CHAPTER 11

Achieving "Energy for All": Solar Mini-Grids for Rural Electrification in Asia

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11.1 Introduction

Electricity plays a vital role in socio-economic development (Pereira et al. 2011). Sustainable, affordable, and reliable electricity is a major driving force for the economic as well as for human development of a nation (Davidson and Johansson 2005; IEA 2018; Kaundinya et al. 2009). Countries with the highest levels of poverty tend to have lower access to modern energy access (World Bank 2017). Countries with a higher Human Development Index (HDI) have better energy access and higher per capita income as compared to low HDI countries (Bhattacharyya 2012). Energy access means physically accessible and available modern energy services. Energy should be of acceptable quality, reliable, adequate

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and affordable in terms of low capital and operating cost (Balachandra 2011). The stable, efficient, affordable and safe energy access will have a positive impact on income and health. Access to energy can reduce poverty, support education, increase access to other services and improves the overall quality of life (Pachauri et al. 2012). In September 2015, member states of the United Nations had agreed to implement 17 Sustainable Development Goals (SDGs) to end poverty and secure peace and prosperity by the year 2030. The UN has included sustainable energy as the seventh goal of the 17 SDGs, to "ensure universal energy access to affordable, reliable, sustainable and modern energy for all" (UN ESCAP 2019a).

The SDG-7 has set five targets to be achieved by 2030: (i) ensure universal access to affordable, reliable and modern energy services; (ii) increase the share of renewable energy in the global energy mix; (iii) double the global rate of improvement in energy efficiency; (iv) enhance international cooperation to facilitate access to clean energy research and technology; and (v) expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in the developing countries. It also supports programs including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promotes investment in energy infrastructure and clean energy technology. United Nation – Economic and Social Commission for Asia and the Pacific (UN ESCAP) monitors the progress of SDG-7 targets and publishes periodical reports. As per the progress report of 2019, the Global electrification rate had risen from 83 per cent in 2010 to 89 per cent in 2017. Since the initiative of SDG 7, every year 153 million or more people have accessed electricity. During this period, electricity deployment has seen tremendous growth; the Global population without electricity access has dropped from 1.2 billion in the year 2010 to 840 million in the year 2017 (UN ESCAP 2019a). The report further mentioned that the average annual gain in the electrification rate for the period 2010–17 was 0.8 percentage points per year, and with this growth rate it would be difficult to reach the said goal of universal access to electricity by 2030. At this rate, only 92% of the global population will have access to electricity, and approximately 650 million people will be left without access to electricity. To achieve universal electricity access goal, the rate of electrification growth should be 0.86 percentage points annually between 2018 and 2030 (UN ESCAP 2019a).

As per UN ESCAP (2019b), approximately 325 million people (7% of the total population) in Asia-Pacific region lack basic electricity. Basic electricity means "having initial access to sufficient electricity to power a basic bundle of energy services – at a minimum, several lightbulbs, task lighting (such as a flashlight), phone charging and a radio – with the level of service capable of growing over time"(IEA 2018). Within Asian region, about 255 million people in South, South-West Asia and 48 million people in South-East Asia lack access to basic electricity. The other regions of Asia have achieved universal electricity access. Although, Asian region is progressing in providing access to electricity, with the current policies, this region can attain 98.4 percent electricity access by 2030 (UN ESCAP 2019b). Even after achieving this gigantic target, approximately 66 million people will be left without electricity (ibid.). Access to electricity has a positive impact on the socio-economic condition of the people. A study by Jiménez (2017) examined 50 impact evaluation studies, focused on the impact of electrification on education, labour, income and other social indicators. The study observed an increase of 7% in school enrolment, 25% in employment, and 30% in incomes with electrification. UN-ESCAP examined electrification programs in the Asian countries Bangladesh, Cambodia, India and Vietnam and observed increased income, improved primary and secondary education and reduced poverty (UN ESCAP 2019b; Table 11.1).

Electricity in most of the Asian countries is primarily provided through central grids (Bernard et al. 2018). However, there is a wide disparity in access to electricity in rural and urban areas. Electrification rate is lower in remotely located regions, and often grid connectivity is not available due to geographical and economic constraints (UN ESCAP 2019b). In the last two decades, cost of renewable energy technologies has declined and service quality improved. In addition, international climate change negotiations have pushed for wider adoption of renewable energy technologies. Due to these factors, several policy actors have promoted the use of solar mini-grids in Asia (Knuckles 2019, UN). According to World Bank, out of 26,000 mini-grids in 134 countries, around 9300 are located primarily in South Asia and several thousand other mini-grids are located in East and Central Asia (ESMAP 2019). The current electricity scenario in Asia will not be complete without analysing the role of mini-grids in the emerging electricity mix.

In this background, we argue that mini-grids could become an important element in the electricity policy of Asian countries. We first discuss the state of rural electrification in Asian countries. We then take a deep dive in the case study of two villages in the state of Bihar in India where solar mini-grids were established to connect un-electrified villages in remote areas of South Bihar. We conducted socio-economic survey in these villages, and examine the impact of electrification on the socio-economic

Table 11.1 Electricity Access Impact Evaluations in Selected Countries

Country	*Impacts*			
	Income	*Education*	*Inequality*	*Poverty*
Bangladesh	21 per cent increase in household income	Girls: Extra 12 minutes study per day and 2 extra months of schooling Boys: Extra 22 minutes study per day and 3 extra months of schooling	Richer households benefit more from electrification than poorer households	Poverty decreased by 1.5 percentage points per year
Cambodia	16.6 per cent increase in daily per capita consumption	8.5 month increase in total schooling and 7 per cent increase in ever having been enrolled	Richer households benefit more from electrification than poorer households	–
India	38.6 per cent increase in household income	Girls: 7.4 per cent more likely to have enrolled and 6 extra months of schooling. Boys: 6 per cent more likely to have enrolled and 3.6 extra months of schooling	Richer households benefit more from electrification than poorer households	Poverty decreased by 13 percentage points in total
Vietnam	28 per cent increase in household income	Girls: 9 per centage points more likely to have enrolled and no change in total schooling Boys: 6.3 per centage points more likely to have enrolled and 1.4 extra months of schooling	Richer households benefit more from electrification than poorer households	–

Source: UN ESCAP. (2019b). Universal access to energy in Asia and the Pacific: Evidence-based strategies to achieve empowerment, inclusiveness and equality through Sustainable Development Goal 7 (Note by the Secretariat ESCAP/75/13; Review of the Implementation of the 2030 Agenda for Sustainable Development in Asia and the Pacific: Energy) development of the households in two stages. Phase-I (pre-grid connectivity): moving from no-electricity to mini-grid and Phase-II (post grid connectivity) shifting from mini-grid to grid power. In addition, the chapter also explores the following questions: a) What happens to mini-grid when a village gets connected with the main grid?, b) Does a mini-grid act as a substitute for the main grid or complement it or goes in oblivion?, and c) What lessons can be drawn to provide affordable, reliable and sustainable "energy for all"? Finally, we conclude with some generic lessons related to mini-grids that can be derived for countries in Asia, based on our in-depth case study of the two Indian villages.

11.2 Rural Electrification in Asian Countries

Asian countries have shown significant progress in deployment of the electricity, 91% of this region is having access to electricity, China, Brunei, Malaysia, Maldives, Thailand Singapore and Vietnam have achieved 100% electrification, whereas Afghanistan, Bhutan, Indonesia, Nepal, and Sri Lanka have more than 95% electrification rate (Table 11.2). Other developing Asian countries such as Bangladesh, Pakistan and India also have shown significant progress in the last decade (IEA 2018; World Bank 2020). Yet, approximately 500 million population in Sub-Sharan Countries (33% of electrification rate), and 340 million population in Developing Asia remain without electricity (UN ESCAP 2019a).

There is a lot of disparity in urban and rural electrification rate, in 2017 global rural access rate was 79% (an access deficit of 728 million population), which is much lower as compared to the urban access rate of 97%. The disparity in Sub Saharan Africa is wider compared to that of Asian countries (as indicted in Table 11.2). During the same time, almost all Asian countries have achieved 90 per cent or more access in urban areas, and 80 per cent or more rural access rate (except in Mongolia, Myanmar and Pakistan) (UN ESCAP 2019a; World Bank 2020). The literature on rural electrification indicates that polices of Asian countries often supports connection with the central grid as a major mode for expansion of electricity services, which is cited as a significant reason for low rural electrification rate in these countries (Heynen et al. 2019; Palit and Bandyopadhyay 2016; Rahman and Ahmad 2013). As an alternative, several governments have promoted off-grid connection in remote rural areas. As per IRENA (2018), the number of mini-grid projects and solar home systems (SHS) has increased worldwide, as of 2016, the estimated off-grid renewable

Table 11.2 Electricity access in Sub Saharan African and Asia

Region/ Country	*Population without electricity as of 2017 (000 s)*	*Electrification rate (%)*					
		2017			*2010*		
		Rural	*Urban*	*Total*	*Rural*	*Urban*	*Total*
Sub Saharan Africa	572,637	22	79	44	14	69	33
China	0	100	100	100	99	100	100
Mongolia	435	56	100	86	42	96	79
Afghanistan	817	97	100	98	30	83	43
Bangladesh	19,760	81	100	88	40	90	55
Bhutan	19	97	99	98	59	99	73
India	98,849	89	99	93	68	94	76
Maldives	0	100	100	100	99	100	99
Nepal	1317	95	99	96	59	94	65
Pakistan	57,548	54	100	71	56	97	70
Sri Lanka	526	97	100	98	83	96	85
Brunei D.	0	100	100	100	100	100	100
Cambodia	1749	86	99	89	16	91	31
Indonesia	4910	96	100	98	90	99	94
Lao PDR	439	91	100	94	59	97	71
Malaysia	0	100	100	100	98	100	99
Myanmar	16,110	60	93	70	32	89	49
Philippines	7344	90	96	93	78	94	85
Singapore	0	100	100	100	100	100	100
Thailand	0	100	100	100	99	100	100
Vietnam	0	100	100	100	98	100	98

Source: (World Bank 2020)

capacity was about 6.5 GW, out of which Solar PV accounts for 2.2 GW. According to ESMAP research and analysis, approximately 47 million people in 134 countries and territories currently have access to electricity through 19,000 mini-grids. Asian countries account for 85% of the total installed mini-grids (approx. 16,000), Afghanistan has most of the mini-grids (5000) followed by Myanmar (4000), India (3000), and Nepal (1500) (Knuckles 2019).

According to IRENA (2018), nearly 133 million people are connected to off-grid, and capacity had increased from 2 GW in 2008 to 6.5 GW in 2017. The growing demand for off-grid technologies is due to a decline in the cost of the technology; advancement in the technological and financial innovation; and supportive public policies and measures. The Global average levelised cost of electricity (LCOE) for solar PV was USD 0.085/kWh in 2018, and it has become competitive compared to fossil fuels, the LCOE is expected to fall between USD 0.02 to 0.08/kWh by 2030 and USD 0.014 to 0.05/kWh by 2050 (IRENA 2019). As per ESMAP database, 210,000 mini-grids will provide electricity to more than 500 million people by 2030 (Knuckles 2019). Figure 11.1 provides an off-grid installation capacity since 2007. During the period 2011–2016, there is a steady growth in the production of hydropower, and also, solar-related renewable energy power has shown remarkable growth. Asian countries have the highest share of Hydro, Solar lights solar home systems (SHS) and other off-grid Solar PV technologies, whereas African countries have the highest share in the deployment of solar mini-grids.

Although access to electricity through mini-grids are increasing worldwide, the functioning of existing installed mini-grids itself faces several challenges (Raman et al. 2012; Sharma 2020). Most of the existing mini-grids provide electricity only for 4–6 hours/day and supports low power consuming devices such as small lighting units, mobile phones, fans, radios etc. Further, the demand for grid connectivity increases in villages installed with mini-grid whenever the neighbouring village gets electrified through grid expansion (Sharma 2020). In India, the rural electrification scheme "Saubhagya" of Government of India, reports that around 820 villages (out of 3059 off-grid villages) were got re-connected to the main grids. In

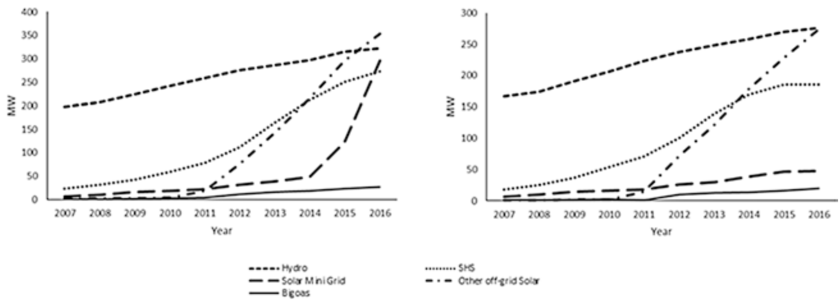

Fig. 11.1 Off-grid installation: Global total (panel a) and Asian Countries (panel b). (Source: IRENA 2018)

the next section, we provide an account of electrification through off-grids in selected countries of Asia, with a focus on solar mini-grids.

11.2.1 The Emerging Alternatives: Off-Grid Electrification and Solar Mini-Grids

Between 2010 and 2019, Asian countries have implemented several rural electrification programs and achieved incredible growth. Except for Pakistan, Mongolia and Myanmar, all other countries have provided electricity to more than 80% of the rural population. In these countries, wherever the main grid was not available, electricity was supplied through off-grid such as solar mini-grid, solar lighting and solar home systems (SHS), hydropower and biogas. SHS had played a significant role in providing access to electricity in Afghanistan (700 thousand people), Bangladesh (14 million), India (49 million) and Nepal (1 million). Solar mini grid (SMG) is more prevalent in Indonesia, followed by India, as of 2016, approximately 540 thousand people in Indonesia and 260 million people in India have access to electricity through SMG (Table 11.3).

The scenarios of the mini-grid connections and their importance in rural electrification in the selected Asian countries are presented below:

11.2.1.1 Lao PDR

Lao PDR's rural electrification rate has seen incredible growth from 59 per cent in 2010 to 91 per cent in 2017 (Table 11.2). Lao PDR contains one-third of the Mekong river basin and receives relatively high rainfall, because of these advantages, the country's energy need is primarily supported by the hydropower. The annual production of the power from hydropower in 2015 is estimated as 14,335 GWh (86% of total power generation), coal-fired power plants contributed another 2225 GWh (14% of total electricity generation), and solar power accounted for a small share with the production of 0.001 GWh (OECD 2019). The country exports hydropower to Thailand and Vietnam. Due to economic growth in recent years, domestic demand for electricity has been growing rapidly; between 2010–18, the annual electricity consumption increased at an average rate of 14.5% per annum (World Bank 2019). At the same time, the generation capacity from hydro reduces during the summer/dry season in summer due to low water inflows. Considering these facts, the country is now focusing more on off-grid electrification. The Government of Lao PDR has aimed to increase the share of non-hydropower to 30% of total consumption by

Table 11.3 Off-grid electricity access in selected Asian Countries

Country	*Rural electrification rate*		*Off-grid energy access in 2016 (thousand people)*						*Funding agency*
	2010	*2017*	*SMG Tier1*	*SMG Tier 2*	*SHS >50 W*	*SHS 11-50 W*	*SHS <11 W*	*Total*	
Afghanistan	30	97		20	15	27	664	726	ADB, USAID, IFC etc.
Bangladesh	40	81		39		13,929	358	14,326	IDCOL, World Bank
Cambodia	16	86				172	148	320	GoC, Private Owners
India	68	88	25	241		2882	46,973	50,121	GoI, NGOs
Indonesia	90	96	85	463	13		414	975	GoIndonesia, UNDP, Private Owners
Myanmar	32	60	10	2			207	219	Myanmar Govt.
Mongolia	42	56			249			249	Global Env. Facility Trust Fund, Govt. of Netherlands
Nepal	59	95				1660	207	1867	World Bank and NGOs
Pakistan	56	54					434	434	Pakistan Govt.
Sri Lanka	83	97			134		154	288	GoS and World Bank

Source: (IRENA 2018)

Note: Solar Mini Grid (SMG) – Tier 1: Basic lighting (>50 W), Tier 2: lighting and other electric appliances (TV, Fridge, Computer etc. 50 W–500 W)

2025 (OECD 2019). The government has identified solar power as an alternative source, as the country receives good sunlight during the dry seasons. With the help of international organisations, foreign aid, and private companies, about 18,657 households across 430 villages (equivalent to 1.64% of total households nationwide) are connected through solar power systems, the number of households connected to solar off-grid is expected to increase in the coming years (OECD 2019).

11.2.1.2 Myanmar

With only 60% of rural electrification, Myanmar is one of the least electrified countries in Asia. As per Pascale et al. (2016) study, only 9.5% of the total villages in Myanmar are covered with grid electrification. Around 70% of the rural households depend on kerosene lamps, diesel generation units, batteries or candles for meeting their lighting requirement. About 1200 hilly communities in Myanmar are electrified through hydropower mini-grids called "waterwheels" (Tharakan and Acharya 2014). In the delta region of the country, biomass gasification mini-grids are common; with the growing demand for the electricity, along with hydropower, the government is promoting SHS in the rural parts of the country. As of 2016, about 200 thousand people have gained access through SHS. But compared to the demand, deployment rate of SMG and SHS are low; this is due to lack of regulatory framework, small budgets and lack of attractive financing (Pode et al. 2016).

11.2.1.3 Cambodia

Cambodia has seen a remarkable rural electrification growth in the last ten years. Access to electricity in rural areas has jumped from 16% in 2010 to 86% in 2017 (see Table 11.1). In the 90s, to promote electricity supply, Cambodia has given license to private owners/village entrepreneurs, because of this initiative, many of the isolated diesel-based mini-grids were started. In 2001, the Electricity Authority of Cambodia was established and allowed the isolated mini-grids to connect to small power distributors which later got connected to the main grid. As of now, more than 250 isolated private mini-grids have been connected to the national grid and is providing electricity to more than one million people. No country in the world has ever connected so many mini-grids to the national grid (Bernard et al. 2018). Cambodia has achieved this success by implementing the following policies: (a) it has issued the licenses to the private mini-grid operators and allowed them to connect to the national grid (b) it allowed the higher tariff and zero loans to the private parties/entrepreneurs (c) it allowed the private owners to operate efficiently and expand to other neighbouring villages. In addition, currently, SHSs are serving more than 300 thousand people in the country.

11.2.1.4 Indonesia

Indonesia has one of the highest rural electrification rates in Asia. Government supportive policies helped the construction of micro and mini-grid projects in the mountainous, remote and island terrain of the country. As per the Bernard et al. (2018) report, around 1300 mini-hydro and mini-grid solar projects were constructed since 1990 and providing electricity to 10,300 villages. These projects vary from 5 kW to 500 kW, most of the projects were in the range of 5–40 kW (Suryani 2013). After villages were connected to the main grid, due to Indonesian law and operational issues, a large number of villages abandoned the mini-grid projects, only 6 per cent of the mini-grid projects were connected to the main grid and exported the electricity to the national grid.

11.3 Solar Mini-Grids for Rural Electrification in Asia: A Case of Two Villages in India

In recent years, India has enacted several policies to ensure universal access to electricity (Bhattacharyya 2006; Narayan et al. 2020). Yet, in the rural areas of the country, a large number of people are still living without electricity (Comello et al. 2017; Hartvigsson et al. 2015). In India, grid extension remained one of the prominent ways of rural electrification (Robert and Gopalan 2018). However, over the last decade, solar mini-grid technology and solar home systems (SHS) have been promoted as an alternative mode of rural electrification (Kar et al. 2016). The government has pushed solar mini-grids to connect people who live in remote areas where electrification through the grid is beyond the reach.

In line with UN SDG, especially to achieve universal electrification for both rural and urban households by December 2018 (12 years ahead of SDG-7 target by 2030), in 2017, Government of India launched a program Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya). The program's objective was to electrify about 25 million households who were not covered under another broader rural electrification program started in 2005, Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) or Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY). Under Saubhagya program, Government of India identified the beneficiaries (Below Poverty Line households) using the 2011 socio-economic and caste census (SECC) data and offered free connections to un-electrified deprived families. Other non-eligible households of SECC were provided electric connection after payment of INR 500; the initial amount can be recovered in instalments from the beneficiaries. With DDUGJY and Saubhagya programs/schemes, approximately 99% of people gained access to electricity through grid extension and decentralised distributed generation such as solar mini-grid and stand-alone solar home systems (places that cannot be reached via grid expansion) (Palit 2018).

On 28th April 2018, Prime Minister of India had announced that every single village of India is electrified. But as per NITI Aayog report on National Energy Policy, about 304 million people are still without access to electricity, and a large chunk does not have access to reliable supply (Aayog NITI 2017; Heynen et al. 2019). This discrepancy is due to the definitions of "village" and "electrification" in the government records. As per the Government of India, a village can be categorised as "electrified" if it has a population of 100 or more households and at least 10% of the households have access to electricity. In other words, if a village has 100 homes, and if ten among them are electrified then it can be considered as an electrified village (Malakar 2018). The official web-portal of the Saubhagya scheme reports that 93 per cent of the un-electrified villages are electrified, remaining 7 per cent of villages (1270 villages) are reported as uninhabited. Even if all the villages are electrified, hamlets which have population less than 100 households, and localities at sub-village levels may not be connected to the grid and will remain without power, and based on estimates the number of people without access to electricity would be around 200–300 million (Singh 2016). Although GoI is aiming to achieve 24X7 access to electricity for all by 31st March 2019 (PIB – GOI 2018), due to inadequate services of the grid connection, high transmission and distribution losses (approx. 23% of electricity), grid-connected households may not get adequate electricity (Heynen et al. 2019). Within India, there are wide differences among different states/region in terms of access to electricity in rural areas. Bihar is one of the laggards. The following subsection will provide the scenarios of recent developments in rural electrification in Bihar.

11.3.1 Rural Electrification in Bihar

The state of Bihar is located in the eastern part of India and area-wise it is the 13th largest state. It is the 3rd populous and 6th densely populated state with a population density of 1106 people per sq. km (Census 2011[1]). Bihar's per capita income is estimated as USD 630 which is lowest among all the Indian states (MoSPI 2019) and per capita consumption of electricity is 280 kWh which is also the lowest among all the Indian states and way below the national average, 1122 kWh/person (Ministry of Power 2018). Low per capita power consumption indicates that a large portion of the population does not have access to modern, stable and clean energy. More than 85% of the population lives in rural areas and mostly rely on conventional sources of energy for meeting their daily energy requirements. In 2016, to achieve universal household electrification in Bihar, the Government of Bihar has started a program Har Ghar Bijli (supply of power to all households). On 31 October 2018, the State has announced that electricity connections to all the households who were willing to get connections were provided (Government of Bihar 2019).

Further, the State has claimed that the availability of power in rural areas has increased from 6–8 hrs to 18–20 hrs. Even if rural areas get 18 hrs power supply, a large section of the rural population still remains dependent on kerosene as an alternative source of lighting (Jain et al. 2018). Bihar has a peak demand of 5139 MW whereas the availability is only 4535 MW (Government of Bihar 2019), due to this gap, often villages face load shedding. A study by CEEW reviewed power situation in nine districts of Bihar and revealed that 93% of the respondents are dissatisfied with grid connection because of the unreliable power supply, voltage fluctuations and inadequate supply. The study also observed that grid-connected villages receive less than eight hours of electricity supply in a day (Jain et al. 2018). A study led by Rockefeller Foundation (2019) observed that one in every two grid-connected households faces power cuts of at least 8 hours daily in the states of Bihar, Uttar Pradesh, Odisha and Rajasthan. It is interesting to explore how the recent rural electrification drive is faring in Bihar. In the next section, we describe the impact of electrification on socio-economic indicators in our study area and along

[1] http://censusindia.gov.in/2011-prov-results/data_files/bihar/Provisional%20Population%20Totals%202011-Bihar.pdf and https://www.census2011.co.in/census/state/bihar.html

with that we explore the challenges and limitations of providing "energy to all" in remote villages of one of the least developed states of India.

11.3.2 Impact of Solar Mini-Grids on Socio-Economic Conditions

In literature, several studies have examined the impact of rural electrification on socio-economic development, income, education, health, and environmental issues (Barman et al. 2017; Chakrabarti and Chakrabarti 2002; Imai and Palit 2013; Kanase-Patil et al. 2010; Mondal and Klein 2011; Palit and Chaurey 2011; Thomas and Urpelainen 2018; Urpelainen 2014). Imai and Palit (2013) study have observed a significant increase in farmers' income with Solar-mini-grid installation in the region of Sundarbans, State of West Bengal, India. The study also observed that Solar-mini-grid installation has a positive impact on reading hours for children and business hours for women. Barman et al. (2017) study has examined the implementation of Solar Home Lighting System (SHLS) in four districts of Assam. The study has observed a significant reduction of kerosene consumption and improvement of lighting, mobile recharging and income generation through small business during evening hours. Due to the extended working hours, women in those regions, have engaged in homemade food businesses like pickle making, weaving etc., which helped them to earn an extra income. The study also identified an increase in the children's evening study hours. The Solar Home Lighting System (SHLS) has improved the daily needs of the household like mobile charging for which they had to travel far distances and pay an amount of INR 10 for one-time charging. These solar systems have also contributed to connecting the households' latest information through television and radio.

Urpelainen (2014) study has examined the implementation of off-grid electrification projects in the villages of three states of India, West Bengal, Rajasthan and Uttar Pradesh. The study observed a substantial improvement in children's education, income generation activities through small businesses and public health with the off-grid electrification. Due to the regional scarcity of kerosene and diesel, solar power has become the most affordable option for the villagers. With a decrease in kerosene consumption for lighting, indoor air pollution has reduced. Aklin et al. (2017) study did not find any consistent effect on savings, household expenditure or in the generation of new business as solar microgrid provides only basic lighting, mobile charging, etc. Earlier studies mostly discussed the success or failure of the mini-grid project and its impact on socio-economic development. In this chapter, we examine electricity access in selected villages in more comprehensive terms. We analysed the electricity access in two phases. Phase-I – pre-grid connectivity: moving from no-electricity to mini-grid and Phase-II – post grid connectivity: shifting from mini-grid to grid power.

11.3.2.1 A Background of Study Villages

Four villages were considered in this study to assess the potential impact of two types of rural electrification systems (Table 11.4). Two villages (Bahsa Pipra and Badil Bigha of Tankuppa block of Gaya district in Bihar) were connected with solar mini-grid and other two villages (Mahadevpur and Pilkhi of Rajgir block of Nalanda district in Bihar) were connected with the central grid. Bahsa Pipra village is situated about 8 kms from the block headquarter Tankuppa and around 20 kms away from the district headquarter Gaya. The geographical area of the village is 288 ha with a total population of 2501 people and about 401 households. Whereas, the other village Badil Bigha has a population of 597 with total no. of 106 households. The Badil Bigha village is about 5 kms from the block headquarter Tankuppa and around 17 kms away from the district headquarters Gaya. Both these villages are predominantly inhabited by marginalised communities. The villages are located in a region, which was affected by left-wing extremism. Most of the working population was either involved in farming or wage labour. Till today, these two villages do not have proper

Table 11.4 Villages considered for the Study

Village	*Number of households*	*Grid connection*	*Mini-grid*		*Dist. from nearest town*
		Year	*Year*	*Capacity*	
Badil Bigha (Dist. Gaya)	106	2018	2016	12 KW	17 km
Basha Pipra (Dist. Gaya)	401	2018	2016	30 KW	20 km
Mahadevpur (Dist. Nalanda)	165	1972	–	–	1 km
Pilkhi (Dist. Nalanda)	710	1972	–	–	2 km

Source: Author's assessment based on various sources road connectivity. They got connected with the central grid just a few years back. To provide a comparison, two other grid electrified villages of Nalanda district were selected, both Mahadevpur and Pilkhi villages are situated near Rajgir block of Nalanda district. According to 2011 census data, Mahadevpur has a total of 165 households and a population of 1065 people with about 564 males and 501 females. Whereas, Pilkhi has about 710 households and a population of 4770 with 2494 males and 2276 females.

With the help of Corporate Social Responsibility (CSR) project, Container Corporation ltd. (CONCOR) has initiated the solar mini-grid pilot project in 2015 with the budget of INR 10 lakh in Badil Bigha and Bahsa Pipra villages. The Central Electronics Ltd. (CEL) has provided technical assistance to install 12 KW in Badil Bigha (106 households) and a 30 KW installed capacity of solar mini-grid in Bahsa Pipra (401 households). For an efficient and easy power distribution to all the beneficiaries, centralised power stations, battery backups and individual meters were installed at each village. Along with solar mini-grid, Badil Bigha village has received a 3KW DC pump to facilitate drip irrigation to the farmers. The beneficiaries of the solar mini-grid project are charged an initial amount of INR 500 and provided with two 5 W LED bulbs, one 20 W DC fan, and one 5 W Solar lantern along with a mobile charging point and individual pre-paid meter system. For smooth operation and maintenance, the pilot project was handed over in May 2016 to the Bihar Rural Livelihoods Promotion Society's JEEVIKA, run by the village women community.

To assess the potential impacts of solar mini-grid in rural electrification and to understand the energy access both through the grid and solar mini-grid electrification system, the study was undertaken in two phases at the two selected villages of Gaya district. In phase – I (24th Dec 2017 to 26th March 2018), field visits were conducted in all four villages and we gathered information related to socio-economic development which accompanied with solar mini-grid installation and grid connection. In phase – II we re-visited the mini-grid connected villages after they were connected through the grid and examined costs and benefits of the grid connection (Badil Bigha on 14th November 2018 and Basha Pipra on 14th April 2019). During the phase –I, a questionnaire-based survey was carried among the beneficiary households. Besides, we have done two Focus Group Discussions (FDG) with the members and officials of JEEVIKA. We also interviewed the technicians and program coordinator of the mini-grid system. A semi-structured questionnaire-based survey was done in all the four villages. We interviewed a total of 165 households, 50 from each of the two mini-grid villages and 65 households from two grid-connected villages. During the survey, we have enquired about the reliability, quality, and affordability of the electricity through solar mini-grid and grid. Both male and female respondents were selected; we employed a simple random sampling technique. In the second phase, we mostly carried qualitative interviews with selected respondents from Badil Bigha and Basha Pipra. In total, we carried out 40 interviews in this phase.

Initially, the study examined the changes in socio-economic conditions with access to electricity in our study area. Badil Bigha and Basha Pipra were not connected to the main grid (the nearest grid-connected village is approximately 10 km far) and considered for the mini-grid installation. Whereas Mahadevpur and Pilkhi are located very close to Rajgir Town and connected to the main grid.

The mean monthly income of the grid-connected villages is 50 percent higher than that of villages connected with mini-grid (Table 11.5). During our visit to grid-connected villages, we have observed several home-based business activities; approximately 25% of the respondents have mentioned that they have a home-based business, and nearly 60% of the respondents earn their income through daily labour. These villages receive approximately 22 hours/day of electricity supply during winter and 18 hours/day in summer. Similar observations are made in other grid-connected villages in Bihar (Jain et al. 2018; Rockefeller Foundation 2019). Although the villages have access to electricity through the grid, there is dissatisfaction among the respondents regarding the peak hour supply and the unit charge of the electricity. Currently, distribution companies in Bihar have a minimum tariff of six rupees per unit (1kWh), which is higher than other states of India[2].

In villages connected through mini-grid, we found that approximately seven hours of electricity supply is provided in summer (6 PM to 1 AM) and 10 hours in winter (6 PM to 4 AM). The increase in electricity duration for the households in the winter was due to less consumption of electricity. Approximately 65% of respondents surveyed expressed that the electricity supply through mini-grid supports their basic needs (provide lighting during the evening hours) whereas others felt that capacity of the solar mini-grid is low and hence it is not able to meet all their

[2] https://www.bijlibachao.com/news/domestic-electricity-lt-tariff-slabs-and-rates-for-all-states-in-india-in.html#bihar

Table 11.5 Electricity Supply and Usages in the Study Area

	Badil Bigha	*Basha Pipra*	*Mahadevpur*	*Pilkhi*
Number of respondents	50	50	15	50
Mean Household size	8	11	7	9
Mean monthly Income	INR 3900	3310	5500	5200
Hours of Electricity Supply[a] Winter Summer	Solar Mini-grid (12KW) 10 hrs 7 hrs	Solar Mini-grid (30KW) 10 hrs 5 hrs	Grid 22 hrs 18 hrs	Grid 22 hrs 18 hrs
Peak Hour Electricity (6 PM to 11 PM) in Summer	Yes	Yes	No	No
Electric Appliances	5 W LED bulbs one 20 W DC fan one 5 W Solar lantern with mobile charging point	5 W LED bulbs one 20 W DC fan one 5 W Solar lantern with mobile charging point	No restriction: Bulbs, Fans, TV, refrigerator, iron box etc.	No restriction: Bulbs, Fans, TV, refrigerator, iron box etc.
Monthly Electricity Consumption[b]	10–15kWh	7.5–15kWh	40–100kWh	40–100kWh
Monthly Expenditure[c]	INR 50	No expenditure	INR 240–700	INR 240–700

Source: Authors assessment

Note:[a] In mini-grid villages, electricity supply in winter: 6 PM to 4 AM and summer: 6 PM to 11 PM
[b]Maximum monthly electricity consumption was calculated in the following way: (two 5 W LED+ 20 W Fan + 5 W Lantern)*10 hrs *30 days; for Grid-connected villages, monthly bills were considered
[c]Beneficiaries in Badil Bigha charged a monthly maintenance charge of INR 50, whereas in Basha Pipra, there were no monthly charges

requirements. Even with these limitations, we found certain changes in the socio-economic conditions of these villages. Our study found similar benefits with mini-grid installation (Palit and Chaurey 2011; Thomas and Urpelainen 2018) such as an increase in the income and savings, extended study hours for children, and safety during the night hours.

11.3.2.2 Impact on Household Income, Education and Access to Other Services

The primary occupation of the households surveyed in the two villages is largely agriculture (53%) followed by small businesses (29%) such as grocery shops, herbal shops, rice mills, husking units, tailoring shops, tea stalls, small eateries etc. Opening hours of their shops got extended till 9 PM. Earlier it used to be closed by 5:30 or 6 PM. In other words, due to mini-grid, their business hours have increased. One of the respondent from Bahsa Pipra mentioned that,

> "After the solar electrification I open my shop till 8:30 PM which earlier used to close at 5:30 PM due to darkness and it was difficult to run the shop on a kerosene lamp, I feel empowered after coming of electricity". (Usha Devi runs a grocery shop at Bahsa Pipra village)

Similarly, another respondent from Badil Bigha stated that,

> "The earnings have increased from earlier, as I can work for more hours on tailoring than before, as it was difficult to do stitching in insufficient light". (Manoj Kumar, Badil Bigha Village')

Although the villagers could benefit from extended business hours, our study could not capture the increase in income as they were unable to provide information about extra income. So, to quantify the benefits, we calculated the extra income/savings gained by foregone cost on kerosene, dry-cell batteries, mobile charging etc. Before these two villages were electrified through solar, the villagers largely depended on kerosene for the source of lighting. The average monthly kerosene consumption of the household was about five to seven litres. They used to receive two litres from the public distribution system (PDS) on a subsidised rate of INR 12/litre and remaining from the private market for INR 60 to 70/litre. The study has observed that with the solar mini-grid, the kerosene consumption has reduced to one to two litres. On average the monthly saving from kerosene is approximately INR 278 to 325.

Earlier villagers use to travel 8–10 km (nearest market) and spend around five to ten rupees for charging mobile. Usually, every person used to get it charged three to four times per week. Along with LED bulbs and fans, the beneficiaries also received a solar lantern with a mobile charging point. With the solar lantern, the usage of batteries and cost for mobile charging was eliminated. The estimated household monthly saving on mobile charging through solar lantern is about INR 171 to 339 in Badil Bigha and INR 214 to 427 in Bahsa Pipra, the evidence from the literature also reflects that the Solar Home Lighting System (SHLS) has improved the daily needs of the household like mobile charging for which they had to travel earlier to far distances and to pay an amount of INR 10 for one-time charging (Barman et al. 2017). Similarly, the study also observed that villagers save an average of INR 114 to 199 per month from buying batteries and candles. It shows that access to electricity is one of the substitutes for all these expenses. The average monthly households savings in Badil Bigha were in the range of INR 645 and INR 986. In Bahsa Pipra savings were estimated in the range of INR 705 to 1111. Given a mean monthly income of the households of the two villages (see Table 11.5), the savings due to mini-grid can add to their monthly income by 20 percent to 30 percent. Interestingly, these savings are not directly observed by the respondents.

Villagers have expressed that with reliable electricity supply from solar mini-grid, their children's study hours have extended by 2–3 hours. Better quality of light does not stress the eyes of children studying in the evening hours anymore. A large number of respondents revealed that access to electricity had enhanced access to media. As electricity has the potential to boost the level of information in a community that resides in remote areas. Electricity becomes the utmost importance as modern information is circulated through an electronic medium. After the installation of solar mini-grids, streetlights were provided in both the villages. It enhanced the mobility of the inhabitants in the night. During the focused group discussion, some of the beneficiaries shared their experience as: "Our village is scattered in three settlements, earlier it was quite unsafe to go out in the evening, it used to be pitch dark, but after the installation of street lights, we are not in tension even if our children are playing outside. The incidence of snakebite has reduced in the community due to sufficient light".

11.3.2.3 Energy for All: Mini-Grid to Main Grid

In the Phase-I, the study identified the socio-economic changes brought through the solar mini-grid project. However, we also found that the beneficiaries of the project were not completely satisfied with solar mini-grid. The primary concern was that of the inadequate amount of electricity supply. Once they got electricity connection, the villagers wished to use more electric appliances; however, electricity provided through mini-grid was only enough to fulfil their basic power requirements. Under the Bihar Governments program Har Ghar Bijli scheme, these two villages were connected to the main grid in August 2018. We revisited both the villages after grid connection i.e. in November 2018 and April 2019.

During the visit in November 2018, we found that solar mini-grid systems in both the villages became almost dysfunctional. The major disruption that changed the energy access pattern was the introduction of the grid connection. The main grid connection provided adequate access to energy and villagers were able to use electric appliances like TV, refrigerator, fans etc. The complaint regarding the inadequacy of electricity supply from solar mini-grid was resolved after the connection with the main grid. Connectivity with central grid has been cited as a major barrier for the spread of solar mini-grids in India (Bernard et al. 2018; Comello et al. 2017; Sharma 2020).

In Basha Pirpa and Badil Bigha, the solar mini-grid failed to emerge as a successful electricity generation and distribution model. In Badil Bigha, village's entire 12 KW solar mini-grid with 40 solar panels were installed on the rooftop of government buildings. The operation and maintenance of the solar mini-grid were with the village women community (JEEVIKA group). In Basha Pipra, 30KW with 100 panels was installed on three different private buildings. The project implementers invited the women community to manage the operation of the mini-grid. However, owners of the private buildings where the solar panels were installed did not let the women group involved in operation. Although the project was funded as part of CSR activity, due to lack of involvement of all the stakeholders, private building owners had emerged as mediators regulating the distribution and use of electricity. They patronised the other beneficiaries. It has eroded the trust of other members on this project. Rather than emerging as a public system taking care of the electricity needs of the whole community, it remained a semi-private enterprise for the selected households in Basha Pipra. The selection of sites for installing solar panels in mini-grids thus have strategic value and if wider community interests are not considered than it can put the future of the project at peril.

To monitor the electricity consumption among the beneficiaries through mini- grid system, a metering system was installed at the household level. A maximum user charge of INR 105 and certain fixed units were allocated to each beneficiary. A delay in installing individual meters during the initial phase of the project (between August 2018 and November 2018) also shaped their response towards the mini-grid. Many of the beneficiaries felt that it is a government-funded project and does not require any financial contribution from the beneficiaries. Even, overall, the maintenance of the meters was not properly carried out and it mostly remained dysfunctional. Another group of villagers considered the user charges beyond their reach. In the Badil Bigha, the beneficiaries were paying a monthly maintenance charge of INR 50 (an amount of INR 50,000 was collected when the solar mini-grid was operational), whereas in Basha Pipra, beneficiaries did not pay any amount for maintenance or user charges. There was another group, which availed the mini-grid connection but never contributed for maintenance or paid the user charges. After the connection with the main grid, the villagers started using energy-consuming incandescent bulbs over CFL or LED (due to price difference and availability) and many other electric and electronic appliances. This was the phase when they completely neglected the mini-grid.

We again visited these villages in April 2019 and interacted with households who were interviewed in November 2018. This time, we have witnessed that villagers were un-happy with the central grid connection. The prime concern was the user charges. The beneficiaries were asked to pay electricity bills from the day they got connected with the main grid. The bill amount of the household ranged from INR 300–700, which accounts for 10–30 percent of their income. Although they benefited in terms of electricity access and savings on kerosene and other benefits. Nevertheless, many of the villagers found it difficult to cope with the new practice of paying the electricity bills. Some of the villagers were reluctant to pay the bills and wanted to go back to the old system (solar mini-grid). However, by this time, none of the mini-grid remained functional. In the case of Badil Bigha, villagers were willing to fix the battery system with the maintenance money (about INR 50,000) that was collected earlier when the mini-grid was functional. Whereas in Bahsa Pipra, as no monthly charges were collected there was no corpus amount available to get the mini-grid fixed. Moreover, as all the panels were installed on private buildings in Bahsa Pipra, the community mobilisation remained absent. Private owners continued to use the solar panels for their own purpose.

11.4 Conclusion and Recommendations

Mini-grids are being discussed as a potential alternative for providing electricity access to millions of people, especially in the developing world. The issue holds relevance for many Asian countries. Our research intends to highlight some important learning for Asian economies through a case study of two Indian villages. The gap in policies and regulations along with weak institutional support, lack of operation and maintenance after deployment, community ownership, adaptability for new technology, and uncertainty due to future grid extensions, are some of the significant challenges faced by developers of mini-grids in Asia. Hence, to address these challenges and for sustainable deployment of mini-grids, an appropriate institutional arrangement and overall capacity building is required. Overall, the study offers the following recommendations:

As private developers are involved in the deployment of mini-grids, governments should make predictable grid expansion plans to protect the investment in mini-grids and its full utilisation. Tariffs should be fixed for end users in such a way that the revenue from mini-grids projects could be viable. The paying capacity of rural communities especially from the marginalised communities is quite low in many parts of developing Asia. PAYG (Pay-as-you-go) financing payment model could be employed for enabling easy adoption of mini-grids without burdening the consumers with the up-front cost. Even then, the initial investment needs to be supported by governments, multilateral agencies, or corporates. Currently, the mini-grids are designed for meeting the basic requirements, increasing the capacity to support the additional demand would allow users to continue relying on mini-grids. In our case, in one of the villages, the solar mini-grid was completely abandoned, whereas, in the other, after the connection with central grid it was partially abandoned. In the second village, people were interested in fixing the mini-grid and using it as complementary to the central grid during the peak hours.

Reliable, adequate and continuous access to energy is still a big challenge in many parts of rural India (Aklin et al. 2017; Barman et al. 2017; Jain et al. 2018; Rockefeller Foundation 2019), as well as rural Asia. In such situation, solar mini-grids can play a significant role in providing universal access to reliable energy. In other words, mini-grids and the main grid can complement each other in providing access to electricity. Once the physical interconnection takes place, different buy and sell transactions between the two delivery technologies can lead to more reliable and less expensive electricity for consumers (Bernard et al. 2018). Community engagement is the key to the success of any off-grid energy project. It has been seen in the past that in the absence of community involvement, such projects do not sustain in the long run (Sharma 2020). Our study, further corroborates this weak link. Local capacity building with an appropriate ownership model and management would enhance the economic benefits and utilisation of mini-grids.

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