and electricity availability continue to lag behind. While average household electrification rate in India is about 75%, the rural electrification rate is only 67% [2].

In addition to the conventional grid based electrification, renewable energy technologies such as solar Photo-Voltaic (PV), biomass gasifier, mini/micro hydro have also been used for providing electricity access in remote areas, forested habitations and islands [3]. These off-grid communities often characterized by scattered settlements consist of small, low-income households. Hence, they are economically unattractive for electricity distribution companies (discoms) to extend the grid. While extending the grid to such areas might be economically unattractive for the discoms, they have also not attempted to cover the off-grid areas with decentralised distributed generation and supply systems, though they are the licensees to provide electricity services in all areas. The state renewable energy development agencies, established in the different states by the state governments and working under the aegis of the Ministry of New and Renewable Energy (MNRE), Government of India, has largely addressed this vacuum. Specifically, Remote Village Electrification Program (RVEP) and Village Energy Security Program (VESP) of MNRE have been able to electrify around 12,000 remote villages and hamlets so far. In addition, NGOs have also implemented number of pilot projects by raising funding support from Corporates (as part of corporate social responsibility initiative) and bilateral/multilateral donors. Off late, private entrepreneurs have also ventured into the field, foreseeing the business prospect of the sector.

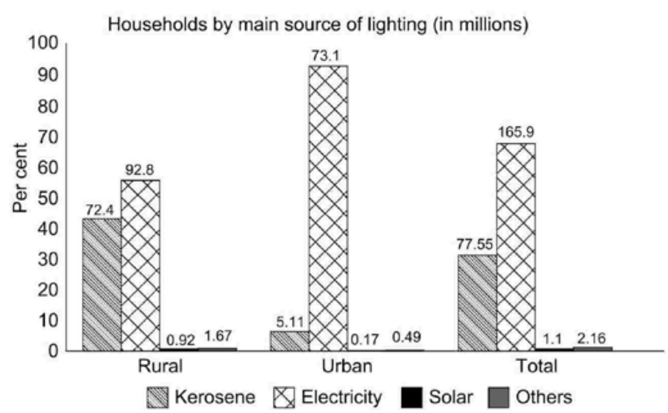

Fig. 1. Electricity access in India (Census of India, 2011)

The expansion of mini and micro grid program has also spurred due to high initial cost of extending grid to far-off remote areas, growing recognition of the effectiveness of such systems for geographically difficult locations, better modularity of renewable energy technologies such as solar PV to meet the energy requirement of small-scale communities

This work was supported by Engineering and Physical Sciences Research Council/Department for International Development research grant (EP/G063826/1) from the Research Councils, UK Energy Program and Global Network on Energy for Sustainable Development (GNESD).

[1]The Energy and Resources Institute, Lodhi Road, New Delhi 110003, India (e-mail: debajitp@teri.res.in).

[2]The TERI University, Vasant Kunj, New Delhi-110070, India (e-mail: gopal.sarangi@teriuniversity.ac.in).

and associated positive environmental effects [4,5]. In addition, adequate policy space for renewable energy based decentralized power production and distribution has accelerated the electricity access through renewable energy based mini-grids in the last decade.

This paper attempts to examine the nuances of renewable energy based mini and micro grid developments in India with special focus on the solar and biomass-based mini and micro grids. The paper, drawing from extensive literature reviews, interview with key stakeholders and field visits to selected sites, shares the experiences and best practices of the renewable energy based mini-grid programmes for rural electrification by analyzing multiple dimensions such as technical features and sizing, business models, financial mechanism, tariffs, operation and maintenance aspects, community involvement and capacity building initiatives.

The paper starts by briefly introducing the renewable energy based mini-grid programs for rural electrification in India. Section II shares the experiences from such programs. The paper then highlights some specific challenges in enhancing electricity access through renewable energy based mini-grids. Finally, the paper concludes by providing the lessons and suggests takeaway points for augmenting the rural electricity access level through renewable energy based mini-grids to complement the grid electrification efforts in India.

II. RENEWABLE ENERGY BASED MINI-GRID PROGRAMS IN INDIA

The concept of mini-grid originated in India in the mid-nineties in the Sunderban region of the state of West Bengal. A solar PV power plant of 25kWp capacity installed in 1996 by the West Bengal Renewable Energy Development Agency (WBREDA) in Kamalpur village, Sagar Island continues to energize the village till date. Thereafter, mini-grids, coupled with solar PV or biomass generators, were taken up in various states, notably West Bengal, Chhattisgarh, Lakshadweep, Odisha, Uttar Pradesh, Madhya Pradesh, and Bihar. In remote areas, mini-grids seems to have been accepted as an alternative to grid-electrification as users perceive mini-grids very similar to conventional power due to its resemblance to conventional grid system such as overhead low-tension lines, service connections and tariff structures. Technically, mini-grids are preferred over solar home systems, as mini-grids provide electricity services for lighting as well as to run small appliances, whereas solar home systems provide only lighting services. However, surveys undertaken by the authors do indicate that restricted hours of electricity supply (viz. 5-7 hours) act as one of the limitations for full acceptability of mini-grids by users.

A structured discussion on various aspects of mini and micro grid developments in India is presented below:

A. Coverage and Management

The mini-grid based electrification program in India has primarily been carried out under RVEP, VESP and also as part of the Technology Demonstration Program, all administered by the MNRE, and implemented primarily through State Renewable Energy Development Agencies (SREDA). Lately, however, decentralised distributed generation programme (DDG) and off-grid scheme of Jawaharlal Nehru National Solar Mission (JNNSM) are also supporting setting up of mini-grids in rural areas. In addition, various NGOs and private sector led initiatives have also set up mini-grids with funding support from MNRE, bilateral/multilateral aid agencies and CSR funds. The solar mini-grids have mostly been implemented in the states of Chhattisgarh, Meghalaya, West Bengal and Lakshadweep Islands [6]. On the other hand, small hydro projects have been set up in the hilly locations of Uttarakhand, Himachal Pradesh, Karnataka and northeastern region. Some of the most successful states who have implemented electricity access programs through mini-grids include Chhattisgarh and West Bengal. Chhattisgarh Renewable Energy Development Agency (CREDA) has reportedly electrified around 35,000 households spread across 1000 villages/hamlets, whereas WBREDA has more than 15 functional solar mini-grids with aggregate capacity of more than one MWp, supplying stable and reliable electricity to around 10,000 households [7]. The biomass gasifier based mini-grids were primarily implemented under VESP (in around 80 villages across different states in India) or through private sector led initiatives such as Husk Power Systems (HPS) and DESI Power and research institutes and NGOs such as TERI and Indian Institute of Science and Development Alternatives.

HPS, for example, has reportedly set up 80 mini-grids, providing electricity to over 200,000 people across 300 villages and hamlets in the state of Bihar. HPS promoted mini-grid systems largely use rice husks, which are amply available in the state, in gasifiers for power generation. Another company called Mera Gao Power (MGP) is setting up solar DC micro grids in Sitapur and Barabanki districts in Uttar Pradesh to provide lighting service using LEDs and mobile phone charging facilities. MGP has reportedly connected over 10,000 households spread across 400 hamlets. Other private led initiatives who are extending electricity services in poorly electrified villages, either through AC or through DC mini-grids, are Kuvam Energy, Sun Edison, Minda NextGen Technologies, Gram Power, Gram Oorja etc.

B. Policy and Regulation

Initially, mini-grids were mainly set up under the technology demonstration program of MNRE. In 2001, with the launch of the Rural Electricity Supply Technology Mission, renewable energy based decentralised generation technologies including mini-grids received the required thrust and for the first time considered as part of mainstream rural electrification. During the same period, the first focused attempt by the Government of India to look into issues related to decentralised generation, particularly in the context of off-grid electrification, also happened through the Gokak Committee. The Committee recommended that decisions between grid connection and decentralised generation, especially in mini-grid mode, should consider the technical, managerial, and economic issues. Considering the higher cost in setting up of mini-grids, the Committee observed that the totality of the socio-economic benefits accruing to the various stakeholders should be taken into consideration while evaluating feasibility of mini-grids in remote areas.

The Electricity Act 2003 that was enacted with the overall objective of developing the electricity industry and providing electricity access to all areas, also provided a policy road map for distributed generation including mini-grids. It envisaged a two-pronged approach for improving rural electricity access: a national policy for rural electrification to extend the reach of grid-connected supply, including the enlistment of local initiatives in bulk purchases and rural electricity distribution; and with a National Electricity Policy to encourage additional capacity addition by way of stand-alone systems, including those based on renewable sources of energy. Section 4 of the said Act mandated the Central Government to prepare and notify a national policy, permitting stand-alone systems (including those based on renewable sources of energy) as a mode for rural electrification. Section 14 (read along with Section 13) further exempted a person intending to "generate and distribute electricity" in a rural area, notified by the State Government, from obtaining any license from a regulator. Section 14 also frees the person from the purview of the Appropriate Commissions in matters pertaining to determination of tariffs and universal supply obligations applicable to licensees. The Rural Electrification Policy provisions that the retail tariffs for electricity supply by persons exempt under Section 14 would be set based on mutual agreement between such person and the consumers. An important point worth highlighting here is that the Section 13 allows exemption to any local authority, Panchayat Institution, users' association, co-operative societies, nongovernmental organizations, or franchisees. It, however, does not clearly mention whether the exemption is applicable to any private service provider for generation and distribution of electricity in off-grid rural areas. The rationale behind the exemption was the assumption that the local generation and distribution of electricity would be a micro-enterprise with low capital expenditure, short gestation periods and no entry barriers, so competitive market forces would ensure reasonable prices reflecting actual costs. However, Section 53 of the same Act also mandates that such persons shall have to conform to the provisions relating to safety and electricity supply from appropriate authority. The National Electricity Policy and Rural Electrification Policy also encourage provisioning of decentralised generation coupled with local distribution network in areas where grid based electrification is not feasible or cost effective. The policy also helped in the inclusion of decentralised generation part of the national rural electrification program, launched in 2005, incidentally, a great step forward in mainstreaming mini-grids within the ambit of the national rural electrification strategy.

C. Technical features and Sizing

The mini-grids are designed to generate electricity centrally and distribute the same for various applications to households and small businesses spread within a particular territory. Depending on their capacity, mini-grids can provide electricity for domestic power, small commercial activities and for community requirements such as the supply of drinking water, street lighting, vaccine refrigeration etc. In India, mini-grids of varying capacities, between 1 kWp and 200 kWp have been implemented, with different agencies adopting different sizing and localized models. While mini-grids in Chhattisgarh are based on micro-solar PV plants (< 6 kW capacity) and biomass gasifiers (~10 kW), the solar mini-grids in Sunderbans and Lakshadweep are of much higher capacities (> 100 kW). Further, while these mini-grids have been using state-of-the-art inverters and storage systems of the time, modification have been made to the capacity and technological platforms, pursuant to technological advancements and shifts in communities' needs and requirements. For example, untill the year 2000, solar mini-grids in the capacity range of 25 - 26 kWp were implemented by WBREDA. Larger capacity schemes were not envisaged at that time as the concept was new for the community and the technology had not yet been proven. With technological advancements and acceptance of the concept, coupled with growth in demand from communities, WBREDA started building power plants of larger capacities (>100 kWp). In a few locations, WBREDA started implementing hybrid systems (e.g. solar-biomass-wind) to improve the overall efficiency of their systems. While solar PV was the dominant source of energy, wind systems – connected through the same battery-inverter systems – provided additional source of energy during monsoons while biomass gasifier systems meet this additional energy requirement during the dry season. The model not only helped to improve the reliability of the systems, but at the same time also addressed the incremental demand. In Chhattisgarh, the mini-grid capacity has been standardized for ease of operation and maintenance (O&M) viz. 1, 2, 3, 4, 5 and 6 kWp being implemented with two rating of inverters. While the systems with installed capacity of 1-3 kWp have a battery-bank of 48V and inverter rating of 3 kVA, the systems with 4-6 kWp installed capacity have 96V battery bank and inverter rating of 5kVA.

On the other hand, biomass gasifier-based mini-grids implemented under VESP, distributed generation program of NTPC Ltd, and private initiatives such as HPS and DESI Power are connected to 10-50 kW generators. The biomass gasifier plants by HPS, for example, are of 33 kWe on average and serve around 300-400 households in a village. Apart from rice husks, HPS plants use wheat husks, elephant grass, mustard stems, corncobs, and wood chips to ensure round the year sourcing of fuel. HPS has also been able to cut down its costs by introducing smart meters and fabricating the gasifiers locally at their own initiative. In case of JNNSM and DDG programs, provision of grid-compatible distributed generation units have been made mandatory, so that when the conventional grid reaches the project site, these mini-grids can be easily connected and kept functional.

Lately, many rural energy entrepreneurs are also setting up low voltage solar DC micro-grids, either on their own or under different programs such as Lighting a Billion Lives by TERI. These micro-grids generate DC electricity from solar panels and the power is distributed over a short distance from the battery banks to cluster of around 20 to 100 households. They usually supply at 12V or 24V DC for providing lighting services for 5-7 hours using LED lamps of 2-6 watt per households (2 -3 light points per household) and power mobile phone charging facilities. MGP operated DC micro grids have central storage system and connects around 20 households within a maximum distance of around 100 meters to keep the technical loss and the cost at the minimum. HPS, on the other hand, is implementing micro-grids using decentralised storage battery in the consumers' households connected to centralised solar PV systems.

D. Delivery models

Most of the mini-grids implemented under the RVEP or VESP are structured around community-based models. Here, the service-delivery model followed involves formation of VEC by the Project Implementing Agency (PIA) – usually the SREDA or NGOs – with representations from beneficiary community and the local governing body. The PIA sets up the energy production systems and hands it over to the VEC for day-to-day O&M. The electricity generated is distributed to the community through a local mini-grid. Often the VEC sets the tariff in consultation with the PIA in such a way that it takes care of the fuel as well as O&M costs. The VEC is also responsible for arranging the fuel (in case of biomass or biofuel projects), either as a contribution from the project beneficiaries on a rotation basis or through purchase from collecting agents. The VEC also undertakes energy plantations in village forests or community land to ensure the sustainable supply of biomass. The VEC collects the tariff, usually fixed on flat rate, from the users to meet the operational expenses of the projects.

CREDA and WBREDA have evolved their own service delivery mechanisms, directly taking care of the O&M through a multi-tier system of maintenance. However, they also form the VEC or a beneficiary committee, which is responsible mainly for local oversight and acts as a grievance redressal forum and does not get involved directly in the technical O&M. For example, CREDA assigns the VEC only a passive role- to deal with the social aspects of project management such as addressing local level conflicts, and up keeping of the project. CREDA, through a top-down approach, directly takes care of the O&M through a three-tier system of maintenance framework to ensure trouble free working of the mini-grids. CREDA selects an operator from each solar powered village to switch on and off the plants every day and clean the modules at regular intervals and to report any faults to the cluster technician. The section on O&M aspects provide further details on its framework followed by CREDA.

Literature indicates that while the community model for solar PV projects have been largely successful, unlike other technologies such as biomass gasifiers, due to easy management of solar technologies [3]. However, there exists challenges especially in mobilizing revenue to meet expenses for replacement of batteries, major repairs and paying remuneration to the operators in most of the community driven mini-grid projects.

In addition to the above-mentioned community led mini-grid models, the projects implemented by private sector follow a commercial approach and are purely demand driven. For instance, MGP is implementing the solar DC micro-grids using a micro-utility approach, where they design, install, operate, maintain and provide the service to consumers in lieu of a fee or tariff. HPS has evolved a franchise-based business model for setting up of mini-grids. HPS follows BOOM (build, own, operate and maintain), BOM (build, own, maintain) and BM (build and maintain) model for providing electricity services. In the second and third case of HPS model, a local entrepreneur is motivated and trained to own and or operate the system.

E. Financial Mechanism and Tariffs

A major component of capital costs in case of mini-grids implemented under the RVEP and VESP came as a subsidy from MNRE. For remote areas, the subsidy has been used to meet up to 90% of the project costs, up to a predefined maximum of Indian Rupees (INR) 18,000 per household. The balance 10% is usually financed through sources such as state government funds, contributions from local Member of Parliament or Legislatures and Corporate Social Responsibility program. The consumers own the household electrical wiring and appliances and pay for the services they use. However, in case of below poverty line households, subsidy fund also take care of wirings and service connections. JNNSM provides capital subsidy for mini-grids either to meet unmet community demand or electrification of un-electrified rural areas. On the other hand, the DDG program of RGGVY considers technology with lowest marginal cost and extends subsidy of 90% of the project cost and some operational subsidies. In case of private sector initiatives, a major part of the project cost is borne through financing from banks/investors and equity by the company. These companies sometimes also avail subsidy from the government programs as per the norms of the respective subsidy scheme.

Further, with regard to the consumer tariff, they do not follow a uniform pattern. In most of the projects, the tariff rate is flat, ranging from INR 30-150 per connection per month. For example, the solar mini-grids in Sunderban has a tariff of INR 100–150 per month for 3-5 light points and 5 hours of supply. CREDA levies only INR 30 per connection per month of which INR 25 comes from the state government as tariff subsidy. Under the scheme, '*ekalbatti yojana*', a tariff subsidy is provided by the Government of Chhattisgarh for single point connection to both conventional grid and mini-grid connected below poverty line households. The pricing strategy adopted by HPS is based on load (kW) as opposed to energy (kWh) and is targeted to compare with the consumers' expenditure on kerosene. For example, every household pay a fixed monthly charge of INR 45 per CFL of 15 W, while small businesses and shops pay INR 80 per CFL per month. For households seeking connection to operate fan and television, the charges are calculated based on the wattage of the appliance. The MGP has developed their own unique way of collecting tariff: through a weekly pre-paid collection mechanism taking lessons from the micro-finance sector. They levy a tariff of INR 25 per household per week (2 light points of 1 W LED and a facility for mobile charging) as the consumers find it easier to pay on a weekly basis due to their less cash disposable income. In the case of private sector led initiatives, the entire cost is recovered through retail tariff, resulting in high tariffs, as compared to the tariffs for projects implemented by SREDAs or electricity tariff set by regulators in case of grid electrified villages.

Since the number of light points and time of supply in the mini-grids are usually fixed and the socio-economic dynamics are similar in remote villages, the fixed tariff was found to be much easier to administer as compared to metered tariff for low consumption. However, a disadvantage of the system is energy overloading by some households (connecting additional electrical points beyond the authorized number of points), which leads to disruptive service. This has been observed in the case of Sunderban, an economically better off area with the local people having higher levels of aspiration to use various appliances. However, it is rare in other very remote areas such as in Chhattisgarh, where most mini-grids consumers are poor and usually do not resort to usage of additional light points or appliances.

Lately, some companies have started experimenting with metered tariffs, especially the pre-paid meters. The difference in tariff for government agency promoted mini-grids vis-à-vis private ones can be attributed to the fact that a major part of the project cost in case of private initiative are borne through financing from banks/investors and company's equity and the cost is recovered through tariff. Moreover, the projects by private service providers are usually in not-so-remote areas, where paying capacities of consumers are high and in the absence of any regulation, the tariff is set at the economic cost of supply and negotiated between the private service providers and the consumers.

F. Operation and Maintenance Aspects

O&M being a critical determinant of the success of the mini-grid model, most projects have evolved their own mechanisms for smooth and uninterrupted operation. While trained local level operators have traditionally managed operation of mini-grids, the operator in the VEC managed projects is also responsible for maintenance. This model seems to have not worked as well, especially for the biomass gasifier projects, where maintenance requirement is relatively higher than solar PV projects. For example, in case of VESP, managing technologies was found to be one of the most critical factors for poor project performance [8]. Technical reasons for non-operation matters were found mainly caused due to poor technical knowledge of the operators and not due to the technology *per se*. Additionally, the inadequate post-installation maintenance network of the suppliers was also found to contribute to a longer lead-time for fault rectification.

WBREDA and CREDA, however, involve qualified technicians as third parties for local O&M of systems. The technicians are either from the equipment supplier, or local service providers who engage trained personnel for the job. For instance, in Sunderban region, annual maintenance contracts are executed for plant O&M and low-tension line maintenance. The maintenance contract to local contractor not only ensures responsive maintenance, but also fosters local entrepreneurship, which in turn ensures quick and reliable service. Another management innovation by WBREDA, that has contributed largely to the sustainability of the model, is that of clear fragmentation of responsibilities between operators and revenue collectors. The operators, appointed by the service contractor, focuses on O&M, while the responsibility of revenue collection rests with a different person engaged by WBREDA in consultation with the Beneficiary Committee. Any shortfall in the revenue collection in a particular month does not affect the discharge of responsibilities by the plant operator. In contrast, one of the reasons for limited success of mini-grids implemented under VESP is because the system operator also acted as revenue collector and where the collection was less, the operators did not receive their full remuneration, eventually resulting in loss of interest in operating the systems [8].

CREDA went a step further, since their power plants are located in very remote and forested areas, and developed a cluster-based approach for maintenance to reduce transaction costs. The model is called "Cluster based service delivery model" or as "GOLD" (Group the partners, Organize their skills, Allocate load in villages, Deliver service), where the installation is steered by CREDA and operation and maintenance of the plants is undertaken through a three tier maintenance set-up. Each cluster has cluster level master technicians and plant operators. The cluster technician, usually appointed by the O&M contractor, is responsible for visiting each village once a week or month (depending on the need) to supervise the work of the plant operator, do preventive and breakdown repairs and send plant operation reports to CREDA. Additionally, CREDA officials monitor all of the installations through a monthly reporting mechanism and facilitate replacement of damaged equipment. In case of HPS and MGP, dedicated teams take care of preventive and breakdown maintenance and reportedly respond to any breakdown call within 72 hours. For each plant, HPS appoints a plant manager, preferably from the same village. At a higher level i.e. cluster level (constituting 5 – 6 plants), a cluster manager is appointed. It is the responsibility of individual plant manager to communicate daily reports to respective cluster managers. Thereafter, cluster managers forward the information regarding plant operation and management to regional managers. Ultimately, regional managers report to the central office. The rigorous monitoring and management system is the key to high plant availability. The authors also observed the good working condition of the solar power plants in case of the sites, where the authors visited as part of this research.

In all the above cases, wherever the maintenance framework was developed in a more structured and organised way, and responsibilities were shared among stakeholders across the operation and service chain, the mini-grids were found to function better. Further, in most of these cases, the VEC's role was limited to acting as local oversight and informing the implementing agencies of any operational and maintenance related issues.

III. SPECIFIC CHALLENGES

Despite the fact that different technological, institutional and financial models have been used to improve electricity access through mini-grids; there are hurdles that limit the scaling-up [3]. Some of the specific challenges are discussed here:

Institutional: Institutional and organizational shortcomings seem to act as one of the major deterrents for the successful operation of projects. This was also corroborated by various researchers who observed that a large number of projects have seen limited success because the focus has been on technical installation without paying adequate attention to long-term sustainability [4,9]. The mini-grids in India are mainly community-centric projects or involve NGOs and thus lack an organised delivery model compared to utility-driven, conventional grid-based projects. This is observed as a limitation of the current institutional model as implementation metrics and operational practises differ from organisation to organisation, and agencies are not all able to benefit from a standardized set of implementation guidelines or manuals. The characteristic example is that of VESP projects, implemented by number of NGOs and state government agencies, where there was lack of clarity on the roles and responsibilities among different stakeholders and thus resulted in sub-optimal community participation and failure of most of the projects [8]. On the other hand, the examples of CREDA, WBREDA, HPS etc., demonstrate that projects have been successful where they have been implemented and managed through a structured approach with clarity in roles and responsibilities of different stakeholders and differentiated responsibilities for operation, maintenance & management.

Financing: Access to finance continues to be a major challenge for scaling up of mini-grid programs. Since these projects operate mostly in remote and socio-economically backward areas, access to credit from formal financial institutions is limited. In this context, Mera Gao Power observes that most companies active in mini-grid/off-grid sector are not able to access sufficient capital to expand [10]. Another related challenge is the financing of the capital cost in community-managed projects due to the power affordability of the community. While part-subsidy from MNRE exists, the generation of remaining capital at a lower cost and/or without any collateral is difficult in the absence of any risk guarantee mechanisms. Given the nascent status of the sector, formal financial organisations are generally reluctant to lend to the sector. Since, majority of the projects operate in rural settings, without any long-term power purchase agreements coupled with poor consumer demand, commercial banks are usually hesitant to finance them. This is primarily because of high-perceived technological and financial risks and lack of history of profit making by rural mini/micro grid entrepreneurs. In addition, smaller capacity of projects also makes it difficult for the developers to attract equity finance due to perceived challenges of scalability.

Policy: Despite efforts to create an enabling policy landscape for the sector, several lacunae continue to persist in the policy and regulatory sphere. For example, current policy frameworks and interconnection standards lack clarity in allowing excess generation from local mini-grid system to be fed into the conventional grid at low voltage level. Further, the remoteness of the mini-grid projects increases their capital and O&M costs and hence the cost of generation and supply. Based on the economic cost of generation, the limited financial ability of rural consumers to pay the service charge is an additional challenge. As a result, projects sometimes fail to operate after few months of installation, as has been observed in the case of VESP [11]. In terms of the legal framework, there is no tariff parity as benefits of cross-subsidization are limited to grid-connected consumers and not extended to the mini-grid consumers. Mini-grid sector is entirely free of licensing obligations and regulatory oversights, leaving tariffs to be determined through the process of negotiation between service providers and consumers or through market dynamics. The cross-subsidization benefit could have helped in achieving financial viability of mini-grids in remote areas where user payments alone are insufficient.

IV. KEY LESSONS AND CONCLUSIONS

Several key lessons emerge from the above discussion and analysis. Firstly, the mini-grid experience reveals that appropriate support systems should be a mixture of both 'participatory approach' and 'top-down approach'. While issues of a local nature could be better addressed through a participatory governance structure, technical, policy and financing matters can be dealt with at the appropriate intermediary and/or higher-level. It is important to design support systems so as to ensure that plans and policies match the needs of all stakeholders – consumers, owners and technology suppliers. The community approach has been more successful where the project has also focused on improving the productive usage of electricity, such as in the case of Sunderban. The Sunderban and HPS experience suggest that collecting revenue is comparatively more successful where villagers have a steady (disposable) cash income, because of either existing income-generating activities or augmentation of their income from newly created activities arising from electrification. Further, divided ownership models, where operation and revenue collection are done by separate verticals and or different individuals, seem to bring better focus on generation and service delivery. It is suggested that service delivery models need to be designed and structured considering the uniqueness of a region. While technical features will require a degree of standardization, uniform delivery model might prove counterproductive. There is also a need for standard contracts and implementation processes for the mini-grid projects to keep the transaction cost low.

Secondly, many of the renewable energy projects, especially under RVEP & VESP, were implemented with the premise that the village community is capable enough to run the system sustainably, irrespective of technology types. This model may be suitable for those remote areas where the strength of local governance is reasonably good, and there exist better social cohesiveness in the village. However, as discussed in previous sections, the VEC is found to be weak in many cases and group activity is minimal in several of the cases. Thus, instead of the VEC model, alternative service delivery models involving Energy Service Provider (ESP) or BOOM and BOM models could be piloted. The ESP, based on an entrepreneurial model, could play the collective role of stand-alone power producer, distributor and supplier of electricity and manage the revenue through payment collection from electricity users and the VEC can act as a local level regulator to negotiate the tariff, biomass prices (in case of local sourcing of biomass for a biomass project) and resolve disputes between (or any grievances of) the consumer & service provider. This model will also be appropriate for not-so-remote villages covering a large number of consumers residential and commercial - to ensure financial viability.

Furthermore, the existing legal and regulatory enshrinements allow cross-subsidies to be limited to the grid-based consumers, while mini-grid consumers do not get the similar facility. This hinders creation of level playing field between the grid-supplied utilities and service providers of mini-grid modalities. Thus, the mini-grid projects often become unviable, as they cannot compete with tariff prevailing in neighborhood grid connected villages(being cross subsidized through regulatory intervention). Thus, a mechanism is required to extend the tariff fixation by electricity regulators in case of mini-grid projects and providing subsidy to the project developer or service provider from a universal service obligation fund. Even though the word ‘subsidy’ has become unpopular as part of electricity sector reforms, it still has relevance in many cases in view of the need to electrify low-demand, inaccessible rural areas. Concessions are beneficial if they can continue to encourage access and bring in social benefits, rather than the area becoming de-electrified due to financial unviability of the projects. The universal service fund can be created through a suitable mechanism from the cross subsidization amount and or deploying savings out of the reduction in kerosene subsidy, which is otherwise used for lighting in such un-electrified villages. However, for such cases, monitoring mechanism must be developed to see that only the functional plants are beneficiaries of such subsidy amount and operators/utilities accept certain commitments on service obligations and tariffs. Being renewable, the distribution utilities that include the cross-subsidy in their annual revenue requirement while submitting to the regulatory commission can also show these mini-grid projects to meet their renewable power obligations [11]. Further, to augment the electricity supply situation in grid-connected rural areas and also achieve better operational efficiency, distributed power generation can be combined with a suitably structured electricity delivery model for better utilization of the rural electricity distribution infrastructure. As the grid supply situation improves, these operators can become franchisees of the distribution utilities and continue to serve the areas, partly with local generation and partly from grid supply at weighted average cost of supply.

The “access gap” relates to communities, which are beyond the reach of the market, due to inadequate income levels or geographical isolation. Market linkages, access to infrastructure and targeted subsidy interventions are needed for attracting business in low-load areas. As mini-grid projects invariably have lower capacity, concentrating energy loads in a given area or bundling projects can increase the size of the market. For example, CREDA has been successfully running projects in remote locations, mainly using a cluster approach. Financial institutions such as banks would also be interested, as project implementation and credit risks would be less. Bundling can also be helpful in minimizing the transaction costs associated with securing carbon benefits. There have been efforts by mini-grid developers such as HPS to capitalize on the bundling of projects to obtain venture capital funding and carbon benefits, taking advantage of cluster approaches. Another financial innovation could be to link the government subsidy to leverage debt and investments where the subsidy helps in increasing the rate of return of project or lower the payback for the private developer.

The study also observe from the mini-grid experiences in India that various actors and factors, namely prevailing policy and implementing agencies at macro level, service companies at middle level and finally the household socio-economic characteristics at the micro level, influence the choice of energy technology and their sizing. A sufficient and steady fuel supply, especially through involvement of the local community, is critical for sustainability of biomass gasifier-based mini-grids. In the case of solar mini-grids, the storage batteries seem to be technically vulnerable. This has created additional challenges for the whole operation and sustainability of the solar mini-grids in the Sunderban region: they are difficult to operate which creates a need for the development of quite advanced technical understanding of the operators and further require appropriate drawing of electricity by consumers according to set norms to extend battery life. All these challenges illustrate the close interconnections that exist between technical and non-technical matters and thus the importance of focusing on these connections to obtain viable solutions. The paper suggests that decision on technology should be based on availability of technical knowledge and skill-sets of local people so that after-sales service and maintenance can be locally provided and rarely outsourced.

Lastly, for the renewable energy sector to reach a significant scale, companies need to address barriers to supply, demand and scalability and at the same time adopt standard processes and metrics, which will also help them attract the necessary level of investment from financial institutions and venture capitalists supporting 'green' programs. The strengthening of the financing, distribution and after-sales spares supply and service chain by facilitating the development of local capabilities to assemble, supply and provide service that will not only facilitate enterprise development on the supply side, but could potentially enhance livelihood activities. The opportunities have to be seen not just from the rural electrification opportunities but in the larger context of enhancing energy security of a country.

V. ACKNOWLEDGMENT

The study was carried out as part of the research project titled "Decentralized off-grid electricity generation in developing countries: business models for off-grid electricity supply", funded by the Engineering and Physical Sciences Research Council/Department for International Development (research grant EP/G063826/1) from the Research Council United Kingdom Energy Program. This paper also draws, in part, on a research study titled "Renewable energy based rural electrification for South Asia: the Mini Grids Experience" undertaken by the authors with support from Global Network on Energy for Sustainable Development. The views presented here are those of the authors and they are only responsible for any errors of omission or commission.

VI. REFERENCES

[1] Census of India. Office of the Registrar General and Census Commissioner, India, 2011
[2] World Energy Outlook, International Energy Agency, Paris, 2012
[3] Palit D and Chaurey A. Off-grid rural electrification experiences from South Asia: Status and best practices. *Energy for Sustainable Development*, 15, pp. 266-276, 2011
[4] Bhattacharyya, S.C. "Energy access problem of the poor in India: Is rural electrification a remedy?", *Energy Policy,* 34, pp.3387-3397, 2006.
[5] Nouni M.R., Mullick, S.C. and Kandpal, T.C. "Providing electricity access to remote areas in India: niche areas for decentralised electricity supply", *Renewable Energy,* 34, pp.430-434, 2009.
[6] Buragohain T. "Impact of solar energy in rural development in India"; *International journal of environmental science and development*; 3(4): pp. 334-338, 2012
[7] Palit D. "Solar energy programs for rural electrification: Experiences and lessons from South Asia", *Energy for Sustainable Development*; 17(3), pp. 270-279, 2013
[8] Palit D, Sovacool B.K., Cooper C, Zoppo D, Eidsness J, Crafton M, Johnson K and Clarke S. "The trials and tribulations of the Village Energy Security Programme in India". *Energy Policy,* 57, pp. 407-413, 2013
[9] Kumar A, Mohanty P, Palit D and Chaurey A. "Approach for standardization of off-grid electrification projects. *Renewable Sustainable Energy Rev*;13, pp. 1946–56, 2009.
[10] Jaisinghani, N. "Islands of light – the experience of micro-grid power solutions". *The Solar Quarterly.* 3(3), pp. 10-18, 2011
[11] Palit D, Malhotra R, and Kumar A. "Sustainable model for financial viability of decentralized biomass gasifier based power projects". *Energy Policy,* 39, pp. 4893-4901, 2011

II. BIOGRAPHIES

Debajit Palit has around 16 years of experience working in the field of clean energy access, rural electrification policy and regulation, distributed generation, solar photovoltaics and biomass gasification. He has also written widely on energy access and rural electrification issues, particularly related to South Asia, and authored a book on rural electricity distribution franchisees. Mr Palit holds a Master degree in Physics and is currently pursuing Ph D in rural electrification policy from TERI University.

Gopal K Sarangi, working at TERI University, has research interests in the areas of electricity sector regulation and competition, issues related to access to energy & socio-economic implications of rural energy interventions, and problems interfacing energy and climate change etc.