Energising Rural India Using Distributed Generation: The Case of Solar Mini-Grids in Chhattisgarh State, India

Debajit Palit, Gopal K. Sarangi and P. R. Krithika

Abstract Conventional grid extension has been the predominant mode of electrification in India. However, solar photovoltaic technology has also been used for providing electricity access in remote, forested habitations and islands. Under the Remote Village Electrification Programme by the Government of India, around 12,000 villages and hamlets have been electrified using renewable energy. The state of Chhattisgarh in Central India has alone been able to electrify around 1,400 remote and forested villages through solar mini-grids. This chapter attempts to examine the development and operation of the solar mini-grid model for enhancing electricity access in India, with special focus on the state of Chhattisgarh. The work, based on extensive literature review, interview with key stakeholders and field visits to selected remote forested villages in the state of Chhattisgarh, shares the experiences and lessons of the solar mini-grid programme for rural electrification in the state by comprehensively analysing multiple dimensions of the programme such as coverage and trend, technical designs, institutional arrangements, financial mechanism and operation and maintenance aspects, which were key to the success of the solar mini-grids. We observe that robust institutional arrangement, strong policy support and an effective maintenance and an oversight mechanism have been the key contributing factors for the success of this initiative.

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1 Introduction

Having the largest rural population in the world, India confronts a huge challenge of rural electrification, especially electrifying the remote, forested and tribal habitations located in far off places. Despite conscious efforts undertaken by the federal and provincial governments since 1951, the level of household electrification and power availability in India remains far below the global average. According to the Census of India 2011, electricity as a source of lighting energy in India (both rural and urban) is limited to 67 % of total households, whereas the world average stands at approximately 81.5 % [7]. In rural areas, the electrification coverage scenario is further bleak where around 59 %, constituting about 72.4 million rural households, still rely on kerosene or other traditional fuel for lighting. Despite various policy and programme specific thrusts (refer to [19] for a detailed discussion of various rural electrification programmes), energy access challenges, especially in the rural areas, continue to derail the overall development process of the country.

While the centralised grid-based electrification has been the most common approach,[1] decentralised renewable energy technologies, especially solar PV (photovoltaic) systems, have also been adopted and being increasingly considered as a cost-effective mode of electrification, especially for areas where it is not techno-economically feasible to extend the electricity grid or in areas where electricity supply from the grid is inadequate to meet the demand [16, 18]. These off-grid communities, often characterised 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 not attempted to cover the off-grid areas with decentralised distributed generation systems either, though they are the licensees to provide electricity services in all areas. The vacuum has been largely fulfilled in many cases by NGOs, through pilot projects by raising funding support from donor agencies and support received through funds from corporate social responsibility initiatives, and by the state renewable energy development agencies, established in different states by the state governments, which work under the aegis of the Ministry of New and Renewable Energy (MNRE). Of late, private entrepreneurs have also ventured into the field, foreseeing the business prospect of the sector.

Statistics from the MNRE indicate that more than 12,000 villages in India have been covered through renewable energy-based mini-grids and solar home systems (SHSs), especially under the Remote Village Electrification Programme (RVEP). Solar PV projects (>1 kWp capacity) that include solar mini-grids with a capacity ranging from 1 to 500 kWp have been installed in the country with a cumulative capacity of 96.61 MWp (as of August 31, 2012). Though the off-grid village electrification coverage may be only around 1.5 % of the total village

[1] Currently about 94 % of the inhabited areas in India are covered through grid electrification [24].

electrification coverage in the country [18], its benefit and impact has been immense in bringing about social and economic upliftment of communities in India, through incremental livelihood opportunities and better facility for health and education [4, 8, 21, 30]. At the same time, literature also shares that many of the renewable energy-based projects in India have met with limited success because of technical, institutional, financial and regulatory issues [11, 22, 25, 32].

While there exists ample literature analysing the solar PV programmes for rural electrification at the country level and also the impact of solar-based electrification projects [8, 10, 12, 18, 23, 28, 30, 31], there is limited literature that has comprehensively examined the solar mini-grids delivery model(s) as a means to enhance rural electricity access. The solar mini-grid model, however, has been receiving lot of attention both in South and South East Asia as well as in Africa to achieve the energy access objectives of the 'Sustainable Energy for All' by the year 2030. This chapter makes an attempt to examine the development and operation of the solar mini-grid model(s) for enhancing electricity access in India, with a special focus on Chhattisgarh, a province in the central region of India.

India has been implementing solar mini-grids since the 1990s as part of the technology demonstration programme by MNRE (called Ministry of Non-conventional Energy Sources before 2004). The state of Chhattisgarh, which is the focus of the study, has reportedly implemented the highest number of solar mini-grids in India, providing electricity to more than 57,000 households, spread across 1,439 villages and hamlets in the state [9]. Despite the state having such a large number of operational mini-grids in India and possibly also globally, it has not received adequate attention in the literature, barring a select few [1, 13, 14]. Millinger et al. [14] carried out a socio-technical bottom-up assessment to study two important dimensions of project, i.e. technical and maintenance factor and impact on beneficiary, more specifically on the women groups while [13] briefly provided the status and implementation of the model. Buragohain [1] carried out an impact evaluation study of the remote village electrification programme in six states that also covered the Chhattisgarh state.

This chapter attempts to examine the nuances of solar mini-grids implementation in India and then attempts a comprehensive assessment of the solar-based mini-grids deployed in Chhattisgarh by examining multiple dimensions such as such as technical design, delivery model, financing aspects, policy and regulatory architecture, impacts, etc.

1.1 Study Methodology

This study applies a triangulation of research methods to comprehensively assess the solar mini-grid village projects in Chhattisgarh. Review of secondary literature has been supplemented by visit to selected field sites and interview with key stakeholders to gather relevant information for the study. While secondary information has also been collected from Chhattisgarh State Renewable Energy

Development Agency (CREDA), the nodal agency implementing the mini-grids in the state, primary data were obtained by visiting eight mini-grid project sites across two different districts—Raipur and Korba—in the state. The field visits were limited to villages in two districts because of logistical constraints and security concerns.[2] However, these districts and villages were selected because they are a representative sample of solar mini-grids of the entire state. The secondary data on status of implementation of the mini-grids, technical design and cost parameters for more than 600 mini-grids were collected from CREDA and detailed information on solar power plant-wise number of connections, month-wise and annual energy generation and consumption, operation and maintenance details was obtained from the CREDA regional offices at Raipur and Korba districts. The field visits consisted of focus group discussions (FGDs) and semi-structured interviews with key stakeholders such as mini-grid consumers, village energy committee (VEC) members, local health centre staff, tribal hostels, schoolteachers, mini-grid plant technicians, plant operators and cluster managers. In addition, some quantitative information was also obtained during the FGDs with mini-grid consumers and VECs to assess the impact of the programme. This was also supplemented by interviews with technology suppliers and CREDA officials. Further, some of the private sector players in other states as well as West Bengal Renewable Energy Development Agency (WBREDA) officials were also interviewed to draw a comparison of mini-grid deployment in Chhattisgarh and other parts of India for cross-learning. Based on the interactions and field surveys, a critical analysis of the mini-grid model and its performance was carried out to understand what worked, what did not and why.

The chapter starts with Sect. 2, which attempts to capture the development of mini-grid model(s) and the current status of implementation including the institutional model, financial aspects and policy architecture instrumental in their promotion. Thereafter, Sect. 3 comprehensively captures the dissemination of mini-grids in the state and analyses the programme based on various parameters. Section 4 discusses key aspects of mini-grid development that have contributed to the success of the model in Chhattisgarh. Finally, Sect. 5 summarises the study.

2 Solar PV Mini-Grids in India

The concept of solar PV mini-grids in India was pioneered in the 1990s in the Sunderban delta region in the state of West Bengal, and in the forested region of Chhattisgarh state (then part of Madhya Pradesh state). A solar PV power plant of 25 kWp capacity installed in 1995–1996 by the WBREDA in Kamalpur Village of Sagar Island, continues to provide electricity to its consumers until today.

[2] The districts affected by severe left wing extremism were not considered for field study due to security concerns.

In Chhattisgarh, the first solar power plant was installed at a village called Lamni in Bilaspur district, which is still reportedly operational. Thereafter, solar mini-grids, stand-alone or in hybrid mode, have been implemented in various states, notably, Andaman and Nicobar Islands, Bihar, Chhattisgarh, Lakshadweep, Madhya Pradesh, Meghalaya, Odisha, Uttar Pradesh and West Bengal.

Solar mini-grids in India have evolved with time and changing priorities of societies. The evolution has not only been limited to technical dimensions of project development, but also to other dimensions such as new and innovative delivery and financial models. Putting it in a chronological order, the first phase of deployment of mini-grids that happened during early 1990s till early 2000 focused on developing pilots, technology demonstration and testing of the institutional models. The second phase focused on deployment of these models as an effective vehicle of electrification of remote and far off villages primarily under the government sponsored remote village electrification programme, which was initiated in 2001. This phase also experimented in deploying larger capacity mini-grids as well as hybrid mini-grids. This was also the phase when the Electricity Act [29] was enacted and mini-grids as decentralised distributed generation was included as a means for providing rural electricity supply. The current phase of mini-grid development, since the last few years, is experiencing the entry of private sector developers thereby also bringing in technical and institutional innovations and also the development of smart mini-grids for better supply and demand side management.

2.1 Solar Mini-Grid Coverage in India

The solar mini-grids in India have been predominantly deployed under the RVEP or lately as part of Jawaharlal Nehru National Solar Mission (JNNSM) by the Ministry of New and Renewable Energy. Specifically, WBREDA has set up more than 20 solar mini-grids with an aggregated capacity of around 1 MWp, thereby benefitting around 10,000 households. CREDA, another key proponent of the model, has electrified 57,968 households with electricity supply from low capacity (2–6 kWp) solar mini-grids [9]. Figure 1 presents a comparative position of states in deploying off-grid solar power plants in India.

Apart from government led initiatives, some NGOs such as TERI, WWF India and private companies have also been implementing solar mini-grids. SCATEC Solar, a Norwegian solar manufacturer has electrified 30 villages in Uttar Pradesh, Jharkhand and Madhya Pradesh. Mera Gao Micro-grid Power, a start-up company is setting up solar DC micro-grids in Sitapur and Barabanki districts of Uttar Pradesh to provide lighting services by using energy efficient LEDs. Husk Power Systems, which is more famous for its biomass gasifier-based electricity supply systems, has also reportedly ventured into solar DC micro-grid space and is connecting un-electrified households in their existing operational areas in the state of Bihar. Other private sector companies which have recently initiated extending

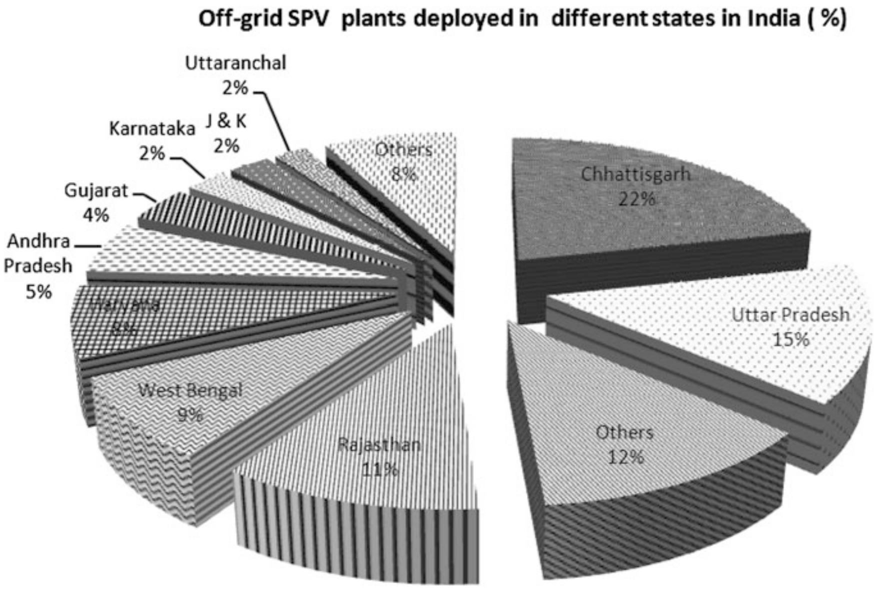

Fig. 1 Off-grid solar power plants deployed in different states in India (*Source* Ministry of Statistics and Program Implementation 2012)

electricity services to poorly electrified villages either through solar AC or DC mini-grids are Sun Edison, Kuvam Energy, Minda NextGen technologies, Gram Power Gram Oorja, among others [26].

2.2 Technical Features

The solar mini-grids are designed to generate electricity centrally and distribute the same for various applications to households and small businesses spread within a particular area. They usually supply 220 V 50 Hz three-phase or single-phase AC electricity (depending on the installed capacity) through distribution network. They consist of (i) Solar PV array for generating electricity (ii) a battery bank for storage of electricity (iii) power conditioning unit consisting of charge controllers, inverters, AC/DC distribution boards and necessary cabling, etc. and (iv) local low-tension power distribution network [23].

These mini-grids vary in capacity and size, typically in the range of 1–200 kWp, with different states adopting different sizing and models depending on their local requirements. While mini-grids in the state of Chhattisgarh are mostly small in capacity (<6 kWp capacity), the ones in Sunderban region and Lakshadweep are of higher capacities (more than 100 kWp solar PV). These solar mini-grids have also been using state-of-the-art inverters and storage systems, available at the time of installation, to ensure long life and reliable field performance. Innovations have also been brought in depending on technological development and communities' changing needs over time. Till 2000, solar mini-grids in the capacity range of 25–26 kWp were mostly implemented by WBREDA. Larger capacity schemes were not commissioned, as the acceptance of the concept and technology was not yet proven. However, observing the strong growth in interest and demand from community, WBREDA also started building power plants with higher capacities (>100 kWp) and in some locations also installed additional generation units using other forms of renewable energy such as small wind-generators and biomass gasifiers to meet the incremental power requirements [23].

The solar DC micro-grids, promoted mainly by private sector companies, generate DC electricity using one or more solar panels and are distributed over a short distance from the battery bank to the cluster of households or shops within the village. They usually supply at 12 or 24 V DC for providing lighting services for 5–7 h using LED lamps of 2–3 W per households. These micro-grids typically cover around 20 to 100 households, providing lighting and mobile charging facilities, generating energy using 100–500 Wp solar panels/array. While the DC micro-grids installed/operated by TERI and Mera Gao Power has a central storage system, Husk Power Systems on the other hand, are reportedly implementing micro-grids using decentralised storage battery in the consumers' households connected smartly from a centralised solar PV systems. Additionally, smart technologies have also been used to conduct remote monitoring and prepaid payment to keep a track of the daily performance of the plant [23].

2.3 Service Delivery Model

Most of the solar mini-grids that have been implemented in India are structured around the community, i.e. they follow the Village Energy Committee (VEC) approach for management of local generation and supply. In such a model, the VEC, formed by members from the community, plays the role of power producer, distributor and supplier of electricity, though they may not have any legal status. They collect payments from users for the electricity and also resolve disputes in the case of a disruption in power supply [18].

In addition to the above community led mini-grid models, the projects implemented by private sector are based on a commercial approach. For instance, Mera Gao Power is implementing DC micro-grids using a micro-utility approach, whereas Husk Power System has evolved a franchise-based business model for deployment of mini-grids. These models by private operators are purely service driven, however, to some extent; they also involve local stakeholders to tackle issues like mobilising people at the local scale, dealing with social problems, and realising better community responses.

2.4 Financing Approach

A major component of capital costs in case of mini-grids implemented under the RVEP came as subsidy from MNRE. For remote areas, the subsidy covers up to 90 % of the project cost and the balance 10 % cost of projects could be financed through sources such as state government funds, contributions from local Member of Parliament or Legislators and corporate sector as part of their social responsibilities. The individual consumers own the internal wiring and appliances and pay for the services they use. However, in case of households below the national poverty line benchmark, internal wirings and service connections are also taken care of from the subsidy funds. JNNSM, which is now the apex scheme for dissemination of solar devices, provides capital subsidy for off-grid solar products and mini-grids either to meet unmet community demand for electricity or in un-electrified rural areas. On the other hand, the DDG program of RGGVY considers technology with the lowest marginal cost for a given area and extends subsidy of 90 % of the project cost and some operational subsidies. The subsidy is released on annuitized basis based on performance of the system for 5 years.

In case of private sector initiatives, a major part of the project cost is borne through financing from venture capital investors and equity contribution by the company. Donor funding and corporate support under their social responsibility initiatives have also been instrumental in supporting mini-grid projects in some instances. Wherever subsidy can be availed, these companies also avail such funds subject to the norms of the government. The entire cost is recovered through retail tariff, resulting in high tariffs, as compared to the negotiated tariffs for projects implemented by state renewable energy development agencies or electricity retail tariff set by regulators in case of grid electrified villages. Moreover, the projects by private investors are usually in 'not so remote' areas where paying capacity of consumers is high and in the absence of any off-grid regulation, the tariff is negotiated between the private service provider and the consumers.

Tariff structures for consumers in different solar mini-grid projects also do not follow a uniform pattern. The tariff is usually based on a flat rate such as INR 30–200 per connection per month. Since, the number of light points and time of supply in the solar mini-grids are fixed and the socio-economic profiles are usually similar in remote villages, the fixed tariff was found to be much easier to administer as compared to metered tariff for such low consumption. However, a disadvantage of the system has been the inability to have control on the over drawl by some households thereby putting extra pressure on the system.

2.5 Policy and Regulatory Landscape

The initial renewable energy-based mini-grids in India, especially based on solar PV, were setup as part of the technology demonstration programme of MNRE during the 1990s. The launch of RVEP by MNRE in 2001 and Rural Electricity

Supply Technology (REST) Mission in 2002 saw a programmatic approach for deploying mini-grids. Under the REST Mission, the renewable energy-based decentralised generation technologies including mini-grids were considered for the first time under the mainstream rural electrification efforts. The Mission, designed to ensure an integrated approach, attempted to change the legal and institutional framework by promoting, financing and facilitating alternative approaches in rural electrification. During the same time, 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.[3]

Thereafter, the Electricity Act 2003 [29],[4] enacted with the overall objective of developing the electricity industry and provide electricity access to all areas, envisaged a two pronged approach for improving rural electricity access—a national policy for rural electrification to extend the reach of grid connected supply together with enlistment of local initiatives in bulk purchase and distribution of electricity in rural areas and a national electricity policy to encourage additional generation and distribution of electricity through renewable sources of energy including mini-grids [29]. It also opened the door to off-grid generation to a much greater extent than what existed before. Under Section 4, it made the Central Government responsible to prepare and notify a national policy, permitting stand-alone systems[5] (including those based on renewable sources of energy) as a mode for rural electrification. Section 14 also exempts a person intending to 'generate and distribute electricity' in a rural area, notified by the State Government, from obtaining any license from the regulator.[6] However, Section 53 of the same Act also mandates that such persons shall have to conform to the provisions relating to the measures which may be specified by the Central Electricity Authority from

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[3] The Committee recommended decentralised generation (especially mini-grid mode) may be considered for remote area electrification and the decisions between grid connection and decentralised generation should be made on the basis of technical, managerial and economic issues, viz., distance from existing grid; load density, system losses and load management.

[4] The EA 2003 [29] made the government (both state and central) obligated to supply electricity to rural areas including villages and hamlets. Section 6 of the act mandates the hitherto implied Universal Service Obligation by stating that the government shall endeavour to supply electricity to all areas including villages and hamlets.

[5] Section 2(63) under Electricity Act 2003 [29] defines stand- alone system as the electricity system set up to generate power and distribute electricity in a specified area without connection to the grid;

[6] While there is no requirement to obtain a license to generate and distribute electricity in rural areas, this also implicitly means that off-grid operators do not get the benefit of cross-subsidisation that are normally extended to rural electricity consumers. Absence of regulatory interventions though have helped in setting up of off-grid projects by different proponents, at the same time, most of these projects set up in remote areas with low paying capacity of consumers become operationally unviable after some months of commissioning [20]. Further, in the absence of off-grid regulation, many projects are also set up without following necessary electrical safety standards (such as using bamboo poles for distribution line) to keep their installation cost low. And in some cases, the tariff is negotiated at much higher price than the prevailing rural electricity tariff.

time to time. The National Electricity Policy and Rural Electrification Policy also state that wherever grid-based electrification is not feasible, decentralised generation together with local distribution network would be provided. The policy development made inclusion of decentralised generation also a part of the RGGVY, which was a great step forward in mainstreaming off-grid technologies within the ambit of the national rural electrification strategy.

3 Solar Mini-Grids in Chhattisgarh

3.1 Demographic and Socio-Economic Profile of the State

Before elaborating the nuances of rural electrification process in Chhattisgarh, it merits highlighting some of the key demographic and socio-economic characteristics of the state in order to better comprehend the context within which remote rural electrification has been carried out in Chhattisgarh. About 44 % of the total area in the state is covered with forests, more than double the national average, and this has important bearings on the rural electrification access in the state. Many of the remote villages are located within the forested areas, out of reach of the centralised grid, therefore, requires alternative energy supply systems such as mini-grids or solar home systems (SHSs) to electrify these far flung areas. Social stratification statistics reveal that out of 25.55 million total population of the state [2], scheduled caste (SC) and scheduled tribe (ST) population constitute around 43.4 % compared to the national average of 25 %. The latest poverty estimates in India indicate that about 48 % of total population in Chhattisgarh lives below the national poverty line. The Multi-dimensional poverty index of Alkire et al. ranks Chhattisgarh as the fourth poorest state in India with 70 % of the population being multi-dimensionally poor [14]. Moreover, poverty levels among SCs and STs are also higher than other social groups with more than two-third of SCs and STs in the state are below poverty line (Govt. of India, 2012). In addition, presence of social problems such as left wing extremism in as many as 16 districts in the state (out of 27 districts in the state) also poses a severe challenge to extend electrification efforts in the state [15].

3.2 Status of Electrification in Chhattisgarh

Creation of the state of Chhattisgarh in the year 2000 led to a major institutional and organisational overhaul especially for electricity provisioning. Two new institutions were created, i.e. Chhattisgarh State Electricity Board (CSEB)[7]

[7] CSEB which was functioning as a vertically integrated power utility was unbundled into five companies in with effect from January 1, 2009.

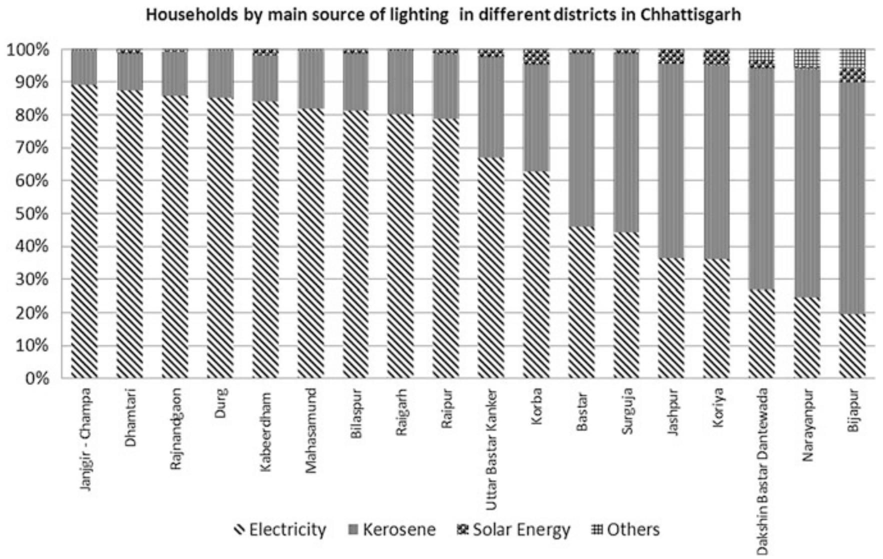

Fig. 2 Households by main source of lighting in Chhattisgarh (*Source* Census of India [2])

and Chhattisgarh State Renewable Energy Development Agency (CREDA). While CSEB was entrusted to provide electricity through grid electrification, CREDA was made responsible for promoting renewable energy sources including off-grid/decentralised energy systems. Though this state is one of the few states in India having electrification coverage better than the national average and also has surplus power supply, a large share of rural people continues to be outside the centralised grid electricity supply as they inhabit in difficult terrains within the forested areas.

In order to understand the macro picture of the electrification status in the State, it merits dwelling on some recent electrification statistics. The overall percentage of households connected to the grid electricity in the state is around 75.3 % whereas the village level electrification stands at 97.1 % [3]. Around 563 villages (out of the total 19,744 inhabited villages) in the state remain to be electrified, with most of these un-electrified villages being in the tribal dominated districts of Sukma, Dantewada, Narayanpur and Bijapur.[8] Some interesting insights about the use of various source of energy for lighting across districts[9] in Chhattisgarh could be drawn from the Indian Census 2011 figures. In case of lighting, huge disparities exist among districts and social classes in the use of modern sources of energy for lighting (Figs. 2 and 3). The districts with poor electrification status are also the same districts that have predominantly poor population and are also affected by

[8] The electrification of all villages in the state is planned to be completed by end of 2014.

[9] At the time of 2011 Census survey in Chhattisgarh, there were only 18 districts, which increased to 27 in 2012.

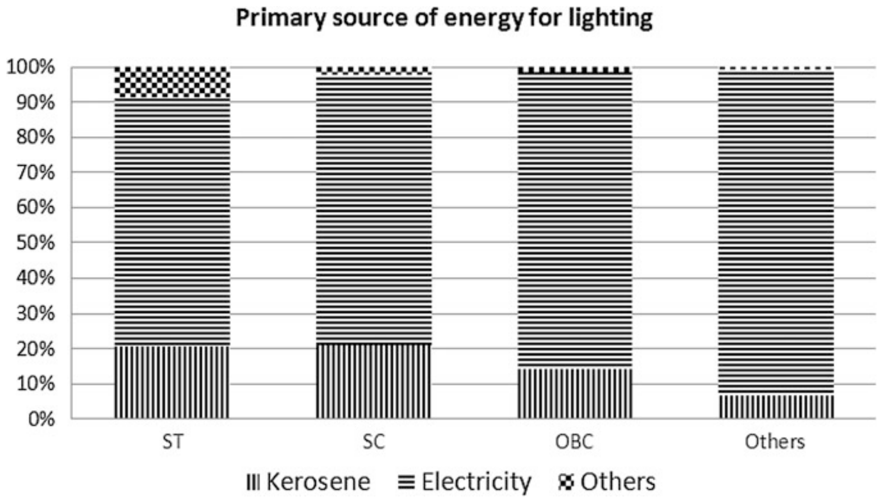

Fig. 3 Primary source of energy for lighting among social classes in Chhattisgarh (*Source* NSSO, 66 Round Survey, 2009–2010)

left wing extremism [15]. However, there is also a positive trend that some of these districts such as Koriya, Jashpur, Korba, Bijapur are utilising solar energy to electrify their households. Almost 1 % of the total households in the state are using solar energy as a source for lighting, which is second highest (after West Bengal at 1.2 %) among the larger states in India and more than double of the national average ($\sim$0.4 %).

While Chhattisgarh is abundantly blessed with sunshine, it was not the sole reason for the promotion of solar mini-grids in the state. CREDA had also implemented biomass gasification technology and bio-fuel generator sets under RVEP and VESP. However, these projects were reportedly not successful due to technological mismanagement and fuel collection issues. The lack of operation and maintenance of biomass-based plants and unavailability of qualified manpower were found to be the key factors responsible for the limited success of biomass-based electrification. In addition, the availability of only standard capacities of biomass projects irrespective of load demand has also been a constraint for their use. All such projects were eventually converted into solar energy-based projects by CREDA. The solar home systems deployed in the state have their own set of problems. While CREDA implemented solar home systems as early as 2003, the effort did not result in visible success primarily because of two major reasons. First, the beneficiaries did not realise the value of these systems, as it was heavily subsidised thereby resulting in mortgaging of the system at a low price by the owner of the system whenever they faced any financial crunch. Second, social problems like large-scale prevalence of theft negated the very purpose of the deployment [13]. Realising this, CREDA started exploring the option of installing solar mini-grids and the first mini-grid, after the creation of the

Table 1 Profile of the villages surveyed in Chhattisgarh

District	Village	Year of commissioning	Capacity of the plant (kWp)	Total number of households
Raipur	Kouhabehra	2003	3	50
Raipur	Rawan	2004	7	72
Raipur	Mohda	2004	4	72
Raipur	Latadadar	2004	3	45
Raipur	Murumdeeh	2003	5	46
Korba	Surkha	2007	4	50
Korba	Sapalwa	2005	5	83
Korba	Raha	2007	6	75

Source Authors' Field Survey 2012

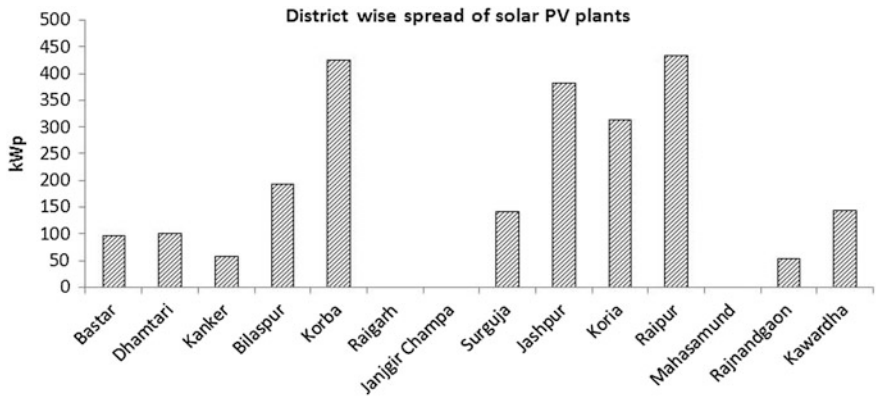

Fig. 4 District-wise spread of solar PV plants (*Source* CREDA 2012)

state, was commissioned in 2004. However, solar home systems as an option have not been discarded altogether. Rather, solar-based electrification in remote areas is carried out in two different ways. Larger villages with concentrated settlements are electrified through solar mini-grids whereas hamlets and villages with scattered households are provided with stand-alone solar home systems.

The following section provides a detailed analysis of the CREDA delivery model including the details of projects deployed, technical contours of the model, institutional arrangement, financial mechanism, functionality and performance, operation and management aspects, system of monitoring and oversight and the observed impacts of off-grid electrification carried out using solar PV technology in the state. As mentioned in Sect. 1.1, TERI team carried out field surveys in eight villages of Raipur and Korba districts to understand the multiple dimensions of project impact on communities. Table 1 shows the profile of the villages surveyed. The focus has been on these two districts as they have the highest capacity of solar mini-grids (Fig. 4). These districts also represent different physiographical and socio-economic profiles. While in Raipur, both urban and rural population are almost equal as the state capital is in the Raipur district; the major population in Korba lives in rural areas. Korba is heavily forested and is designated as tribal district whereas Raipur represents plain region in the state [6].

3.3 Coverage and Trend of Solar Mini-Grids

Chhattisgarh has a cumulative capacity of around 3.5 MWp of solar power plants covering 1,439 villages (as on June, 2012) spread across different districts in the state [9]. Figure 4 provides the district-wise installed capacity and Fig. 5 provides the year-wise installation and dismantlement by CREDA. Most of the power plants have been installed in Raipur, Korba, Jashpur and Koria districts, which account for around two-thirds of the total installed capacity. These districts are under dense forest cover, especially districts such as Korba, Koria and parts of Raipur and thus traditionally have higher number of un-electrified villages.[10]

Of the total installed capacity, around 45 kWp capacity was also found to be dismantled by CREDA mainly during the last 5 years. While in few cases, the power plants have to be dismantled due to panel theft and poor management by villagers, in most other cases, dismantling was deliberate owing the grid extension by the CSEB. While CSEB and CREDA are well coordinated while taking up of a village for solar-based electrification, with CREDA taking up the off-grid route only after CSEB's concurrence, often political compulsions lead to grid extension to village where solar mini-grid also exists. However, the dismantled systems have also been utilised mainly in two ways—(1) those villages which are facing an increasing demand for solar power and need capacity augmentation were provided with new capacities using the dismantled systems (2) the systems are retrofitted in those power plants which have some mal-functioning components such as faulty battery, panels, etc. Further, the annual installed capacity figure also portrays a reverse U shape, indicating that annual incremental increase in the installed capacity up to the year 2007 and declining thereafter (Fig. 5). This gradual decline in annual installation capacities is primarily due to increasing annual electrification rates thereby reducing the leftover villages for electrification.

3.4 Technical Contours of the Model

As mentioned in Sect. 2.2, the solar mini-grid essentially consists of a centralised solar power plant and a power distribution network that distributes the electricity to the households. It was found that in Chhattisgarh, capacity of the installed

[10] Grid extension through forests is not permitted in India as they may require the uprooting of forest trees for which necessary permission is required to be taken from the central government [17].

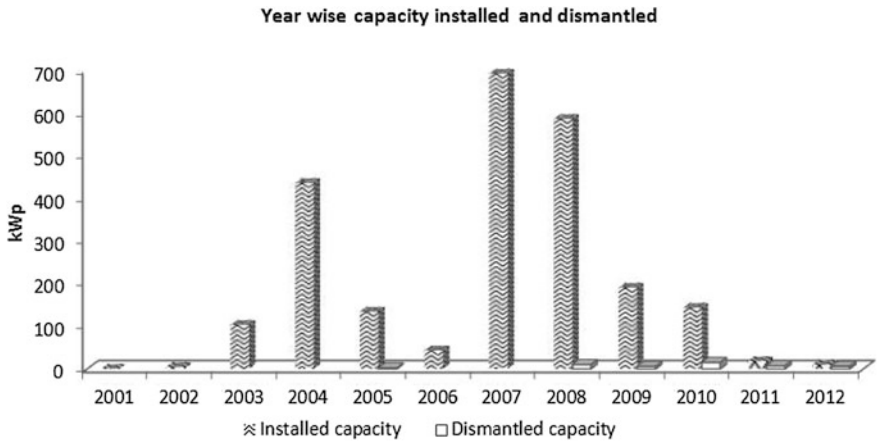

Fig. 5 Year wise solar PV plants installation and dismantlement in Chhattisgarh (*Source* Authors compilation 2013)

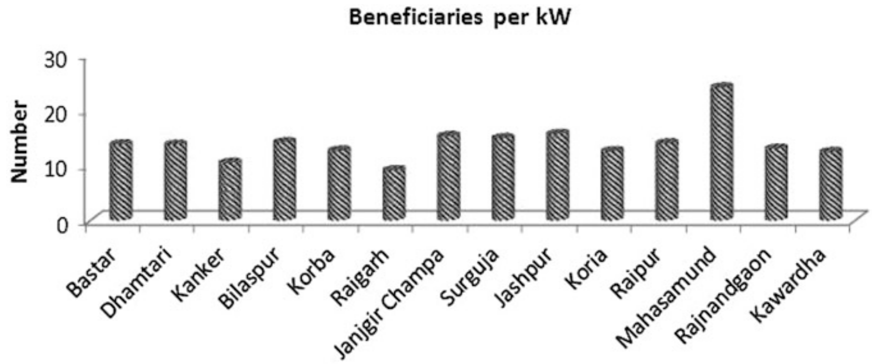

Fig. 6 District wise average number of beneficiaries connected per kWp (*Source* Authors compilation 2013)

systems ranges between 2 and 6 kWp and supply electricity in single phase. The lower capacity of installed systems is because of the smaller habitation size in terms of population (mostly 50–75 households per village or hamlets) and also because the projects were implemented mainly to provide lighting access either for residential needs or community load such as street lighting, lighting for schools, health centres and community hall, and do not include any productive load. Typically, 4 kWp plant capacity was found to be the most preferred across the different districts. It was also observed that an average of 12–14 beneficiaries are connected to solar power plant per kWp capacity across the different districts in Chhattisgarh, with average load (in terms of per household) being 73 W (Fig. 6).

Every village is provided with household as well as streetlight connections. A household connection consists of two 11 W CFLs and the supply is given for 6 h per day in most of the villages—2 h in the morning from 4 to 6 am and 4 h in the evening from 6 to 10 pm. The streetlights are mandatorily provided in all the villages mainly for ensuring security at night and operate for the same time as the domestic connections. Since the solar mini-grids are designed to cater only to the lighting requirements, duration of supply is thus designed for the optimal use of the system. However, the systems have been designed such that they generate 10–20 % incremental power to meet possible future demand. At present, the power plant is not automated through load limiter and is switched on and off by the operator who stays in the village. In fact, the primarily responsibility assigned to the operator is to do this job. There is, however, a battery protection panel, which is a switching device meant for isolating the battery bank.

A key feature of the CREDA model is the technical standardisation that contributed to the ease of operation and maintenance and minimization of cost. While the systems with installed capacity of 1–3 kWp have a battery bank of 48 V and inverter rating of 3 kVA, the systems with 4 to 6 kWp installed capacity have 96 V battery bank and inverter rating of 5 kVA, respectively. While in the beginning of the programme, solar panels were mounted on the ground and fencing provided around the same, for all later installations the civil structure has also been standardised with panel mounted in the rooftop and inverter and battery kept in the room. The height of the room is designed at a little more than usual, which reportedly helped in prevention of theft of the panels. Also, roof mounting reduced the cost of maintenance which otherwise is incurred for ground mounted panel on expenses such as fencing, theft, damage during monsoon, etc.

The battery bank in most power plants was found to have last for around 8 years, much higher than the usual battery life of 4–5 years prevalent in most others states such as in the Sunderban region where solar mini-grids have been implemented extensively [30]. The longer battery life has been ensured by CREDA by keeping a tab on the quality of battery purchased and by controlling the damage through misuse or overloading of battery capacity through routine monitoring (mandatory installation of ampere-hour meter to check battery health) and maintenance, using the three-tier model of operation and maintenance (refer to Sect. 3.8).

3.5 Institutional Arrangements

In Chhattisgarh, off-grid electrification through solar mini-grids is mainly a state-led programme by CREDA in partnership with the private sector. While this is essentially a top-down approach, there are several actors involved in the process including state, private as well as local actors imbibing the essence of a pro-poor public–private partnership model. The provincial and federal governments provide policy support and financial assistance to set up and operate the power plants, while the private sector is responsible for installation, operation and maintenance services.

As a first step in mini-grid installation, CREDA, which can be regarded as the off-grid electricity utility in the state, carries out an extensive survey in the village and builds consensus among villagers about setting up of the plant. One of the important initial steps for selection of a village is to get consent from CSEB regarding the future target of CSEB for grid electrification of that village. Once CSEB gives a green signal that the village is not going to be electrified through centralised grid system, then CREDA takes up the village to electrify through the off-grid mode. The next step is to carry out surveys, which are aimed at estimating the demand, decide on the potential capacity of the plant, keeping in mind the short-term to medium-term energy demand in the villages. Consensus is built by convincing village people about the utility of solar lights and the benefits it brings to rural people. Limitations of the proposed plant such as limited application of electrical appliances, and limited hours of supply are also informed to the potential beneficiaries of the plant. As a symbolic gesture and to build in sense of ownership, the villagers are also asked to hand over a piece of community land identified for setting up the plant. A village energy committee is also formed to facilitate the project implementation and management. Often, these activities are carried out through direct supervision of CREDA. Survey is followed by cost estimation for installation of the plant and power distribution network (PDN). After the completion of the estimation exercise, it is then sent to the state government and MNRE for necessary approval and release of fund for actual installation.

CREDA then floats tenders inviting technical and financial proposals from solar PV companies and private service providers known as ‘system integrators’, for setting up the power plant and also for maintaining it. A critical requirement for participation in the tender is that the solar companies or the system integrators are having their offices in the state. This is done to ensure that fly-by-night operators and non-serious bidders cannot take part in the bidding process. One or several companies are then chosen to implement the projects, under the supervision of CREDA. In addition, CREDA also enter into an annual maintenance contract (AMC) with the selected contractor for operation and maintenance of the plant. In some cases, both AMC contractor and system integrator are the same entity; however, in most cases they are different (Fig. 7).

At the last rung of the institutional hierarchy, lies the village energy committee (VEC), which acts as an interface between consumers, CREDA and private service providers and also acts as a local monitoring body. A local youth, selected by the VEC, is provided the responsibility by CREDA to operate the power plants and to take care of minor maintenance (details on roles and responsibilities are highlighted in Sect. 3.8). The entire process of implementing this model, selection of service provider and monitoring and supervision of service providers post implementation, communicating with VEC for feedback, lies with CREDA, which spearheads off-grid rural electrification process in the state.

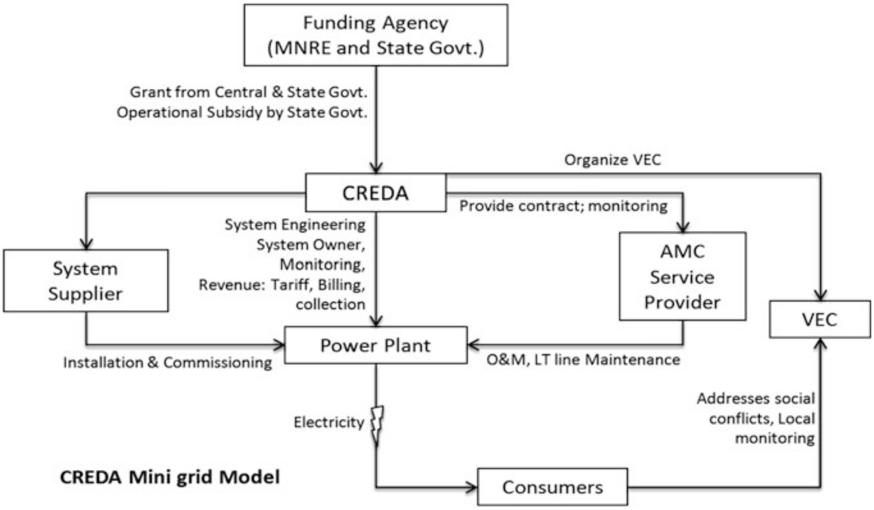

Fig. 7 The CREDA mini-grid model (*Source* Authors' compilation)

3.6 Financing Mechanism

Since a majority of the mini-grids have been deployed under the RVEP, installation costs were taken care of through the capital subsidies by Government of India supplemented by support from the State Government. On an average, the cost incurred to set up a solar power plant in the remote areas in the state has been INR 350,000 to INR 400,000 per kWp (1 US dollar is equivalent to 60 INR at present). In addition, civil construction costs were INR 150,000 to INR 400,000 depending on the capacity of the power plants and type of civil construction. Similarly, INR 150,000 is the average cost of power distribution network per kWp of solar power plant including household connectivity. Typically, the cost of connecting a household through solar mini-grids is INR 25,000/- [13]. Initially, connection charges were not imposed and were provided free of cost. However, lately CREDA has started charging for electricity connection. CREDA records show that the cost for implementing the power plant, civil construction, PDN and electricity connection to households was shared between the MNRE and state government, with MNRE's share varying between 38 and 48 % during various years (2002–2003, 2003–2004 and 2004–2005) [5]. The variation in MNRE's share is due to the fact that MNRE's share is dependent on their benchmark cost while the actual cost may be different for different power plants based on remoteness of the site and distance covered by the distribution line in the village.

Tariff structures have been devised keeping the socio-economic profiles of the beneficiaries under considerations. The tariff is INR 30/- per household per month per connection. Out of which INR 25/- is from the state government as operational subsidy and the balance is collected from the beneficiaries. After meeting the

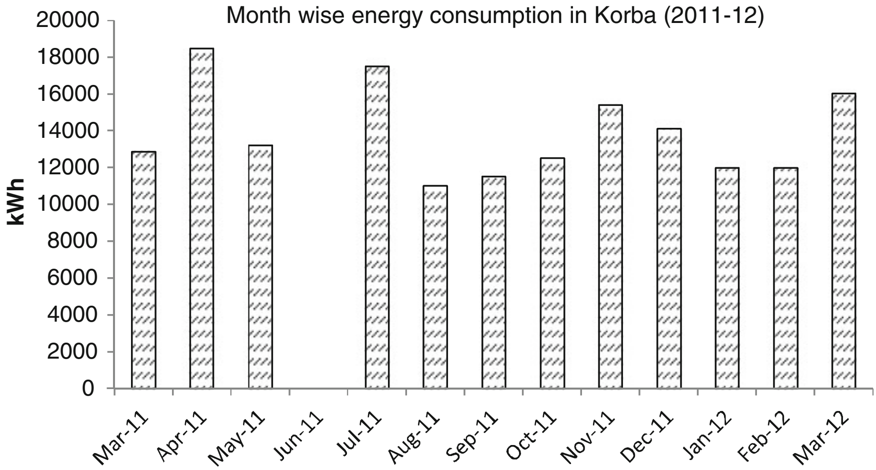

Fig. 8 Monthly energy consumption in Korba in 2011–2012 (*Source* Authors' compilation, 2013)

expenses towards operators and cluster technicians, the balance amount is also utilised to buy spares and other incidental maintenance activities. It must be mentioned here that contribution per beneficiary has been decided in line with the existing subsidy schemes under grid electricity supply for the BPL households. Under this scheme, known as '*ekalbatti yojana*', a tariff subsidy is provided for single point connection for below poverty line (BPL) households.

3.7 Aspects of Functionality and Performance

During survey in the eight villages, it was observed that almost all the plants were functioning and more than 90 % of the home light connections (HLC) were in working order. However, for street light connections (SLC) the functional status was found lower at around 70 %. The faults were mainly related to CFL blackening or loose connections. The power plants mainly serve the domestic load of the village and cater to the lighting needs of the community (Figs. 8, 9, 10 and 11). Thus, in terms of energy consumption pattern, the consumption per month for Raipur was found at 3.34 kWh/household while that for Korba it was found at 2.57 kWh/household. Based on these figures for energy consumption, it can be said that the power plants are operational for around 4–5 h as against the designed 6 h of operation. Further, the statistics for March 2012 reveals that in Raipur, a cumulative capacity of 429 kWp was serving about 10,170 home light connections and 1,120 street light connections. While in Korba, a similar cumulative capacity (426 kWp) was serving 5,350 home light connections and 874 streetlights.

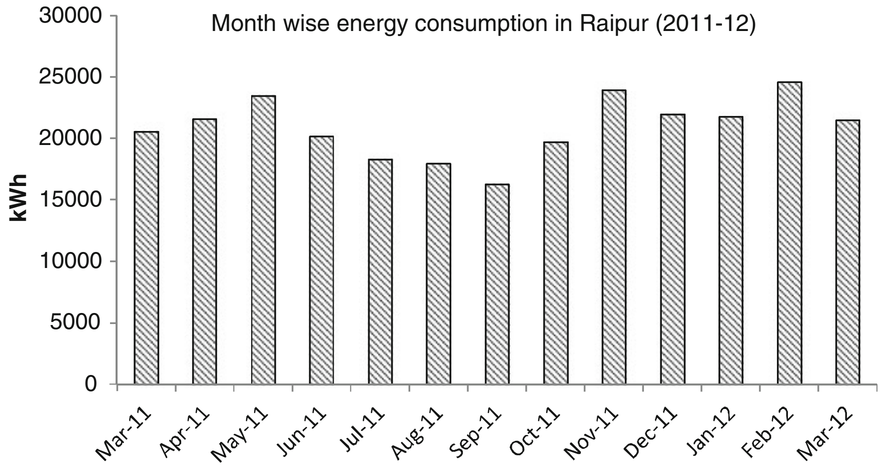

Fig. 9 Monthly energy consumption in Raipur in 2011–2012 (*Source* Authors' compilation, 2013)

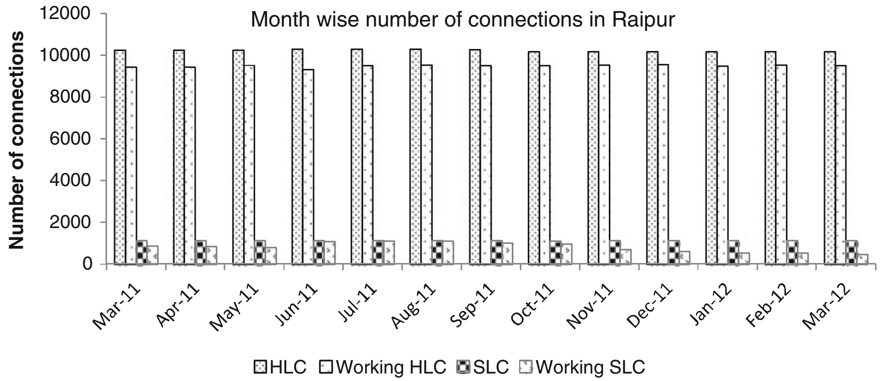

Fig. 10 Month-wise no. of connections served by solar mini-grids in Raipur (*Source* Authors' compilation, 2013)

3.8 Operation and Maintenance Aspects

In most of the states in India, where mini-grids have been implemented either by state renewable energy development agencies or NGOs, the system operator under the supervision of the VEC is always made responsible for O&M of the mini-grids. However, in Chhattisgarh, CREDA has developed its own innovative model by standardising all aspects of O&M. The model is called 'Cluster based service delivery model' or as 'Group the partners, Organize their skills, Allocate load in

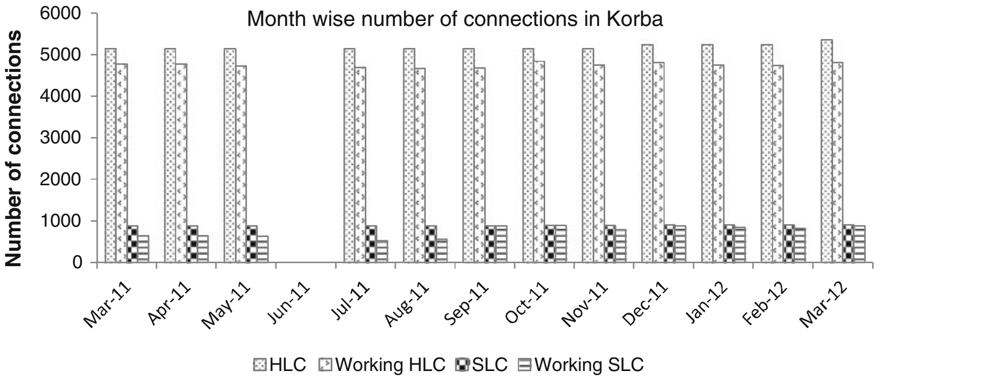

Fig. 11 Month-wise no. of connections served by solar mini-grids in Korba (*Source* Authors' compilation, 2013)

villages, Deliver service' (GOLD), where the installation is steered by CREDA and operation and maintenance of the plants is undertaken through a three-tier setup. CREDA signs an annual maintenance contract with the system integrators/AMC contractors for operation and maintenance of the solar power plants. O&M at the village/individual plant level is carried out by the operator, selected from the village and paid by the system integrators. The operator is responsible for cleaning the solar panels, switching the plant ON–OFF, daily reading of the energy metre and recording and checking the battery top-up. At the next level, a "cluster technician"—who handles cluster of villages—performs more advanced maintenance deals. The cluster technicians, engaged by the system integrators, are assigned the responsibility to supervise the operators, make weekly visits to the villages for preventive maintenance, check wiring and power distribution network, attend to any break down calls/repairs, and duly fill up and send the monthly monitoring report as per the format provided by CREDA. Every technician is provided with a motorbike by the service provider, so facilitating weekly visits to villages. The supervision of the activities at multiple clusters or a block level is done by the supervisor who monitors the activities of technicians, makes monthly visits to villages and collect reports for submission to CREDA. The appointment of the operator, technicians and supervisors is the responsibility of outsourced companies and the salaries and incentives of staff are paid by the AMC contractor or outsourced company. However, regular CREDA staff is engaged in parallel with AMC staff to ensure that assigned tasks like routine maintenance are being properly carried out.

A third-tier is managed by CREDA, which monitors all of its installations through monthly reports and replaces damaged equipment. This record based on continuous power output, has not only minimised cases of stealing and selling solar modules, it has also fuelled commercial demand for solar systems in the region. CREDA's maintenance framework also ensures that the mini-grids provide an uninterrupted power supply and an adequate supply of replacement lamps is kept in stock with each technician in case a light burns out.

Continuing with the innovative mechanism, CREDA has a structured mechanism in place to address the fault management. Especially during the monsoon season, when heavy rain can make roads inaccessible, spare inverters for each cluster is supplied by the authorities. Thus, if failures occur, inverters can easily be replaced thus reducing the external dependency on the manufacturer's technician to come and repair it. Since only two rating of inverters are used with the power plant, the replacement is easily done as spare inverters of such rating only need to be kept at the regional office of CREDA. In addition, CREDA have also ensured that extra inverter circuit boards of the two selected ratings are provided by system integrators during the setting up of any power plant, so that faulty circuit boards can easily be replaced, from the spares supplied, by the cluster technicians. Furthermore, the drivers of the vehicles, who transport technicians and supplies, are also provided basic training on replacement of lamps and topping up of batteries in cases of emergency.

Technicians and operators are trained by CREDA and are also provided periodic refresher training courses every 6 months. All the expenses for the trainings are borne by CREDA. CREDA has provided training to more than 1,400 operators for carrying out responsive maintenance of the mini-grid systems [13]. Further, 75 technicians and some 60 supervisors repair inverters and other electronics. CREDA has also trained more than 500 people to install and maintain various solar power systems that have been implemented in the state. The training session for the technicians is, in general, around 1 week with 6 h of training per day teaching them about electricity, electronic components, batteries and solar power and maintenance [14].

Every cluster has around 15–25 villages with around 50–75 households in each village. Given the operational subsidy provided by the state government, the revenue from each cluster is to the tune of INR 22,500 per month, while the expenses inclusive of operator, technician and other staff salaries are around INR 16,500 per month ensuring the operational viability of the model (Table 2). During the field visits, the model was found to be effectively working with regular payments ensured to the staff. In addition, some additional fund is also provided by the state government to meet the expenses like replacement of battery and inverter and for conducting the trainings. This fund is generated by keeping 10 % of the project cost at the beginning in bank fixed deposits.

3.9 System of Monitoring and Oversight

Strong monitoring is ensured through the presence of well-structured hierarchical monitoring system developed by CREDA, depending on the strength of each stakeholder. Starting from the village level up to the top of the hierarchy of monitoring at CREDA head quarter, the presence of a strong and routine

Table 2 Income and expenses for cluster based service delivery of solar mini-grids (in INR)

Revenue/month/cluster			
No. of villages/cluster			15
No. of customers/village			50
Total No. of customers/cluster			750
Collection per customer			30
Through CREDA from government			25
Direct from beneficiary			5
Total collection/cluster/month			22500
Expenses/month/cluster	No.	Rate	Total
Technician	1	4000	4000
Helper	1	2000	2000
Conveyance	1	2000	2000
Others	1	1000	1000
Operators	15	500	7500
Expenses/month/cluster			16500

Source CREDA 2012

monitoring system is playing a key role in the better functionality of the plants. Importantly, since operation and maintenance activity is outsourced to private companies, CREDA officials are employed at each level of hierarchy for oversight on the activities of the private companies.

The overall monitoring and oversight is the responsibility of CREDA, however, at the village level VEC is also involved for local monitoring of systems. The VEC keeps an eye on the performance of the operator and receives first level of complaint from users. Unlike in mini-grid projects implemented under VESP or RVEP in other states, here the VEC is not involved in technical operation of the power plant. Instead, they act as a lubricant for the social engineering required for smooth operation and management of the plant. VECs are also entrusted to resolve social conflicts and control theft and other management aspects of plants. Though their role has been kept limited, their importance in the whole institutional hierarchy cannot be ignored.

3.10 Project Impacts

While the focus of the study was more to understand the institutional and financial aspects and nuts and bolts of operation and maintenance, the study also attempted to qualitatively assess some of the direct impacts of the mini-grids. Based on the results from the focus group discussion, it can be said that the solar mini-grid systems in the state have been able to contribute to the socio-economic development of the community in many ways. During the visit it was observed that some households in the villages were also using mobile phones, fans and entertainment facilities such as TVs and radios. This has led to increase in flow of information resulting in higher level of awareness among beneficiaries. In specific terms, it was found that educational benefits are accruing through provision of lighting during the evening hours. Environmental benefits are being accrued through reduction in use of kerosene use. Information obtained through focus group discussion with community reveals that before these interventions were made, a household on an average used to spend about INR 100 per month on kerosene. However, with the provision of solar lighting systems, kerosene use has been drastically reduced and average monthly expenditure on kerosene has come down to less than INR 50. The study by Millinger et al. [14] also observes that the average saving on kerosene for households with mini-grid connection in Chhattisgarh is INR 30 per month. It should be mentioned here that since the lighting facility is for limited hours in the evening, some households still rely on kerosene, to some extent. In addition, electrification process has also led to income generation and employment creation. For instance, in the surveyed villages of Surkha, Saplowa and Raha, villagers reported working till late in the night for dona pata making (sal leaf cup-plate), thereby generating some incremental income for their families. In addition, at the system level, installation of mini-grids and other solar devices has been able to create a vast pool of skilled and semi-skilled human resources in the state, thereby meeting the employment needs and contributing to the socio-economic development of the state. CREDA also organises regular training courses for developing solar technicians in the state. Such trained technicians are then engaged by the service providers maintaining the solar mini-grids and other solar devices in the state.

4 Discussion

While CREDA solar mini-grid model has been comprehensively discussed in the previous sections, this section highlights the key aspects contributing to the success of the solar mini-grids in the state.

4.1 Robust Institutional Framework

One of the key ingredients of mini-grid's success could be linked to the strong and robust institutional structure created, nurtured and enlivened by CREDA. This is evident in multiple dimensions of the operational and management of mini-grids starting from the policy makers and planners in the state down to the very level in the hierarchy like operator of a single plant. Policy level support has been an important part of this institutional structure, which has been acting as a major impetus for the success of the model. In addition, it is also noteworthy to mention the public–private partnership structure engaged in the management and operation of the plant. The CREDA model also contradicts the notion that bottom-up approach with community involvement is the key to success of any decentralised project. While many researchers and practitioners have argued that decentralised energy systems should be implemented with a decentralised approach, with full planning and implementation by the community, the CREDA model clearly indicates that top-down approach of using standard designs, implementation and maintenance, with community's involvement for only local social engineering work, which they can do best, is a better (if not best) model to implement and operate the decentralised electricity infrastructure projects in remote communities. The outsourcing of maintenance to private management also brought in better efficiency of service into the project operation and management, which is difficult to ensure in a publicly devised and operated model.

Further, tariff collection is done by the AMC technician and supported by the operators in his effort. It is important to mention that there has been a clear-cut fragmentation of the amount collected from tariffs and salary of operators. Irrespective of the tariffs collected in a village, the operator gets a fixed monthly remuneration from the AMC contractor. This has led to successful operation of the plant as operator is assured to get their monthly payment. This is also corroborated from the study by Palit et al. [22] on Village Energy Security Program where one of the key reasons for failure was that the project management was completely entrusted with the VEC without ascertaining whether they are adept at managing the project or not. Further, the same operator was made responsible for system operation and tariff collection and in-case of non-payment by consumers, the operators' salary was delayed by the VEC, which acted as a disincentive for the operator. The solar mini-grid experience from the Sunderban region also shows that decentralised projects are more successful when implemented and managed in an organised way with clear cut roles and responsibilities of different stakeholders [30]. Shrank [27] also observes, that the community management system does not always create incentives for maximising profit at each power plant, thus creating problems for the coverage of costs of the power supply.

4.2 Social Engineering is Pivotal

The study also indicates that one of the key reasons to the success of solar mini-grids in Chhattisgarh is social engineering through regular and continuous engagement and making the community adopt the system. While, there have been places where social conflicts have led to dismantling of the installed system, overall the VEC has played their role in shaping the social engineering. This was also made possible as the VEC could focus on this aspect only, as the technical operation and maintenance was outside their purview. Extensive capacity building and awareness generation of local stakeholders also helped as the social engineering is executed through regular training programmes, both formal and informal, to different stakeholders.

4.3 Electricity Supply and Creation of Productive Activities

While provision of electricity has been primarily for lighting and no productive loads have been targeted as part of the initiative, there have been positive impacts on the local livelihood. Direct impacts are in terms of doing additional hours of work in the evening. For instance, during the *tendu* leaves collection season, extended hours of work could be possible as lighting is available during the evening. Further, in some cases, appliance uses such as use of radios, televisions, etc. was also found in some of the households in the villages visited. Indirect impacts are in the form of growing awareness by use of mobiles, radios, televisions, etc. Further research on this subject may be required for Chhattisgarh to quantitatively and qualitatively investigate the impacts of solar electrification on local economies in the state. It may be relevant to do a social cost benefit analysis of installing smaller capacity systems, as have been done in the state, to see if benefit outweighs costs. Though productive applications has its own importance in increasing local income, it was also important for the Chhattisgarh government to facilitate electricity access for lighting for such remote population and provide necessary exposure, where they can initiate or get involved in some income generation activities to pay for the services availed. The critical aspect here is that since the solar mini-grids have been primarily used to provide electricity services, any new demand for load enhancement can now be met using the existing grid infrastructure by increasing the solar panel and using additional inverter (as productive demand may be during daytime, additional storage will not be required) at a marginal cost which otherwise may not be possible with individual solar home systems.

4.4 Enabling Policy Environment

Enabling policy regime for promotion of solar mini-grids has been instrumental in accelerating the growth of off-grid electrification in the state. Realising the importance of off-grid electrification for the state, the government of Chhattisgarh has been very proactive in providing supports to mainstream off-grid electrification options for geographically difficult locations of the state. While the solar mini-grids have been implemented under the REVP, the state government has also equally been generous of sanctioning fund to as high as 55 % of the project cost to install mini-grids at remote locations. Further, the tariff subsidy mechanism provided to grid electricity consumers was also extended to subsidise households getting electricity through off-grid generation. While it can be debated whether we can call the CREDA model a success or not, as operational subsidy is also provided by the government in addition to capital subsidy, it is to be kept in mind that the provision of electricity is for villages with extremely poor economic conditions. Thus, envisaging a business sense through energy intervention becomes difficult. Moreover, the state is following an equitable approach whereby the off-grid areas are also getting similar support provided in the grid connected areas, which otherwise is absent in most of the other states (where only grid connected consumers are provided tariff subsidy or cross-subsidy). Provision of electricity in these remote and far off localities could at best be considered as merit goods as also envisaged in Integrated Energy Policy of the Government of India. Lately, however, there is an on-going thinking within CREDA that now the time has come for a strategic shift in the provision of electricity from subsidised service to a paid one in at least few select sites. The idea is to spilt up the entire beneficiaries into two different groups. Households will be provided at a marginal fee whereas business units such as rural banks, tailoring shops and grocery shops will be provided on the basis of full recovery of operation and maintenance cost.

5 Concluding Remarks

This chapter has attempted to present an analysis of the development and operation of the solar mini-grid model for enhancing electricity access in India, with special focus on the state of Chhattisgarh. It is observed from the study that the rate of success of mini-grids is directly dependent on the government's commitment to create an enabling environment, which includes having a clear-cut policy framework and milestones, systems for defining and enforcing appropriate technical standards, financial support mechanisms both towards installation and operation, and support for capacity building. Chhattisgarh has developed a robust institutional framework not only for implementation, but also for ensuring responsive after-sales service and maintenance of the solar mini-grids in the state paving the way for success of the programme.

While there may be a debate on what constitutes a success as the model followed in Chhattisgarh is highly subsidised and the power plants are designed to take care of only lighting load, there is no denial of the fact the provisioning of basic minimum electricity access to the population at the extreme base of the pyramid is also important and requires innovative approach for success. While many mini-grid projects fail in such remote areas because of lack of strong institutional framework and maintenance services, the implementing agency here has been successfully operating and maintaining the power plants by utilising the fund made available by the state government towards the operational subsidy.

The mini-grids have proved to be a reliable solution for such remote areas in comparison to solar home systems. Technically, mini-grids are preferred over other modes like solar home-lighting systems and solar lamps, as mini-grids can provide electricity services for lighting as well as to run various appliances, whereas solar home-lighting systems and solar lamps typically provide only lighting services. Organisationally, Chhattisgarh experience shows that managing mini-grids may be easier compared to individual systems due to their centralised operation in a village through a proper institutional structure. Further, the design also ensured that any future demand, in the form of new household connection or power for community load, could be catered to. The standardisation of design and operation and maintenance model by local-level service providers also ensured that the solution is cost-effective at the local scale. The system also does not lock-in the community to a particular development path as the mini-grid capacity can easily be enhanced by addition of modular capacity in case of enhanced demand for any productive loads in future, which otherwise is a constraint in case of individual solar home systems. In fact, the study clearly brings out this fact of capacity enhancement, which has been carried out in case of some villages both through installing new power plants and also using dismantled systems from other project villages where grid has reached over time.

Another key lesson from 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 a design support system, so as to ensure that plans and policies match the needs of all stakeholders—consumers, owners and technology suppliers. 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.

Lastly, for the renewable energy-based, rural electrification sector to reach significant scale, implementation agencies need to work on overcoming the challenges of supply, demand and scalability and at the same time adopt standard processes and metrics, which will also help them to attract the necessary level of investment from financial institutions in support of 'energy access' programmes.

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