MSc Program
Environmental Technology & International Affairs

Rural Electrification in India by Solar Photovoltaic Technologies : Analysis of Case Studies, Incentives and Cost, and Future Direction

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Em.Prof. Dr. Günther Brauner

Syreel Mishra

1528139

Vienna, 27 May 2017

Affidavit

I, **SYREEL MISHRA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "RURAL ELECTRIFICATION IN INDIA BY SOLAR PHOTOVOLTAIC TECHNOLOGIES: ANALYSIS OF CASE STUDIES, INCENTIVES AND COST, AND FUTURE DIRECTION", 87 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 27.05.2017

Signature

Abstract

Around a third of the rural population in India are un-electrified or have unreliable access to power. The power sector in India is currently heavily dependent on non-renewable sources of energy such as coal. However, as this practice is un-sustainable, India is seeking to move on the development path of employing more renewable energy sources in power generation. India understands the global efforts needed to combat the negative effects of climate change, greenhouse gases, and exhaustible fossil fuels and aims to encourage the use of clean energy in India through subsidies, targeted policy changes, incentives and initiatives. The paper highlights the efforts of the Indian government, in spheres of program initiation, financial incentives and subsidies, R&D and training. The Jawaharlal Nehru National Solar Mission (JNNSM) has been explained in great detail in this paper. All the case studies, presented in this paper, have been implemented with government incentives and also with the involvement of the private sector. Solar photovoltaic (PV) systems have been successfully used for rural electrification programmes, all around the world. The paper presents information on minigrids, microgrids, hybrid power systems and solar home lighting systems. In India, with its great solar potential and Governmental support and initiatives in rural electrification programmes through renewable sources of energy, solar energy has been gaining momentum. With the downward trend in PV cost, developments of efficient appliances, and encouragement of cost-effective strategies, PV systems have become economically attractive to the rural districts. However, there are still some villages, that have no access to power, that continue to use kerosene for lighting. The trend of kerosene use in rural India has been illustrated through case studies. These systems have also imparted many positive impacts in the lives of the rural community. In spite of all the positives, there are still some challenges that limit these systems from reaching their full potential. The paper enumerates recommendations on how to overcome these hurdles and takes a look at the future direction that solar energy can take in Indian rural electrification programmes.

Table of Contents

List of Abbreviations

AC	Alternating Current
CFL	Compact Fluorescent Lamp
DC	Direct Current
ESCO	Energy Service Company
FDG	Focus Discussion Group
GW	Gigawatt
IREDA	Indian Renewable Energy Development Agency
JKPDC	Jammu and Kashmir Power Development Corporation
JKPDD	Jammu and Kashmir Power Development Department
JNNSM	Jawaharlal Nehru National Solar Mission
kW	Kilowatt
kWh	Kilowatt per hour
kWp	Kilowatt per peak
LAHDC	Ladakh Autonomous Hill Development Council
LeDG	Ladakh Ecological Development Group
LREDA	Ladakh Renewable Energy Development Agency
MOU	Memorandum of Understanding
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MWh	Megawatt per hour
NABARD	National Bank for Agricultural and Rural Development
NREL	National Renewable Energy Laboratory
O&M	Operations and maintenance
PV	Photovoltaic
PPP	Private Public Partnership
REC	Rural Electrification Corporation
RVEP	Remote Village Electrification Programme
RGGVY	Rajiv Ghandi Grameen Vikas Yojana
SELCO	Solar Electric Light Company
SHS	Solar Home Systems
SPV	Solar photovoltaic

T&D	Transmission and distribution
UN	United Nations
WHO	World Health Organization
Wp	Watt per peak

Acknowledgements

Foremost, I would like to express my sincere gratitude to my supervisor, Professor Dr. Günther Brauner, for his continuous support, immense knowledge and guidance. With his guidance and motivation, I was able to construct and write my thesis efficiently and with great diligence.

Besides my supervisor, I would also like to thank Professor Dr. Hans Puxbaum for his encouragement and motivation. I thank him for all his insightful comments during the Master Thesis presentations, which enabled me to think further about my thesis and helped me strengthen my work.

Furthermore, I would like to thank all my professors at the Vienna University of Technology for teaching me and opening up to me, an entire world of environmental technology. This year has been an enriching experience for me, educationally and personally.

Last but definitely not the least, I would like to thank my dad and mom. For everything. For their constant support, guidance, love, and belief in me. I am where I am because of them. Thank you.

I. Introduction

As India seeks to alleviate poverty and improve the living conditions of its rural population through socio-economic development, rural electrification is an important aspect and way to achieve that goal. Though a majority of Indian population lives in villages, for the social and economic growth of villages, energy has not played an important role so far. Some steps have been taken in association with the Rural Electric Corporation, State Electricity Boards (Kamalapur and Udaykumar, 2011, 596). Some Reforms in Power sector have also been undertaken. However, there is a large gap between energy demand and supply due to the increasing population. To meet the difference in demand conventional supply from grid is not enough and some alternative source need to be found (1). India is the second populous country in the world, with a majority of its population living in rural areas. India is also one of the fastest growing economies in the world and ranks No. 6 in the total consumption of energy, worldwide.

As the population of India grows and the villages become more populated, India is facing a rapid depletion of rural energy resources. The Government of India, with its Jawaharlal Nehru National Solar Mission (JNNSM) established on January 11, 2010, has stressed the importance of rural electrification. The lack of electricity in many villages is associated with socioeconomic and technical problems. The JNNSM aims to set reforms to the power sector of India, leading to a reduction in T & D losses and restructuring to meet the electricity needs of the rural population of India (Kamalapur, 2015).

As per the Sustainable Development Goals adopted in September 2015, access to basic electricity for the entire population is an important goal. In this regard, India is making striding efforts through its rural electrification and renewable energy electrification programmes. India has more than 300 million of its population living in rural districts, and some of them live without any electricity. That means one in every four people who do not have off-grid power access belong to India and this figure is higher than in any other country (Pearce, 2016).

Since 1960s when the issue of rural electrification was first raised, little has changed as no great visible improvement has been observed (Campen, Bart Van, et al, 2000, 1). Traditional sources of energy such as wood, biomass residues and both human and animal power are still the prime sources of energy for millions of rural households. In order to bring the issue of rural electrification to the forefront, various international forums have taken initiatives. The 1992 UN Conference on Environment and Development in its Agenda 21 has called for a "Rural Energy Transition". Food and Agricultural Organization (FAO) was tasked with Chapter 14 which deals with Sustainable Agriculture and Rural Development (SARD) through improvement of socio-economic conditions of rural people by "increased productivity and income generation” (1).

In recent years, PV has established itself as the potential technology to fulfill the requirements of rural electrification and to meet the basic needs of rural population of developing countries. Photovoltaic systems are now capable of being connected to bigger rural electrification programmes around the world. Overall, it can be said that PV technology is arriving at a mature state and the growing investments in new power generation units is bound to create a reduction in prices and increase competitiveness (1).

Besides providing electricity to a large number of rural population, the challenges of rural electrification are compounded because of following reasons (4):

- Potential customers with low requirements of electricity are dispersed
- Concentration of high demand of electricity during a short period of the day, which is afternoon hours. This leads to relative high peak capacity and low load factors
- Low purchasing power of consumers with regard to costs on account of energy and appliances
- Billing, servicing and maintenance circumstances tend to be difficult

Due to aforementioned reasons, rural electrification in many cases is not financially attractive investments and therefore grant subsidies by government are required. The objective of the Jawaharlal Nehru National Solar Mission (JNNSM), initiated by the Government of India under the Ministry of New and Renewable Energy, is to popularize renewable energy systems, including PV systems, through provision of various incentives (4).

India is now emerging as a major global power. But it faces a number of challenges in connection with development and poverty eradication (Buluswar, Shashi, et al, 2016, 5). Around 300 million people in India do not have electricity and it is a major challenge for India to provide them the basic electricity (International Energy Agency, 2015). Most of these rural populations are either totally out of reach of the main grid or have only a token access with which very little electricity flows into their households. As illustrated in Figure 1, in states like Bihar, Odisha, Uttar Pradesh and Jharkhand this problem is very acute where there are large concentrations of poverty in rural population (Government of India, 2011 Census).

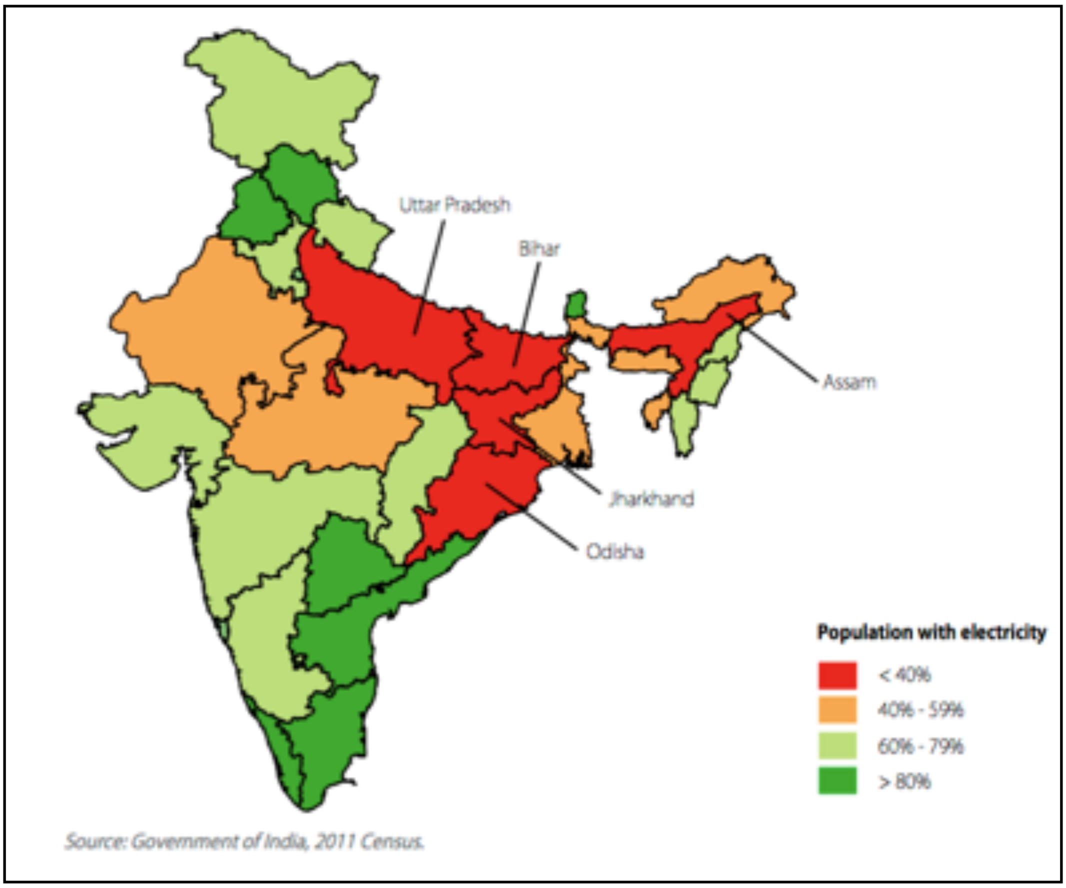


Figure 1: Majority of Indians lack access to power.

In this paper, the question that has been investigated is: To what extent have the rural electrification programmes in India improved the socio-economic conditions of its rural population and what have been the impacts of those programmes? The focus has been given to solar photovoltaic technologies. First, the current energy scenario and the solar potential of India are examined. An overview of the current rural electrification programmes and applications have been listed. Secondly, a detailed profile and technical explanation of minigrid and microgrid technologies will also be examined. The paper will analyze and investigate four case studies, each highlighting a specific PV technology (minigrids, hybrid power systems, solar home lighting systems and other PV decentralized systems). Each case study has been chosen to portray the variety of PV technologies used to electrify rural districts. The impacts of the programmes on kerosene consumption, education, living standards, income and gender roles is analyzed. The case studies cover over 9 rural districts and villages across India, all from different geographical locations. The aim of the paper is to investigate the current impact and work of the rural electrification programmes and to explore the future scope of the programmes by looking at government incentives, costs and investments. At the end, recommendations for improvement of the programmes and government policies have been enumerated.

II. Rural Electrification in India

2.1 Programmes in India (Government of India)

The former Prime Minister of India, Dr. Manmohan Singh, initiated the Jawaharlal Nehru National Solar Mission (JNNSM) on January 11, 2010. By 2022, the target is to have 2 GW of grid connected solar systems and to reduce the solar energy generation cost by means of long-term policy frameworks, installation goals in large scale, emphasis on R&D, in-house manufacturing of components, raw materials (Government of India, 2017).

The JNNSM seeks to make India an international leader in harnessing solar energy. The Mission aims to develop and establish suitable policy conditions for solar energy to become a widespread and acceptable form of energy countrywide. In order to accomplish this objective, the JNNSM has adopted a plan with 3 phases, as illustrated in Table 1 (Government of India, 2017). Phase 1 sought to harness the easier solar projects. For example, some of the Phase 1 projects included the promotion of off-grid solar systems to provide rural electrification and increasing the capacity of the grid systems to a suitable amount. Phase 2, from 2013-2017, includes the 11th Plan and the initial year of the 12th plan. In contrast to the modest capacity increase in Phase 1, the main target of Phase 2 was to increase the capacity of the solar systems to a bigger amount. The objective was to establish suitable conditions for increasing the capacity and increase the competitiveness of the solar energy distribution from both the centralized and decentralized zones. Phase 3, from 2017-2022, includes the 13th plan (Government of India, 2017).

Table 1: 3 Phases of JNNSM

Segment	Target for Phase 1	Cumulative Target for Phase 2	Target for Phase 3
Utility Grid Power including rooftop	1,000-2,000 MW	4,000-10,000 MW	20,000 MW
Off-grid solar applications	200 MW	1000 MW	2000 MW
Solar collectors	7 million m2	15 million m2	20 million m2

A majority of the rural population, around 60 percent of India's total population, are predominantly dependent of fossil fuels and commercial sources of energy such as wood, kerosene and diesel (Thirumurthy, N., et al., 2012). They also do not have reliable access to energy and have many frequent interruptions in their electricity supply. The study examines the data of expenditure of 2012 and according to the data, the study estimates that the rural population spends around € 4.37 billion per annum on energy (Thirumurthy, N., et al., 2012). The government of India acknowledges the inter-relation between the nation's GDP growth, quality of living standards, and reliable supply of energy and it aims to energize the deployment and programmes for rural electrification.

Under the framework of the Jawaharlal Nehru National Solar Mission (JNNSM), the Ministry of New and Renewable Energy (MNRE) announced, on January 2010, its aim to deploy by 2022, 2 GW of off-grid solar systems and 20 GW of grid connected systems (Thirumurthy, N., et al., 2012). The current Prime Minister of India, Mr. Narendra Modi, has set a target of 175 GW energy from renewable energy sources including 100 GW of solar energy by 2022 from 20 GW of solar energy target set earlier (Prime Minister's Office, 2015). The goal of the Government of India is to invest in the abundant solar resources available in India and distributing the solar energy on a countrywide scale so that millions living in rural districts can enjoy modern energy. The Government of India realizes that access to reliable energy and electricity is a basic right and will elevate the living standards of the population living in rural areas. The Government of India has also been taking steps to make investments and development of clean and renewable energy projects in India more lucrative. For instance, they have been providing incentives for such renewable and clean energy projects, such as capital subsidies of around 90 percent, tax holidays, and loans with low interest rates. The Government hopes that all these incentives will boost the development of renewable energy projects in different corners of the country. During the 5 year plan (April 2012- March 2017), it was estimated that an investment of € 270-360 billion to meet the electricity demand of 1,400 billion kWh by the end of five year plan. An investment of € 3.96 billion was estimated to be required to meet the solar minigrid capacity target of 1,100 MW under the MNRE programme (Thirumurthy, N., et al., 2012).

By means of conventional grid extension, the government of India is doing the electrification of villages. However, as 25,000 villages are located in remote and difficult terrain, it has not been found possible to electrify them. Therefore the Ministry of New and Renewable Energy (MNRE) has introduced a programme called the 'Remote Village Electrification Programme (RVEP). Through this programme, the government plans to electrify the remote villages in all states through solar PV home lighting systems (Buragohain, Tarujyoti, 2012). However, the functioning of the system is not uniform in all the states but varies according to seasons. During rainy season when the solar radiation is limited, one light bulb can work only for 2-3 hours a day whereas in winter and summer, it can work for up to 4-5 hours a day. However the performance keeps on decreasing as years pass. It has been found that use of kerosene has reduced in rural areas. A survey observed that 37-78% of rural population said that their standard of living has increased and 53-69% said that their children's education has seen huge improvements (Buragohain, Tarujyoti, 2012). More time is now spent by the beneficiaries in activities to generate income and the rural crime rate has also gone down due to illumination of streets by the solar street lights.

The power sector reforms implemented by the Government of India, is as follows (Kamalapur, 2015, 9) :

i. Increase of IPP from 1% in 1990 to 16% in 2014
ii. Reduction in shortage of power to 11.7%
iii. Per capita electricity consumption increased from 238kWh in 1990 to 864 kWh in 2014
iv. Increase in cost of electrical energy (not considering system costs) from 0.015 €/kWh in 1992 to 0.056 €/kWh in 2014
v. Cost of power sector reforms has been estimated at € 85.5 billion.

2.2 Features and Current Scenario of Rural Electrification in India

Table 2: Electrification of Rural India	
Total Number of Villages	5,87,258
Villages Electrified	5,08,515
Villages to be Electrified	78, 743

(Source: Ministry of Power Report on 1/4/2015)

The following aspects have influenced the rural energy supply in India (Anantha and Chowhan, 1996):

1. While the gap of demand and supply is increasing, there is shortage of supply from commercial and traditional energy sources
2. Increasing population has put pressure on traditional fuel such as wood
3. It is alarming to note that there is increasing dependence on coal and fuel which is fast depleting
4. A transmission loss of 22.4 percent has been reported for electricity supply to rural areas. As mentioned in *The Economic Times* (2014), around one-third of the transmission loss is technical and the remaining loss is due to stealing or because of supply of power to farmers and households either free or at subsidized rates.

Some features of rural electrification highlighted by Kamalapur and Udaykumar (2011, 596), are as follows:

In India, 'Integrated Rural Development' is aimed at overall development of villages and rural electrification is an integral part. In comparison to urban development, rural development has received less attention because of following reasons,

1. Location of villages, such as most of the villages are 3 to 80 km or more, from the functioning grids
2. Many villages are in difficult terrain, forests, deserts or hilly areas
3. In India, out of total number of inhabited villages of 594,000, as many as 145,000 villages have population of 500 to 999 people, 130,000 villages have

population of 100 to 1999 people and 128,000 villages have 200 to 499 people. There are 3961 comparatively large villages with population of 10,000 people or more. (Census of India, 2011) .

The Government of India has identified the importance of rural electrification policy (Ministry of Power, India). Electricity is recognized as a basic human requirement and it is essential for economic growth, employment generation, poverty alleviation and human development in villages. In India a large percentage of rural people, around 21% do not have electricity and they meet their energy needs by means of wood, animal dung and agricultural leftovers (Kamalapur and Udaykumar, 2011, 597). Private companies like Tata BP Solar, Orb Solar, Emerson, Wipro Eco Energy and Kotak Urja are working towards rural electrification. Other companies which are working in this area are Azure Power, SunEdition, Solar Semiconductor and Solar Infra, Mera Gao Power and Minda Group (Thirumurthy, N., et al., 2012 9).

There are characteristic features of the rural loads in India which have been highlighted by Dr. Gopalkrishna Kamalapur (2015). The loads are dispersed with voltages lines that are long and medium. The rural areas also experience unreliable supply for about 6-8 hours a day, with phase imbalances. For one village, the average load is 5 kW to 25 kW with a 0.2 load factor. The grids are weak and characterized by high peak loads and low load factors as a result of increased domestic consumption in the form of lighting, agricultural and industrial activities. The power quality is also low with low voltage and frequent fluctuations. These fluctuations in electricity are experienced by consumers in the domestic, agricultural and industrial sectors. In India, farmers prefer water pumps with higher capacity and the use of phase convertors and capacitors. This, however, results in increased consumption of energy.

The current energy scenario in rural India consists of non-commercial sources of energy such as firewood, cattle dung, and agricultural waste. Firewood is the main source of energy in rural districts and it accounts for approximately two-thirds of the non-commercial source of energy. In rural homes, energy for cooking and heating purposes is supplied by fuelwood, cattle dung, and biomass. These are some major traditional sources of energy in rural homes today. Biomass consists of agricultural residue, fuel-stick and various types of low thermal sources of energy. Most of the villagers depend on tree branches and twigs from their agricultural lands. Sometimes they have to spend around 3-4 hours a day looking for these sources of energy (Garg, 2015).

In India, modern types of fuel and energy sources are also employed, such as kerosene, diesel oil, electricity, petroleum, and biogas. They are known as commercial sources of energy. In rural India, kerosene is widely used for lighting. Approximately 4 to 5 liters of kerosene per month is needed for every single household (Garg, 2015). Diesel is another source that has been used. It is used for irrigation pumps, agricultural machines such as tractors and vehicles for transporting harvest projects and fertilizers to the urban markets and vice versa.

India has become economically stronger and made huge developments in electrification, over the last two decades (Buluswar, Shashi, et al., 2016, 6). Compared to 50 percent electrification in 1990, the current rate of electrification in India is around 80 percent. The Deendayal Upadhyaya Gram Jyoti Yojana initiative of the Government of India seeks to improve and boost the rural electrification programmes in India (Government of India, Deendayal Upadhyaya Gram Jyoti Yojana). In the past, majority of the electrification in rural districts was achieved through hydropower plants, coal and natural gas; they still are the main source of power in some villages (India Central Electricity Authority, 2015), as illustrated in Figure 2. With the intention of reducing the impacts of climate change, the Government of India has announced that it is planning to develop 175 GW of renewable energy by 2022 (Buluswar, Shashi, et al., 2016, 6). The government has also added, that it plans to have 40 percent of its energy come from renewable sources and other low-carbon clean alternatives by 2030. If the Government is successful in fulfilling these targets then it will not only benefit the environment and climate, but also improve the status of electrification in India (7).

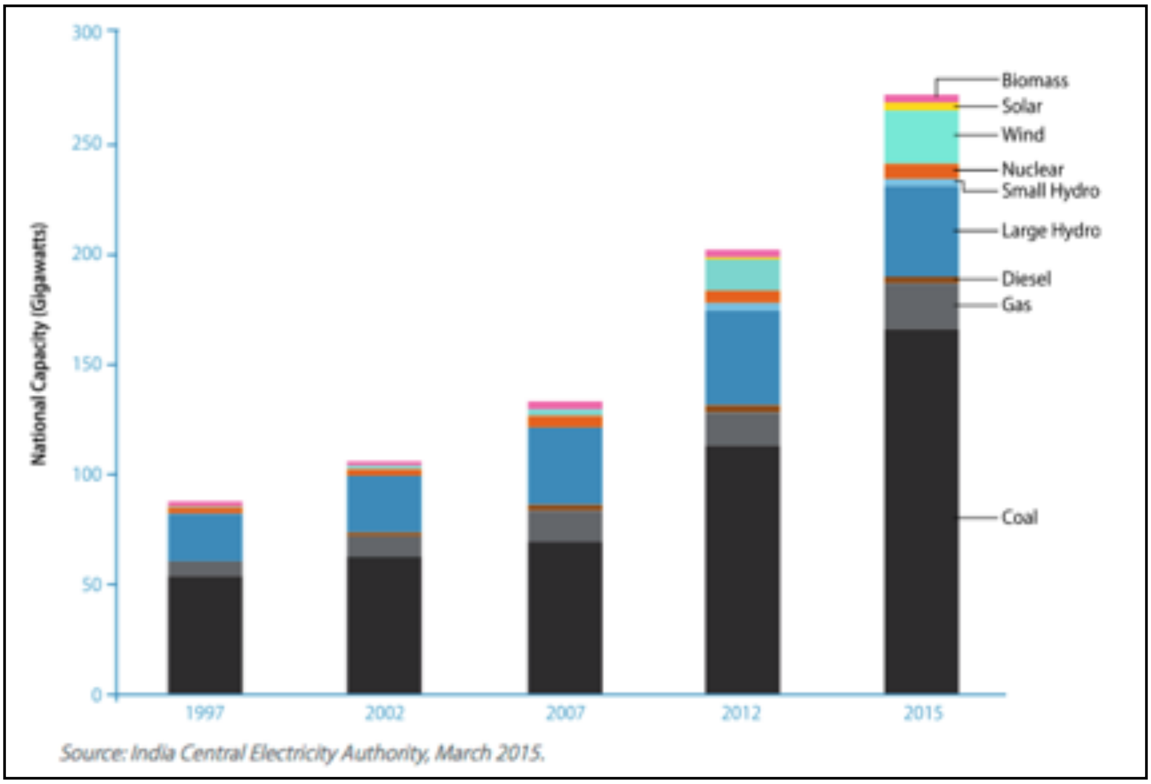


Figure 2: Electrification in rural districts

2.3 Photovoltaic Potential in India

India is a tropical country and solar energy best suits it. Other factors that makes India more suitable for solar power is (Kamalapur and Udaykumar, 2011, 598):

i. Sunshine is available for most of the year for about 300 to 320 days per year (Purohit at al, 2002). India receives around 5000 trillion kWh of solar energy per annum (MNES 2005).
ii. Reduction of cost of PV cell over the years
iii. Power is generated onsite and there is no loss of power on account of transmission and distribution
iv. Customer is the owner of the power production system
v. No cost on account of fuel
vi. In comparison to mini-grids, PV system has proximity to the utility as it can be installed on rooftop and power is generated on site

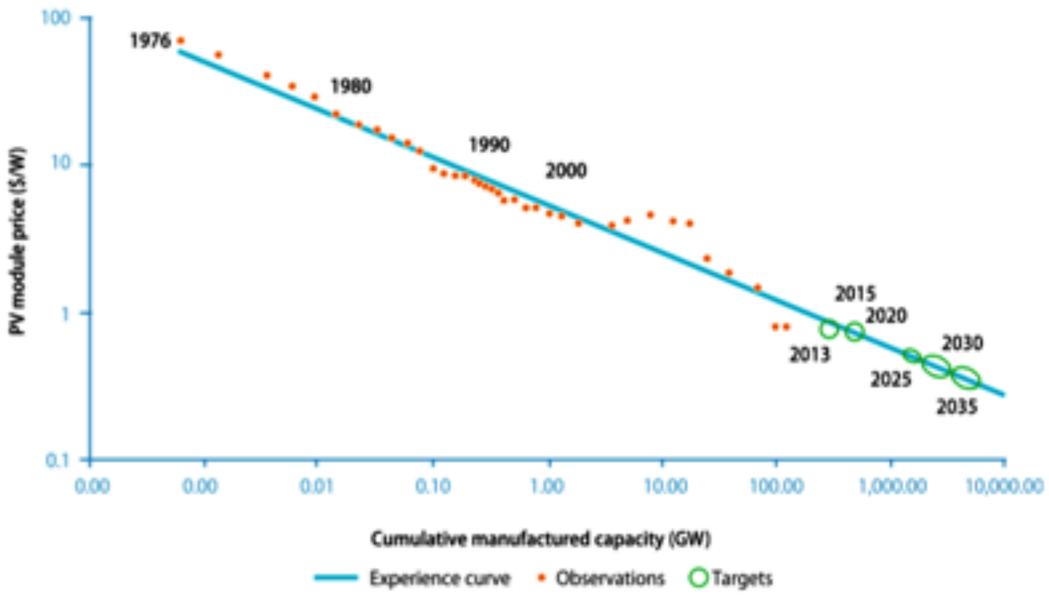
vii. For any part of India, the system is very suitable

viii. Technology of solar panel, battery and controller have been proven to be reliable

ix. With less maintenance, the solar PV systems last long

In India the dry and arid areas receive sunshine energy of 4 to 7 kWh per square meter per day and the availability potential of power is 20 MW per sq. km (599).

Though the national production is less than 4 percent, it has seen great development during the last few years (India Central Electricity Authority, 2015). The increase of solar power in India is due to the rapid fall in prices of the PV technologies, as illustrated in Figure 3. Besides the positive trend in PV technology prices, there are many other factors that play a key role in making PV energy a suitable energy source for rural electrification in India, such as (Buluswar, Shashi, et al., 2016, 9) :



Source: International Energy Agency, "IEA Technology Roadmap – Solar Photovoltaic Energy", 2014.

Figure 3: Price trend for PV systems

i. There is abundant sunlight throughout India. As illustrated in Figure 4, around 60% of India receives on an average per annum global irradiation of 5 kWh/

m2/day and this is enough for decentralized solar power (Ministry of New and Renewable Energy, 2010).

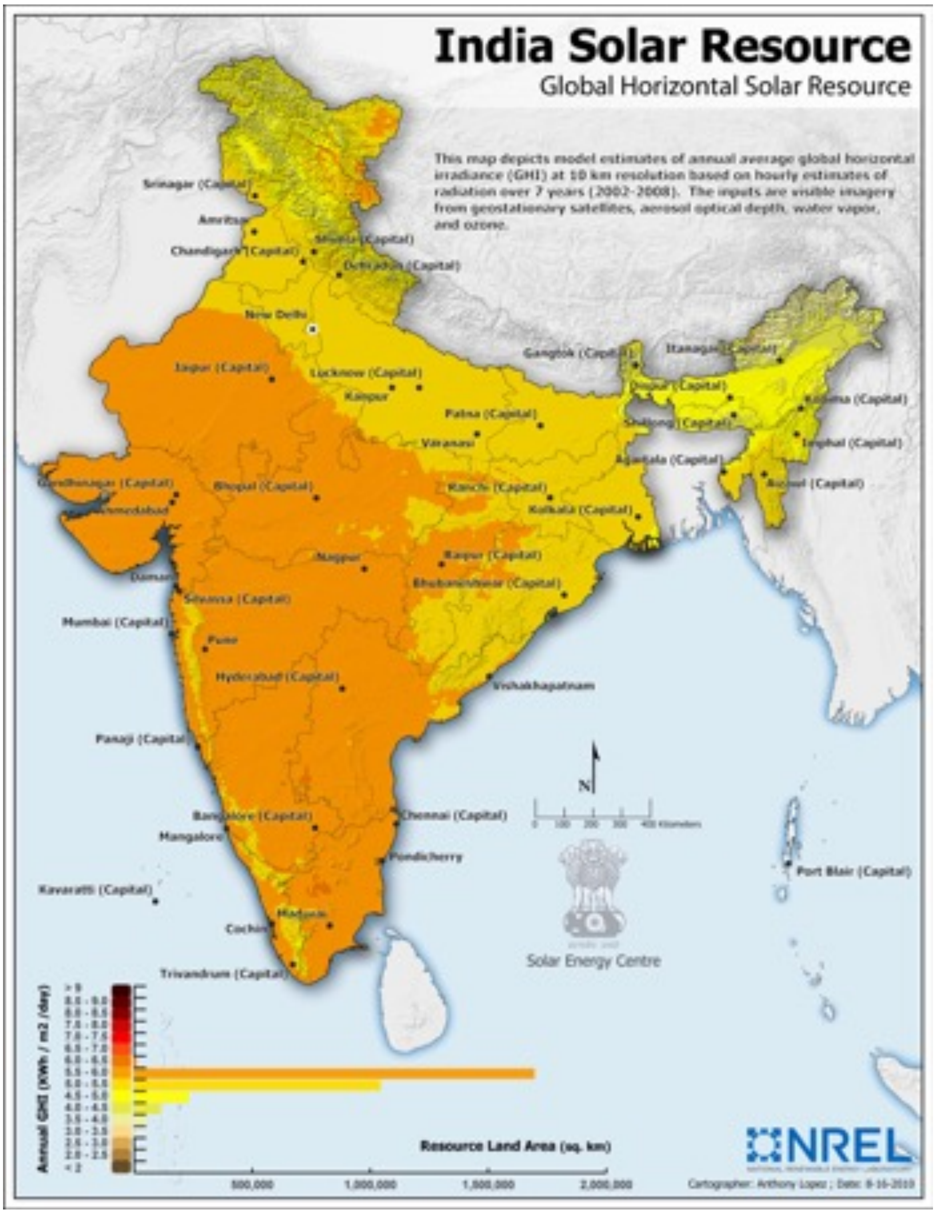


Figure 4: Annual Global Irradiance, *Source: NREL, 2010*

ii. Modular nature of solar systems aid to their installation. There is little maintenance requirement and its capacity can be increased when required (International Energy Agency, 2015).

iii. In the past, there were many technical obstacles that obstructed the development of distributed networks of solar systems and reduced the reach of solar energy to remote and rural districts. However, the market for solar energy has been rapidly growing due to technological advancements.

iv. India has many qualified manufacturers in their home-base who can produce the different components required in PV systems. After passage of time, when this market develops and grows, there will not be any obstacles to the setting up of and development of solar PV systems as the issue of availability of key components will not be an issue anymore. In the near future, rural India will be more than capable of conducting operational and maintenance activities on its own.

v. Policies developed by the Government of India, especially regarding solar power and other renewable energy technologies, has been promising. Investments have also been promoted. The Government of India has set a target of 100% electrification by the mid 2018 with an investment of € 1.12 billion. The states sponsored Decentralized Distributed Generation (DDG) scheme also provides additional incentives for solar PV (Government of India, Ministry of Power)

vi. India has numerous possibilities of utility in both the private sector and public sector. Furthermore, with PPPs, India has the possibility of developing solar mini-grids and rapidly electrifying rural districts.

2.4 Advantages of PV System

PV technology is the most environmental friendly, as the requirement is only sunlight as the fuel. Its modular design enables it to increase its capacity for meeting the additional demand. PV systems can be easily dismantled and can be reconfigured for other applications, besides it needs very less maintenance. The components of PV system can be made and assembled locally. Benefits of PV technology are, as follows (Kamalapur and Udaykumar, 2011, 599):

i. No emission of gaseous and liquid pollutants, therefore environmental friendly
ii. The system is easily transportable to remote areas and can be easily assembled and installed
iii. DC electricity is produced and can be stored in batteries

iv. No fuel and no noise

v. It is reliable, sustainable in all weather and with regular maintenance can last for 25 years

According to the grey energy content by production and energy mix of today, 0.7 kg of CO_2 is released for one kWh of solar power generated. So use of PV in high solar insolation areas can reduce CO_2 emission by 450 million metric tons in the next 25 years. It is estimated that emission of 10 tons of SO_2, 4 tons of NO and 0.7 tons of particulate matter into the atmosphere can be prevented with the production of each gigawatt of PV solar energy (599).

Some of the key advantages of decentralized solar energy are that there are no T&D losses and the customer is the owner of the system. It is also environment friendly with no fuel costs and pollutants. Solar energy can be used to produce DC electricity which can be stored in batteries. With proper maintenance, the solar energy system can have a lifetime of 25 years as it is robust, reliable and can withstand harsh weather conditions. Tropical India receives 5000 trillion kWh of sunlight in a year. If only 1 percent of this solar energy is converted into electricity, India will be able to meet its energy need (Kamalapur, 2015).

PV systems besides providing clean basic energy to rural population also help in maintaining a clean environment (Chaurey A, and Kandpal TC, 2010, 2273). Benefits of SHS and displacement of kerosene has been proved. 70 percent of the SHS have potentially reduced annual emission of more than 200 kg CO_2 per household (Kaufman R, et al., 2000 & Kandpal TC, et al., 2003, 64). Carbon reduction by use of renewable energy which also included use PV in India has been researched extensively. One such research assessed the reduction in CO_2 emission for PV pumps when diesel is substituted by electricity (Kumar A and Kandpal TC, 2007). Diffusion potential of PV pumps for irrigation in India has been analyzed by Purohit and Michaelowa (Purohit P and Michaelowa A, 2008), and a large amount of reduction in CO_2 emission has been established. CO_2 emissions reduction efficiency of SHS under CDM in India has been assessed on a macro scale and it was found that possibility of annual Carbon Emissions Reductions of SHS to arrive at a figure of 23 million tonnes is there (Chaurey A, and Kandpal TC, 2010, 2273). However with various government sponsored programmes, the use of PV technologies could bring about realistically an annual CER volume of 4 to 9 million tonnes by 2010 (Purohit P, 2009).

Energy Payback time (EPBT) and life cycle analysis (LCA) of PV technologies have been studied and a number of studies are now available besides the studies on its CO2 mitigation potential (Chaurey A, and Kandpal TC, 2010, 2273). Results from this analysis involved calculation of a panel of gross energy requirement (GER) of 1494 MJ and of a global warming potential (GWP) of 80 kilograms CO_2 equivalent per panel. It was found that even in the most adverse geographical conditions, the energy payback time was less than the panel operation time (2273). The photovoltaic energy production is beneficial to the environment is established by the results of the LCA. The technological advancement of in PV technology in the coming years is going to significantly decrease impact per kWh. This has been established by analysis done by Rauger and Frankl (2009). The GHG emission from generation of energy from a PV system is less than a quarter of that from an oil fueled steam turbine plant and 50 percent from a gas fueled cycle plant. This has been observed from the EPBT analysis of PV systems. From the perspective of GHG emission and cycle energy use, the PV system has been found to be a good option for power generation.

2.5 Storage capacity in rural electrification Programmes

A 'sizing curve' pertaining to storage capacity and generator rating has been generated using a methodology which is based on a time series simulation and has been presented in a recent paper (Chaurey A, and Kandpal TC, 2010, 2271). The speciality of this methodology is that for a specific site it identifies a 'design space' which takes account all possible system configurations that meet a given demand for that site. It also acts as a tool which optimizes the system (Arun P et al., 2007). By the use of same approach, the authors of the study have suggested a new methodology for optimal sizing of PV battery system for electrification in remote areas. This methodology also has taken into account the uncertainties involved with solar insolation. The sizing curve is a curve which relates various combinations of the photovoltaic array ratings and the minimum capacities of battery which can meet the specified load (Arun P et al, 2009). By the use of HOMER and through similar approach, trade-offs between load loss or capacity storage and unit cost of power for SHS has been presented. The study also mentions that different configurations of PV systems such as a combination of PV module and battery capabilities are possible to be used for various applications and various load patterns (Chaurey A and Kandpal TC, 2006).

Shaahid and El Amin (2009) have presented in their paper the techno-economical viability of hybrid PV-diesel-battery electricity systems in Saudi Arabia. An example of a hybrid power system being used to electricity rural districts in Uttar Pradesh, has been presented as a case study in this paper, in Chapter III. The paper mentions some of the benefits of hybrid systems, such as maximum load satisfaction, rate of high utilization of photovoltaic generation, minimum maintenance and optimum diesel efficiency, reliable electricity supply and meeting the peak loads. Importance has been given on fuel savings, percentage reduction in carbon emissions in different combinations like photovoltaic-diesel with storage and without storage as compared to only-diesel solution. Use of the hybrid system resulted in 24% reduction in carbon emission as compared to diesel-only systems (Chaurey A, and Kandpal TC, 2010, 2271).

Use of Compact Fluorescent Lamps (CFLs)and Light Emitting Diodes (LEDs) which consume less energy in solar lanterns has been explained in details to provide clean energy lighting the entire system g in LDCs and developing countries (Mukerjee AK, 2007). Mashelenia and Carelseb (1997) have highlighted in their paper the benefits of intelligent charge controller, like incorporating an SGS-Thompson micro-controller to increase the efficiency of a system and in case of automobile batteries to protect the storage.

2.6. Linkage between energy and poverty

Access of rural areas to electricity and its linkage to poverty alleviation has started to receive attention lately. However there is lack of research in this aspect and very little studies can be found. Poverty alleviation programmes so far have been based on income and employment generation, improved health care, drinking water supply but the programmes are yet to be linked to access of energy to the poor (Campen, 2000, 5). Various factors such as availability of credits and subsidies besides availability of PV systems on lease have contributed to some extent to the success of rural electrification. However, Cecelski (2000) feels that these measures are not enough because such measures can only bring about 50 percent to 75 percent of rural electrification and even the poorest section of people are less likely to benefit from this.

In contrast, there are also a number of studies that demonstrate that rural electrification is very important for any country that wants to develop socio-economically (Buragohain, 2012, 334). Many studies argue that there is a correlation between electrification and improvement in living standards in rural districts. In a study conducted by the World Bank where rural electrification in 11 countries was studied, it was concluded that rural electrification can lead to improved standard of living, better healthcare facilities, reduced kerosene consumption in domestic and market sectors, improved education and storage facilities such as operating refrigerators (World Bank, 2008). Without access to affordable electricity, improvements in healthcare, education, and alleviation of poverty would not be possible, as stated in a report by Global Network on Energy for Sustainable Development (2007). The Commission on Sustainable Development, in its 9th session in 2001, stated the importance of energy in attaining sustainable development (GNESD, 2007). From about 1.6 billion of global population living without power, around 80 percent are rural communities in developing nations in Latin American and South Asia (Buragohain, 2012, 334)

As most children in rural districts spend a majority of their time performing domestic activities during the day, they do not have power at night to study (334).

As will be illustrated in case studies presented later, a few hours of power during night time can significantly improve the rate of education and performance of students in rural areas (United Nations, 2005). Women also spend around 2-6 hours per day to collect wood for generating light in homes (Cabraal et al., 2005). With electricity, these rural districts can experience socio-economic benefits. The social and economic development of a country can be gauged from the rate of consumption of electricity of that country. In India, the per capita consumption of electricity is the lowest in the world (Buragohain, 2012, 335).

III. Impacts of Rural Electrification

The benefits of rural electrification will be quantifiable and non-quantifiable (Kamalapur, 2015), for example, quantifiable benefits such as cost saving and increased productivity. Children will be able to study during the evening and women will be able to take up work in the evenings as well. Rural electrification can have many uses in the commercial, agricultural and industrial sectors. Additionally, for example, non-quantifiable benefits such as modernization, improvement in quality of life, higher income and increased employment rates. The JNNSM aims to improve rural electrification in India so that the country can move forward together rather than leaving the rural population behind.

Ouwens (2006) explains how increasing the socio-economic status of women, renewable energy can play an important role. Without increasing the income of women it is not possible to improve their status in the society. Sustainable implementation of renewable energy system is a means to alleviate poverty (Buragohain, 2012, 335). Income generation which is the most vital can be achieved in a number of ways. There is a possibility to create small and medium enter prices through various activities. For example, women can collect oil seeds from plants and sell in the market. Women can also play an important role for processing of oil seeds to produce oil and to use oil to produce soaps. The relation between energy and Millennium Development Goals (MDGs) now the SDGs has been recognized by the international community (United Nations, 2003). The SDGs aim to gradually reduce the global population who are without electricity and are dependent on traditional solid fuel for cooking.

3.1 Case Study: Uttar Pradesh (Hybrid Power System)

Figure 5: Uttar Pradesh, India
(*Source: Google Images*)

Electricity is needed by people for every activity that they perform at their workplace, school, or home. As stated earlier, basic access to electricity can improve the standard of living in rural districts. This case study, presented by Mohibullah et al. (2014), analyses a hybrid power system using abundant natural resources to generate electricity for the western parts of Uttar Pradesh. The rural districts in this region are namely Aligarh, Harduaganj, Hathras, Sasni, Saatha and Baraithi. These districts are located in flat regions of Uttar Pradesh and the population density in these regions is 200 people per sq. km. Due to its topography, it was a challenging task to provide these areas with electricity (178). The case study presents a hybrid system utilizing wind, solar and biogas energy. It highlights its reliability and impact in Uttar Pradesh. It depicts its advantages to the villagers.

Usually, it is a challenge to electrify remote rural districts as extending the grids to such regions can be very expensive. The authors also state that, earlier it was even a challenge to provide electricity, in an economical and uninterrupted way, to charge phones, operate the television and light homes. The paper argues, that in order to ensure reliable supply of electricity in an economical way, especially to rural districts of India, the potential of renewable abundant resources must be tapped. Therefore, the authors agree that the hybrid system powered by wind, PV and biogas was the best way to electricity rural homes in Uttar Pradesh as it has the capability of providing cheap electricity to operate simple gadgets such as mobile phones, TV, and bulbs (Mohibullah et al., 2014, 178). An important point to note for the success of rural electrification programmes, the rural areas need to be 'self-sustaining'.

A set of data on solar radiation on hourly basis for one year was collected from the Aligarh Environmental office, located in the state of Uttar Pradesh. To find out the average annual irradiation, scaling of these data was done. Data on solar radiation, average wind speed and clearness index on the basis of latitude are at Table 3. Depending on the level of solar radiation, average radiation data on daily basis are available throughout the year and is shown in Figure 6[1]. It is observed that in summer, level of solar energy is higher than in winter and in rainy season, solar radiation availability and clearness index are less than in winter and summer (180).

[1] The data in this graph has been calculated on the basis of the Global Horizontal Radiation formula, whereby GHI = DHI + DNI * cos (Z), where Z is the solar zenith angle. From: http://rredc.nrel.gov/solar/glossary/gloss_g.html

Table 3: Average Data sets on rural village of Aligarh

Month	Wind Speed (m/sec)	Solar Radiation ($kWh/m^2/day$)	Clearness Index
Jan	1.800	725.000	80.20
Feb	2.100	780.000	79.457
Mar	2.200	800.000	92.540
Apr	2.400	830.000	49.263
May	2.700	875.000	86.598
Jun	3.000	880.000	72.196
Jul	3.200	860.000	76.861
Aug	2.800	700.000	96.524
Sep	2.300	825.000	80.62
Oct	1.900	830.000	74.33
Nov	1.700	780.000	78.95
Dec	1.650	740.000	85.23

Source: ICJSEE, Volume 2, Issue 4 (2014)

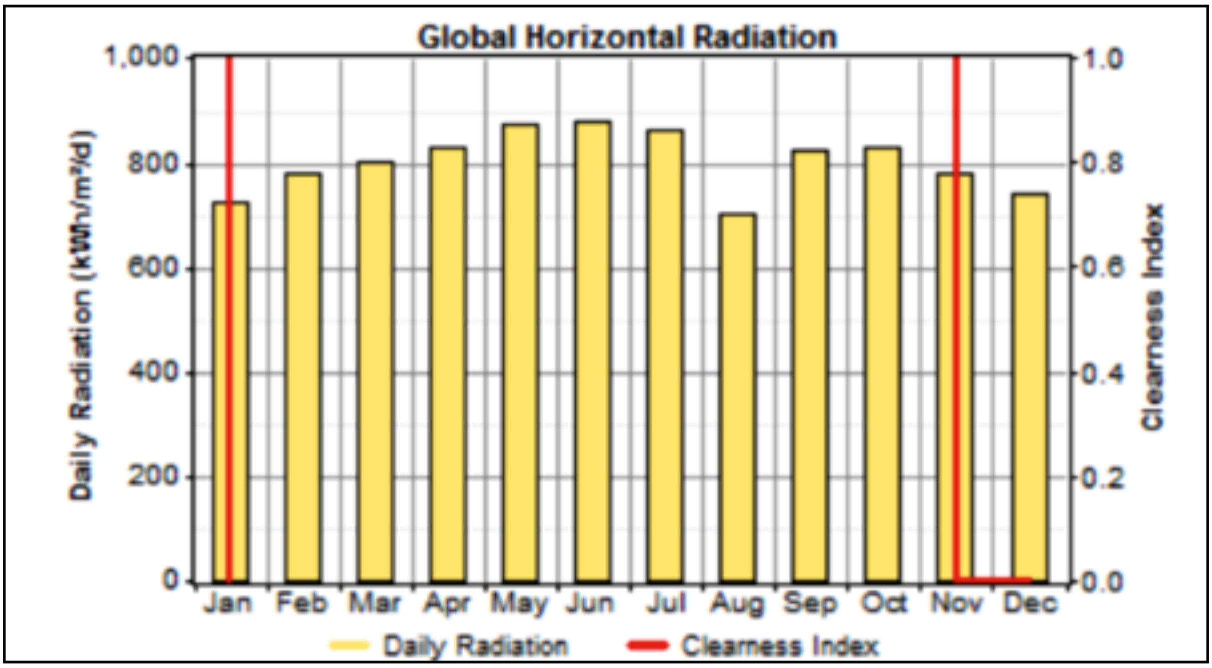


Figure 6: Average Daily Radiation per year
Source: ICJSEE, Volume 2, Issue 4 (2014)

As opposed to the grid power systems, hybrid power systems have greater net costs, however they incur less service and monitoring costs. In India, when power crisis starts, it deepens very quickly. In such a situation, alternative energy sources like solar, wind and biogas play an important role to mitigate the crisis. The price of transmission, installation and distribution processes have been decreasing to almost half. However, there has been a decrease in payback times on the investments on hybrid solar-biogas-wind systems due to increase in equipment prices. If a location has pleasant weather conditions, with good amount of irradiance and wind speed, a hybrid system powered by wind, solar PV and biogas can be developed to generate electricity. Such a system can be profitable after two to four years as it has reasonable operational and servicing costs. Therefore, as a result of the effectiveness and efficiency of the hybrid power systems, the rural areas in western Uttar Pradesh are faring well with these systems. The authors state that as these systems are good for the environment and are economical for the villagers. The villages are using these systems along with diesel backup systems to generate power. Due to these hybrid power systems, the villagers have also been experiencing benefits of mobile phones and extended networks. In addition to fulfilling the energy needs of the rural areas, these systems have also proven fruitful for the environment as it is cited to decrease the emissions of harmful substances and carbon by 90 percent. Irrespective of whether they are located in densely populated areas, remote areas, hilly and tribal areas, the solar and wind run systems benefit both the environment and the business (Mohibullah et al., 2014, 180).

Thus, from this case one can conclude that remote and hard-to-reach rural districts in India can benefit from the installation of hybrid power systems powered by solar PV and wind. This is a great alternative as extending the conventional grid can be very expensive and challenging due to topographical, climatic and financial reasons. An added bonus of the hybrid system is that it taps on the abundant renewable resources of the country - wind and solar energy - which are available all year-round. Due to their cost-effectiveness and such case studies, hybrid power systems have become increasingly popular in supplying power to rural regions, compared to the conventional grids.

IV. Sectors of Applications

The following are the sectors of rural districts that require energy, as presented by Garg (2015):

(a) Households

The energy demand for households consists of energy required for cooking, heating and cooling, supply of water and electricity.

(b) Commodity

Energy is required for transportation, water, environment and cultural purposes, and buildings.

(c) Agriculture

Energy is required for various inputs of agriculture such as seeds, fertilizers and manure, irrigation, agricultural machines and activities for post-harvests.

(d) Small-scale industries and services

Energy demand is used in agro-based industries such as rice mills, agro-based equipment, construction and artisanal industries.

There are many programmes launches to meet the growing energy demand of the rural population. In order to meet basic cooking and lighting needs, the following programmes have been launched (Garg, 2015):

(a) Biogas plants

(b) Improved Chulhas (cooking stoves)

(c) Lighting systems powered by photovoltaics (for example, solar lanterns).

Additionally, programmes have also been launched to improve rural electrification, irrigation activities and other agricultural processes by the use of solar pumps powered by photovoltaics and solar power plants. The government has also launched programmes known as integrated energy programmes at the village level and block level. In this program, a combination of renewable energy systems and conventional energy systems is employed to meet the growing needs of the rural population. The integrated energy program at the block level is known as Integrated Rural Energy Program (IREP) (Garg, 2015). The main aim of IREP is to meet the basic energy needs of the rural areas and to utilize the regionally available energy resource to the fullest. This will lead to economic development in the rural districts as it will lead to increased employment, productivity and income.

In a large number of off-grid applications, solar energy is being increasingly used. The following table 4 illustrates all the applications of solar PV in many developing countries around the world (Grimshaw and Lewis, 2010). Most of these applications are used in India.

Table 4: Off-grid solar applications			
Application	Technology	How it works	Benefits
Solar vaccine refrigerator	PV panels + lead-acid batteries	Solar panel provides electricity to power fridge; batteries store it to ensure continuous operation.	Reduces reliance on harmful kerosene; extends life of vaccines.
Solar water disinfection (SODIS)	Sunlight + plastic PET (polyethylene terephthalate) bottles	Exposure to UV sunlight destroys pathogens and bacteria.	Provides a source of clean water; reduces waterborne diseases.
Solar pasteurisation	Solar cooker (see below) + water pasteurisation indicators (WAPIs)	Solar cooker heats water and WAPI (small tube/capsule containing wax that melts at 65°C – the temperature at which viruses and bacteria are killed) indicates when it is safe to drink.	Saves fuel; reduces waterborne diseases.
Solar water pump	PV panel + electric motor	Solar panel drives electric motor which powers pump to feed water into reservoir/ storage tank.	Provides water for domestic use or irrigation; saves labour.
Solar food drier	Box with glazed cover and vents + mesh racks	Food is placed on mesh racks and dried as sun heats box.	Reduces use of fossil fuels; reduces contamination; reduces post-harvest losses

Application	Technology	How it works	Benefits
Solar electric fencing	PV cells + power conditioner + battery	PV cells charge battery, which provides DC voltage to 'live' wires in the fence.	Reduces animal raids; protects livestock and crops.
Solar wifi	PV panel + wifi router and antenna + battery + charge controller	Solar panel charges battery to power wifi antenna and router that 'hop' Internet signal from single broadband access point across multiple nodes.	Increases Internet access; decreases digital divide.
Solar phone	PV solar charger integrated into mobile phone; or solar panel + electric sockets	PV cells charge battery within phone; PV cells charge battery to power socket.	Improves rural communications; provides livelihoods (via charging stations).
Solar radio	PV panel + radio transceiver + battery	Solar panel powers batteries for transceiver.	Improves rural communications; reduces transport costs; if connected to a laptop, also increases access to online information and advice.
Solar cooker	Solar thermal: heat-trap boxes, curved concentrators, panel cookers	Device such as mirror or reflective metal concentrates light and heat into small cooking area.	Reduces reliance on traditional fuels such as wood or charcoal; reduces indoor pollution.
Solar water heating	Solar thermal collector + water storage tank	Collector heats fluid passing through it and heat is stored in tank.	Reduces reliance on traditional fuels; reduces carbon emissions and local pollution.

Source: David J. Grimshaw and Sian Lewis (2010)

The following are some of the sectors of solar PV applications, as presented by Campen (2000):

i. PV systems for healthcare sector

(a) Vaccine refrigeration

Use of PV for refrigeration of vaccine in health clinics in rural areas is very prevalent. Application of PV equipment is very extensive in world immunization programmes (Campen, 2000, 24). Though PV has been found to be very reliable for the health care sector, high initial investments and quality maintenance costs are its main drawbacks. It has been experienced that though high reliability of PV systems reduces the frequency of maintenance and the costs, it becomes prohibitively expensive in case of isolated PV systems. Need for innovative approaches has risen as the health care programmes in most of the least developed and developing countries are not adequately funded (24).

Due to reliability and low requirements for maintenance, PV refrigerators and freezers are very popular in the health sector (45). PV refrigerators help conserve the potency of the vaccines which are crucial for the rural immunization Programmes in India. However, compared to the widely popular refrigerators powered by kerosene and propane, PV refrigerators are very expensive and not an economical choice for the rural districts. Additionally, PV refrigerators are starting to get popular in the veterinary sector, for the same purpose of preserving vaccines (46).

(b) Use of PV systems for supply of drinkable water

Clean and reliable supply of drinking water is very important for reducing the risk of suffering from water-borne diseases (25). Children in poor rural districts are the most vulnerable to such diseases. Plus, a reliable supply of clean drinking water also frees up time for women to carry out other productive activities and also increases the welfare and hygiene of the community. However, there are some challenges to this use. Though financial and technically, the technology of PV water pumps is sound and accepted, it initially has high investment costs and the cost keeps increasing due to the absence of pre-existing infrastructure and maintenance costs (26). This in turn leads to low operational reliability. The PV pumping systems experience the same problems to that of the PV systems for health clinics, e.g. PV refrigerators. They both experience challenges when it comes to aggregating funds for maintenance and operation.

ii. PV systems for the entire community

(a) Street Lights

One of the main uses of rural electrification is for street light installation in villages which increases the feeling of security in the evenings. This is one of the main objectives under the programmes for conventional grid extensions (29). Villagers want to experience such positive aspects of electrification. The Gosaba Island in the Sunderbans region of India presents us with a great example where a group of rickshaw-men clubbed bought a street lamp for the main rickshaw stand in order to improve security and services, especially during evening hours (Sinha, 2000). An important point to note, with regard to community-shared PV systems, is that those systems need to be taken care of and their maintenance should be done properly and with diligence so that the longevity of those systems is ensured (Campen, 2000, 29).

(b) Telecommunication

In remote areas, solar PV is the most reliable and affordable power source for telecommunication infrastructure. Small solar panels of 10-50 Wp can easily run mobile phones and single radio connections. When telecommunication facilities are made open to the public, villagers use them extensively for social and other productive purposes. Telephone shops have become profitable options for rural entrepreneurs (29).

(c) Charging the PV batteries

The demand for charging stations for the batteries for PV systems has been on a rise in rural districts. Many villagers use old batteries from their vehicles to power their televisions and single light bulbs. They often have to travel large distances and pay a lot to get those batteries charged from the nearby electrified rural areas. Charging stations for PV battery provide a great middle ground between the conventional charging methods and the private PV system (29).

It has been observed that improvements in home battery systems have encouraged the households to acquire on long term basis a small solar panel. Many of the PV charging stations have received government subsidies and are maintained and operated by the entire community. Nowadays, due to the falling prices and increase of technical know-how, local businesses are being attracted towards these PV systems for investment opportunities (30).

iii. PV applications outside the agricultural sector

There are many activities, besides the agricultural sector, that requires energy. For instance, the cottage industry, the service sector such as delivery of electricity, and the business sector (31). A great way to boost the employment rates and income levels in rural districts is via installing PV systems and developing businesses for maintaining and operating such systems. PV systems have been gaining acceptance in the cottage industry and the business sector. Many of the businesses in rural areas have been able to work longer hours, especially at night and evenings, due to light. Their productivity per hour has increased. The availability of electricity has also led to positive changes in the quality of the business activities and also attracted more customers (32).

PV systems have also been widely accepted by micro-enterprises in rural districts (37). Once PV systems are developed in villages, the villagers experience an extra source of income as they are then employed for deployment purposes and maintenance services for a variety of PV systems in the region. This is also a great avenue for the economic development of rural districts as it is a great way to develop rural markets. The success of the current PV electrification program is found to be consolidated with their commercialization and when their after-sale service is undertaken in a decentralized manner through formation of networks of solar technicians and rural micro-enterprises. SELCO India is one of many privately run Energy Service Company (ESCOs) that provide servicing to solar PV systems in rural areas through a network of rural offices and in the process they have provided employment to a large number of rural population (37).

iv. PV systems for agricultural sector

(a) PV water pumps for irrigation

In a FAO report (1986), it synthesis the positive effects of developing efficient irrigation techniques. They state that with an increase of irrigation systems there would be an increase in quantity of cultivable land, a three-fold increase of good quality crop harvests compared to the crops dependent on rain, an increased intensity in agricultural activities, decrease of droughts per year, increase in economic and food security (Campen, 2000, 38). According to the FAO, however, the already mentioned positive effect of irrigation is not a definite result of using any kind of pumping system. In order to experience the positive effects of irrigation techniques summarized by the FAO, in addition to an efficient pumping system, there should also be an improvement in market accessibility and development of effective and sustainable farming practice (39). New innovations such as drip irrigation and micro-irrigation are known for their 'water-conserving' properties and they complement the PV pumping systems.

Functioning of PV systems match the requirements of new irrigation techniques which transports water in closed pipes to avoid contamination and water loss (39). It also involves regular irrigation, and flow of water to plants at exact rate. PV systems meet these requirements. On the other hand, there are some disadvantages to such irrigation systems. For instance, they could experience interruptions due to lack of servicing and poor maintenance which would reduce the crop yields. Though the investment costs associated with PV pumping systems is high compared to diesel and electric powered water pumps, based on the lifespan, the PV water pumps are far superior. Some of the other advantages are that PV pumps require less maintenance and are highly reliable if organized and designed properly. PV pumping has a relative advantage in areas of low-water use and low power pumping range. Thus, for un-electrified rural districts, PV pumping systems are the best option as it is cost-effective and can be provide a reliable supply for clean drinking water. Furthermore, PV water pumps are also popular for watering the livestock, which will be discussed further (39).

Hahn (1998) summarizes the conditions under which PV pumps have economic advantage over other competitive technologies. The conditions outlined are arid and semi-arid climates, inaccessibility to public electricity grid, problems in maintenance of diesel pumps and supply of fuel for their use, small field sizes, high variety crop cultivation and irrigation methods involving water and energy conservation such as drip irrigation which have low electricity requirement. The use of PV pumps is advantageous in regions with water scarcity, however it requires training (Campen, 2000, 40). Without training, the villagers will not be able to experience the benefits of such a new irrigation system. In India, as per practice in rural electrification programmes, it is evident that crop yields increase and water and fertilizer are saved when suitable training is provided to the rural population on how to use PV systems.

PV water pumps and other PV technologies share the same advantages and disadvantages (40). An important aspect of the PV pumps is that they do not require a battery for energy storage and can instead use a simple tank of water for storage. This further increases the reliability of the system and lowers investment and servicing costs. Therefore, all in all, PV pumping systems have two bonus points of having the ability to conserve water and being extremely reliable; this makes PV pumps an effective irrigation technology. The market share of photovoltaic water pumping irrigation system is very small, also very less capital is available with small farmers. A conclusion can be deducted from this programme. Farmers can be imparted training on advanced techniques on irrigation from a particular institution so as to popularize the use of PV pumping system of drip irrigation. As the farmers require financial support in order to install PV pumps, the Government of India has established a program that provides subsidies, credit and technical support in order to ease the burden (40).

v. PV systems for watering cattle and other livestock

In many remote villages around the world, PV pump systems for watering livestock are implemented. Therefore, as a result, the villagers can manage their resources efficiently and also benefit from the increased milk and meat production. Some of the positive aspects of PV systems is that they are mobile and low-maintenance systems, requiring no fuel or monitoring. PV pumps, as stated earlier, do not require batteries for storage. PV water pumps can be used in place of livestock for irrigation purposes (42).

vi. PV systems applications in fishing

Light from PV systems are being used by fishermen to capture more fish. PV refrigerators are also used by them to store the fish in cool spaces before transporting them to urban far-away markets. However, as started earlier, refrigerators powered by propane and kerosene are used more as they are affordable for the fishermen (45).

vii. PV systems for electrified fences

As electrifying fences with electricity from the conventional grid extensions can be quite costly, stand-alone battery power is used in rural districts. Also, by attaching a solar panel to this battery could also extend its performance to many more years and would also eliminate costs for charging the system and transportation. Therefore, in many rural districts, electrifying fences with PV power is seen as a cost-effective solution and an increase in security of the fields and farmland. Thus, such fences are sought in remote and far-from-grid rural districts as it requires no monitoring and charging (46).

V. Economic and health impacts on replacement of Kerosene

Lighting through electricity is much more energy efficient as compared to a kerosene lamp. A lamp powered by kerosene is 200 times less bright than a lamp powered by electricity. Kerosene also degrades the overall quality of life. When lamps are powered by using electricity from a renewable and abundant source of energy, it improves the quality of life as children are able to study in the evening and women also are able to receive income by doing work in the late evening times (Kamalapur and Udaykumar, 2011, 599). On a plus side, solar power and photovoltaics are gaining acceptance from the villagers in rural districts as the availability of kerosene decreases and the price of diesel increase.

In developing countries, light is often powered by kerosene, which is very harmful for health as it emits harmful substances leading to many health related problems such as respiratory problems, eye, kidney and liver infections. Each family pays on average €36 to €72 per annum (Grimshaw and Lewis, 2010). There have been many stories of homes catching on fire due to kerosene lamps being knocked over. Usually, reliable and quality electricity can be provided with little energy and cost leading to positive effects and improving the standard of living.

The latest innovation of solar powered lamps can provide light to rural homes in a much economical and reliable way. Compact and efficient solar lanterns of only € 31.50 per piece are produced by an Indian company known as NEST Ltd. Buyers can pay for them in one or two year installments and not buy kerosene. These lanterns have contributed to the reduction of more than 20,000 tonnes of CO_2 per annum, as around 100,000 homes in Andhra Pradesh and Maharashtra use NEST solar lanterns (Grimshaw and Lewis, 2010).

5.1 Case Study: Solar Home Lighting Systems under the RVEP of MNRE

Figure 7: Map of India indicating Assam, Meghalaya, Jharkhand, Madhya Pradesh, Odisha and Chhattisgarh
(*Source: Google Images*)

As mentioned earlier, The Remote Village Electrification Programme (RVEP) initiated by the Ministry of New and Renewable Energy (MNRE) has been active in the whole country. In this case study, Buragohain (2012) analyses and studies the effectiveness of this programme in rural electrification. The paper starts by describing the methodology of the case study and then presents the results of the study to highlight how the solar PV domestic systems are operating in these villages and what are the impacts of these systems in the daily lives of the villagers. The survey-study was conducted by NCAER in 2008 in Assam, Meghalaya and Jharkhand (MNRE, 2008) and in 2010 in Odisha, Madhya Pradesh and Chhattisgarh (MNRE, 2010)

NCAER conducted the survey to aggregate information on the installed PV systems from 371 villages in 41 rural districts of the six states. The survey received information from approximately 10,000 rural homes. There were two surveys conducted, one was conducted at the village and the other was conducted at the rural home level. The survey questions aimed to analyze and study whether the PV systems were operational, how they were being managed and how the lives of the rural districts had changed as a result. In order to improve the qualitative aspect of the study, Focus Group Discussions (FGDs) were also conducted so that the impact of the installed PV systems could be better understood. The systems being analyzed in this case study are solar home lighting systems which are powered by either solar power plants or through solar PV domestic systems. While in Jharkhand, Assam, Odisha, and Madhya Pradesh the solar electricity is generated from solar PV domestic systems, in Meghalaya and Chhattisgarh, it is generated from solar power plants (Buragohain, 2012, 335).

Factors such as module capacity and installation, installation of cables, fixing of light bulbs determine the proper functioning of the system. Proper fixing of module, cable and bulb results in optimum result, like one CFL can give up to 10 hours of light and two electric bulbs can provide light up to 4-5 hours, a day in a normal weather day. An important point to note on the solar domestic systems is that if the rural homes consume less electricity, then in such a case, the batteries can store energy for more than 2 days (335). The case study provides statistics on how long the rural homes get light from such systems.

In winter days, states such as Assam and Jharkhand reportedly experience moderate performance of their light fixtures. Only two to fourteen percent of the rural homes receive less than three hours of electricity. While in Assam and Meghalaya, a mere 20 percent of rural homes reportedly receive around three to four hours of electricity in a day, Madhya Pradesh, on the other hand, reports that around 53 percent of rural homes receive electricity for the same amount of hours, as illustrated in Table 5 (336). In all states, besides Madhya Pradesh, rural homes reported that they received more than 4 hours of power in winter days. As India has three seasons (monsoon, summer and winter), the performance of these solar systems are much better during winter and summer days due to maximum irradiance. Light fixtures work for around 4 and a half hour in winter days (an average estimate). On the other hand, in summer days, the performance of the lighting system is suitable for livelihoods. In states such as Jharkhand and Assam, electricity is received for four hours or more by seventy-five to ninety-one percent of the rural families. Light fixtures work for 4.4 to 4.8 hours in summer days (an average estimate) (336).

Table 5: Average Number of Hours Light Fixtures Work per day by seasons (Percent)

State	During Rainy Season			During Winter Season			During Summer Season		
	> 3 hr	3-4hr	< 4hrs	> 3 hr	3 -4hr	< 4hrs	> 3 hr	3 -4hr	< 4hrs
Meghalaya	99.0	0.0	1.0	0.0	20.5	79.4	0.0	16.2	83.7
Jharkhand	70.9	27.6	1.4	14.1	31.0	54.9	2.1	6.6	91.3
Assam	65.3	32.9	1.8	1.6	20.2	78.2	4.7	20.8	74.6
Odisha	50.4	38.4	11.3	4.6	40.9	54.6	2.6	19.7	77.8
Madhya			1.4			34.1			87.4
Pradesh	73.3	25.4		12.9	53.0		1.7	11.0	
Chhattisgarh	45.5	22.6	31.9	0.4	39.1	60.5	0.1	21.0	78.9

(Source: International Journal of Environmental Science and Development, August 2012)

Two CFL simultaneously can provide illumination for 4 to 5 hours on an average in normal weather conditions. It has been found that the system´s performance is better in summer season than in winter and rainy seasons. In the state of Jharkhand, where the weather is relatively hot, 63 % people said that they received light for more than five hours a day whereas in the state of Meghalaya, where the weather is comparatively cooler, people reported that they got light for 4 to 5 hours a day (Buragohain, 2012, 336). When the system gets old its performance decreases. This statement has been found true in findings in some states. In Jharkhand, 52 % people who got the system installed in the year 2004 reported that they received light for more than 5 hours, as illustrated in Figure 8.

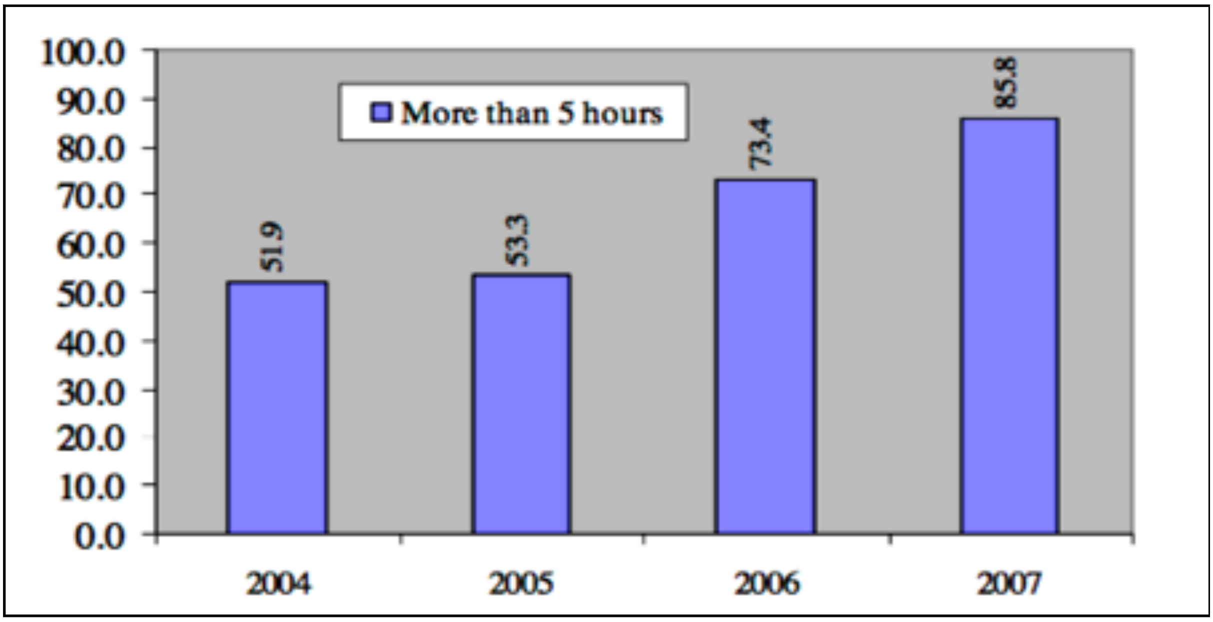


Figure 8: Link between system performance and year of installation in Jharkhand (%)

In the state of Odisha, the performance was found to be better. 76% of people who got the system in the year 2007 said that they got light for more than 5 hours a day whereas more people, around 81%, who got the system after two years in 2009 responded that they got light for more than 5 hours, as illustrated in Figure 9 (336).

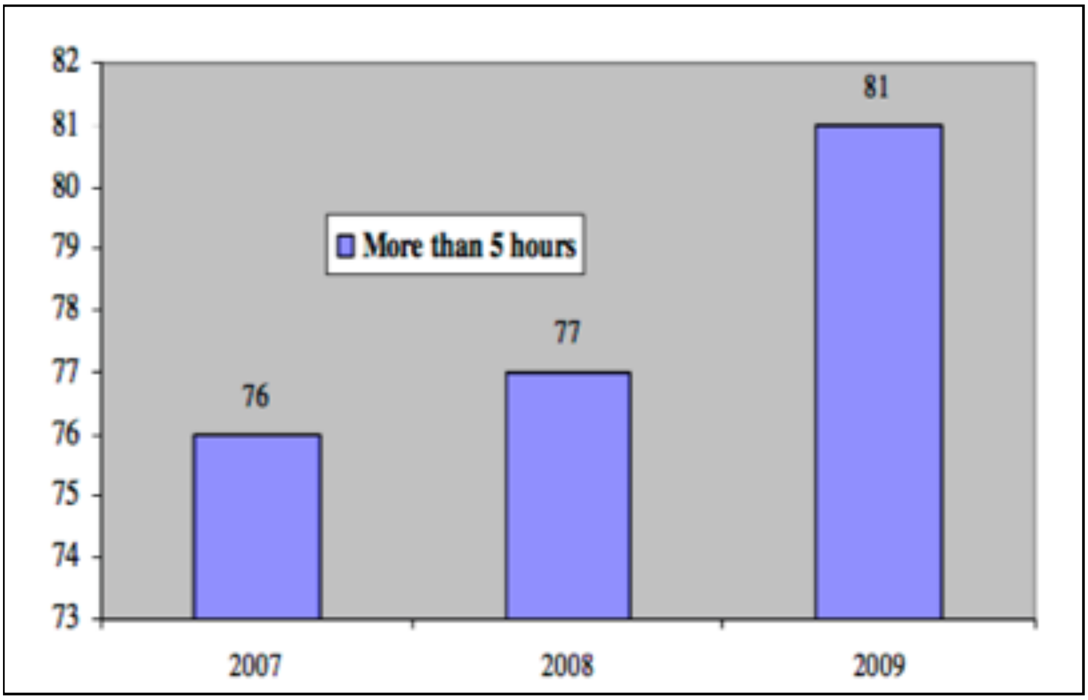


Figure 9: Link between system performance and year of installation in Odisha

Similar trend was also observed in the state of Meghalaya. 28.5% who got the system in 2003 got light for 4-5 hours and 100% of those who got the system after 3 years in 2006 received light between 4 to 5 hours, as illustrated in Figure 10. Thus it has been confirmed by these surveys that performance of old system decreases (336).

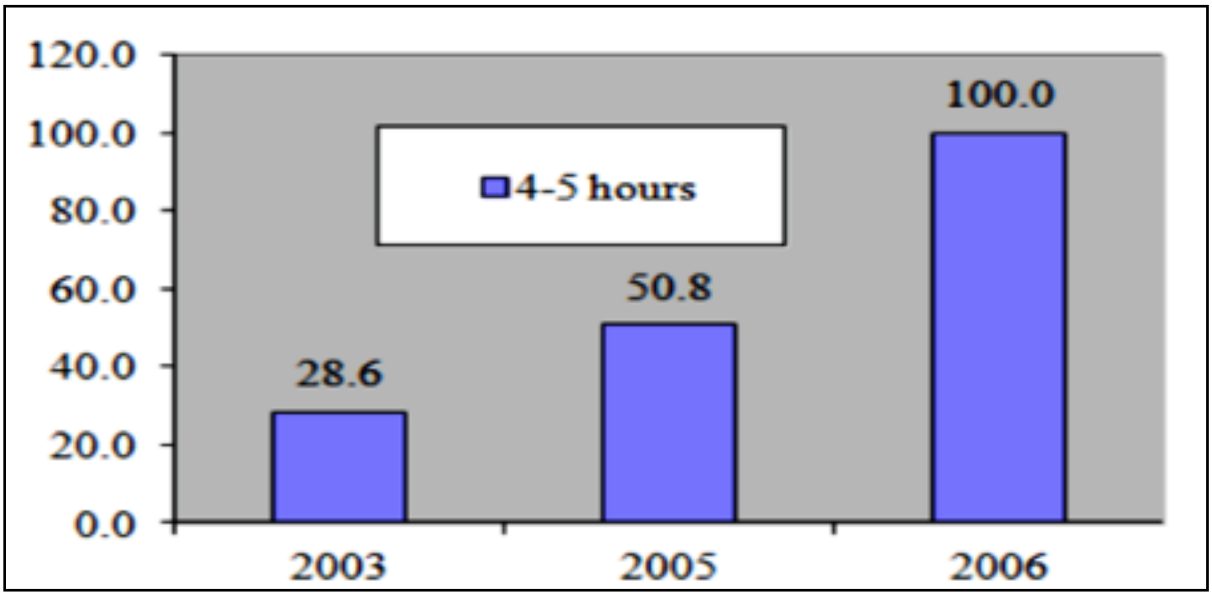


Figure 10: Link between system performance and year of installation in Meghalaya

The survey-study conducted by NCAER also examined the spending changes on kerosene. The study showed that, after the installation of the solar domestic power system, the monthly spending on electricity has fallen. However, the rural homes have been using kerosene for other activities, other than electrifying homes. The spending on kerosene has fallen on states such as Meghalaya, Assam, and Jharkhand by more than 50 percent (336). However, the spending has not fallen as much in Madhya Pradesh, Odisha, and Chhattisgarh, as illustrated in Figure 11. Furthermore, due to the availability of electricity during evening hours, the rural families have been able to perform various activities till late at night, such as studying, cooking, and other chores. After the establishment of the PV systems, performing domestic chores as become much easier. The levels of satisfaction, insofar as domestic work is concerned, have been found as 35, 39, 48, 75, 60 and

49 percent in states such as Chhattisgarh, Madhya Pradesh, Odisha, Meghalaya, Assam and Jharkhand respectively (337).

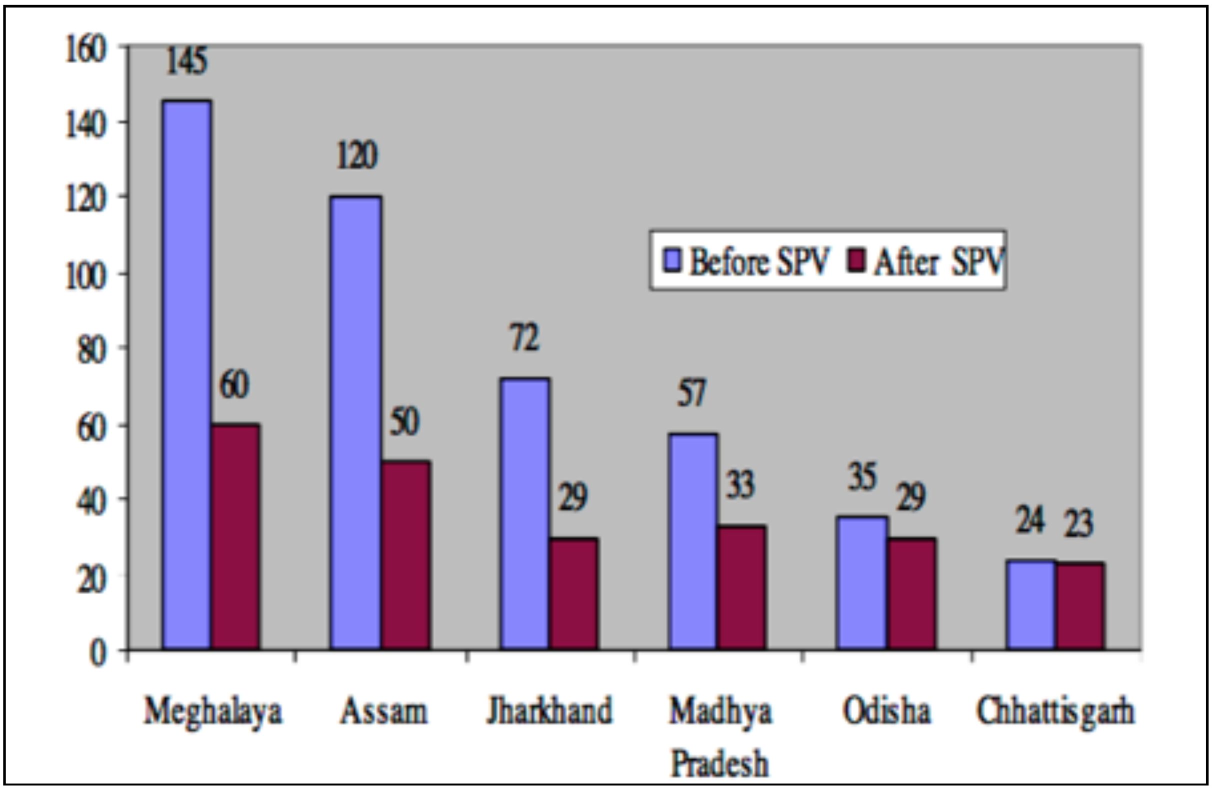


Figure 11: Monthly spending on lighting before and after Solar PV systems were installed (per month in Rupees)

This study is a great illustration that solar domestic systems in India have presented the rural population with many benefits and have improved the quality of life. The authors agree that these systems provide many benefits to their users. For instance, improvements were noticed in the income of the villagers. The installation of systems created more jobs and provided the rural districts with more income opportunities. However, only 2-3 percent of the rural homes agreed that new jobs with more income were created after the system was installed. Even though, in Jharkhand, the income per rural family has increased by 5 percent per month, the same benefit has not been as pronounced in the other five states analyzed (Buragohain, 2012, 337).

As stated earlier, two FGDs were created, one for women and another for men. The aim of the FGDs was to analyze the participation of the rural homes in the rural electrification programme and to assess the impact of the solar domestic electrification systems experienced by the users. The qualitative information received from the FGDs greatly complemented the quantitative aspects of the study. In total, there were 33 FGDs in Jharkhand, Assam, Meghalaya, Odisha, Madhya Pradesh and Chhattisgarh (337). After the installation of the domestic solar lighting systems, women have been able to engage themselves in productive activities during the day time and contribute to the household income and during the nighttime, they can engage themselves in household chores such as cooking, grinding, and weaving, to name a few. Thus, there has been an increase in indirect ways to generate income. The lives of women have greatly improved since the installment of these systems and they expressed their content in the study. Furthermore, it was also found that while some households have completely stopped using kerosene, others experienced a reduced spending on kerosene to around 60 or 70 percent (337).

Under the RVEP, solar powered streetlights were also installed in these six villages. Before the installation, the villagers were threatened by wild animals entering their villages and attacking their cattle and children. However, after the installment, such incidents have not been occurring. Consequently, crime rates have also reduced. The villagers in Chhattisgarh can now watch cricket matches on television, which has been a drastic improvement in their quality of life (337).

Thus, this case study is a perfect demonstration of the impact of rural electrification programmes by the Government of India, under the Ministry of New and Renewable Energy. As illustrated in these six states, solar domestic lighting systems have had a huge impact in the lives of the rural districts. From reduced crime rates and wild animal attacks to reduced consumption and spending on kerosene, the lives of women and children alike have created improved. According to the survey-study, there has also been a significant increase in the number of children attending school in these six villages, after the installation of the solar systems. Majority of the rural districts are also satisfied with the performance of the systems.

5.2. Solar PV systems in selected villages of Sundarbans region

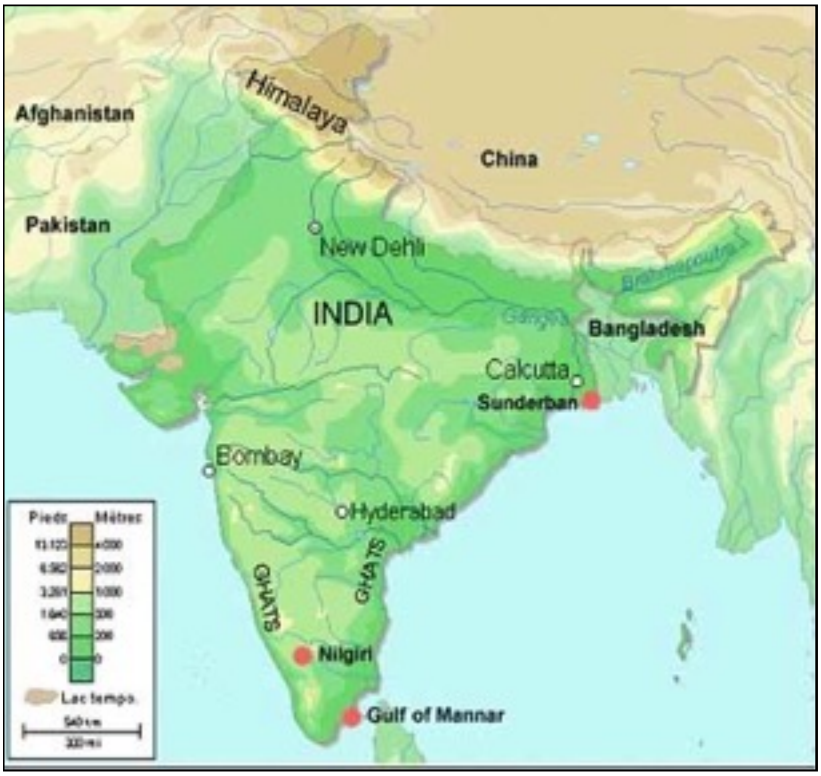


Figure 12: Map of Sundarbans, India
Source: Google Images

The study, by Murali et al (2015), focuses on solar PV systems such as domestic solar systems, solar mini-grids and solar AC pico-grids in a couple of villages in the Sunderbans region in West Bengal. The authors sought to assess these systems for socio-technical aspects. In addition to assessing the impacts of the rural electrification systems, the institutional, financial and technical aspects are also studied. The results of this study have been very positive, similar to the case study on 6 states under the RVEP by MNRE, presented in Section 5.1. The electrification program in the rural districts in the Sunderbans region have led to decreased spending on kerosene, increase in number of children going to school and ease in performing household work. The details of the study will be presented below.

The rural districts in the Sunderbans region, were selected for this study as many types of solar PV systems have been installed in the villages in support of the rural electrification programmes in India (Murali et al., 2015, 613). The various solar systems are: The solar pico-grids commissioned under the Off-Gris Access Systems for South Asia (OASYS South Asia), implemented by Mlinda Foundation and TERI in the state of West Bengal, West Bengal Renewable Energy Development Agency (WBREDA) commissioned solar mini-grid and solar home systems (SHS) which were financed by the NABARD and marketed by private sellers. A small solar photovoltaic panel, a rechargeable battery, a charge controller and an inverter comprise an AC solar pico-grid. Their capacity varies from 100 Wp to less than 1 kWp. They have capacity to supply 220 V, 50 Hz 3-Phase or single phase electricity to 5 to 20 households in a small radius. The electricity is centrally generated and distributed to households and shops in a locality. SHS supply DC electricity to households and shops to run CFL or LED bulbs, Fan, television and other household appliances. The electricity outflow and inflow from the battery bank is controlled by the charge controller (Palit, 2013).

In this socio-technical study of the installed PV systems, the attention was given to the technical, social and institutional aspects of the delivery model of the PV systems in the Sunderbans region. The objective was to assess the performance of the decentralized systems by studying different parameters, related to design, delivery models, service and maintenance and operational aspects of the system. The funding and tariffs were also examined in this impact assessment study, especially to assess the social and economic impacts of the systems installed in the rural distrust of the Sunderbans region (Murali et al., 2015, 615).

In order to understand the impact of a PV system, both qualitative and quantitative analysis, using primary and secondary data, should be conducted. In this case study, a questionnaire was developed to survey and understand the technical financial and social impact of the installed PV systems. It was very important, for the study, to cover wide range of factors for the impact assessment. There were two set of questionnaire that were prepared: one set of rural homes and one set for the business and markets. Focus Group Discussions (FGDs) also played a part in this study. Members of rural homes from various Joint Liability Groups (JLGs) from different rural districts in the Sunderbans region were a part of the FDGs. The authors of the case study conducted the two survey-questionnaires and FGDs in the Sunderbans region during February to March 2015. Brajaballvpur, G-Plot, K-Plot, and L-Plot are some of the villages in the Sunderbans region. Solar AC pico-grids have been installed in these villages under the project initiative of OASYS South Asia. As the number of pico-grids installed were more in Brajaballavpur and G-Plot than the others, these two villages were selected for the case study (615).

The typical capacity of the solar home systems (SHS) installed in rural homes is usually 20 Wp to 75 Wp, whereas those installed in market places have the typical capacity of 20 Wp to 125 Wp. Power supply from solar AC pico-grids to individual households is through JLG, in which a common grid supplies power to 6 to 10 customers. In this case, a 225 Wp system is connected to a larger group of dwelling say 10 and the smaller group of 6 households is connected to a system of 150 Wp. There is an electricity supply of 5 hours in the evening. Each household is supplied with 3 light points with 2W LED lamps and a mobile charging point. Pico-grids for markets carry capacities of 250 Wp, 500 Wp, 1 kWp, 1.5 kWp and 2 kWp. The market customers are provided with 5W and 10W LED lamps and a mobile charging point, the number of the lamps depends on the size of the system (616).

The case study highlighted the performance of the installed PV systems in the homes and markets. As per the survey of the rural homes with SHS, the systems were performing well. While the rural homes with SHS used the solar electricity to power DC fans and TVs, the markets used the electricity to power other devices such as weighing machines, computers, DVD/CD players, and CFLs. At the time the study was conducted (February-March 2015), the solar AC pico-grids were relatively new as they were only 6 months to 2 years old at the time and were all performing well. However, there were some survey results, from the pico-grid users, who indicated that there were a few interruptions with its performance. An important point to note, regarding this case study is that, the focus of the survey was given to solar AC pico-grids and SHS as solar microgrids were not operating at the time due to faults with the battery (617). Though the solar panels were in good condition, due to issues with the battery, the plant had to be shut down with only a few months of operating properly. A study conducted by Ulsrud, Winther, Palit et al. (2011) in different parts of the Sunderbans region, concluded that batteries are not the strongest part in the solar microgrid systems.

Unscheduled interruptions of the installed solar PV systems were also examined through the survey-study. Varied responses were received. From the total SHS domestic users surveyed, unscheduled interruption once per annum was experienced by 25 percent, around 18 percent of the domestic users experienced interruptions only once per month and interruptions of more than 3 times in a week was experienced by 14 percent of the users, as shown in Figure 13. On the other hand, with regard to pico-grid domestic users, 34 percent of the surveyors indicated that they did not experience unscheduled interruptions and an interruption was experienced once in the year before February 2015 by 42 percent of the users. As per the responses, it was noticed that the interruptions every year were due to the monsoon season (Murali et al., 2015, 617).

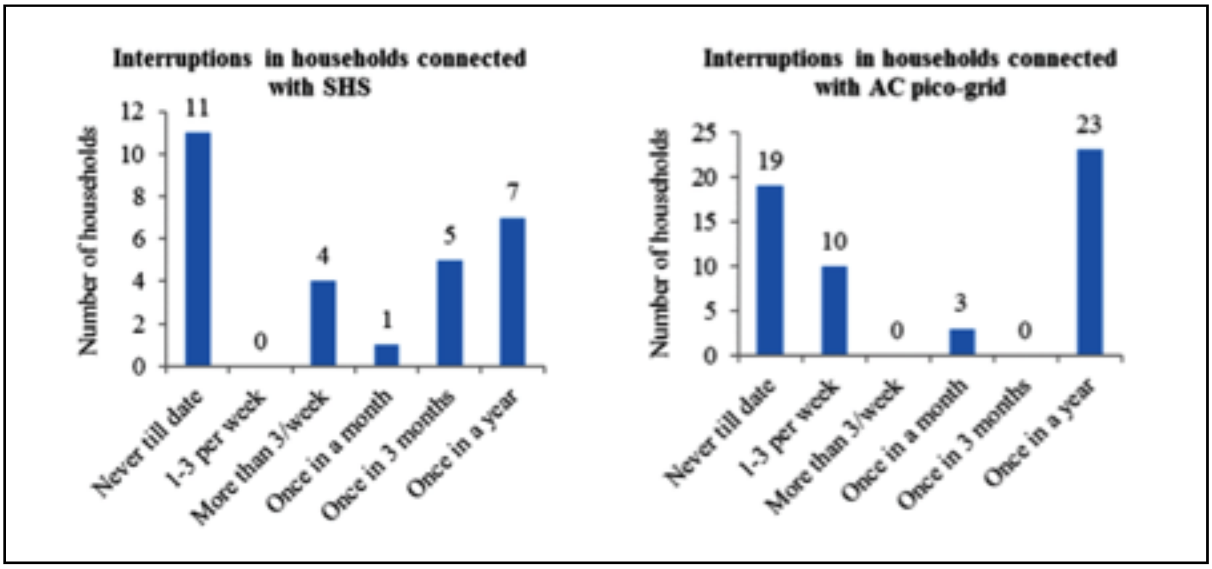


Figure 13: Frequency of unscheduled interruptions
(Source: Murali et al., 2015)

In addition to unscheduled interruptions, technical faults in the systems were also investigated. From the total SHS domestic users surveyed, around 36 percent indicated that they never experienced any technical issues with their systems. However, the other 64 percent of the respondents did come across some technical issues. The fusing of the bulb was experienced by 40 percent of the respondents, 24 percent experienced issues with bulb flickering, issues with the charge controller was experienced by 24 percent and other damages of the bulb were experienced by the remaining 12 percent (618). On the other hand, with regard to solar AC pico-grid domestic users, no technical issues have been experienced by 35 percent of the surveyors. The other 65 percent of the respondents have experienced issues. While fusing of the bulb is the common problem in domestic SHS users, bulb flickering is most common issue in domestic pico-grid users with 67 percent experiencing such issues. Problems with the charge controller functioning have been experienced by 22 percent of the respondents and other bulb damages have been experienced by 11 percent (618). However, one plus point with pico-grids is that, there have been no issues with fluctuations with voltages. The technical difficulties experienced by both domestic SHS and pico-grid users are illustrated in Figure 14.

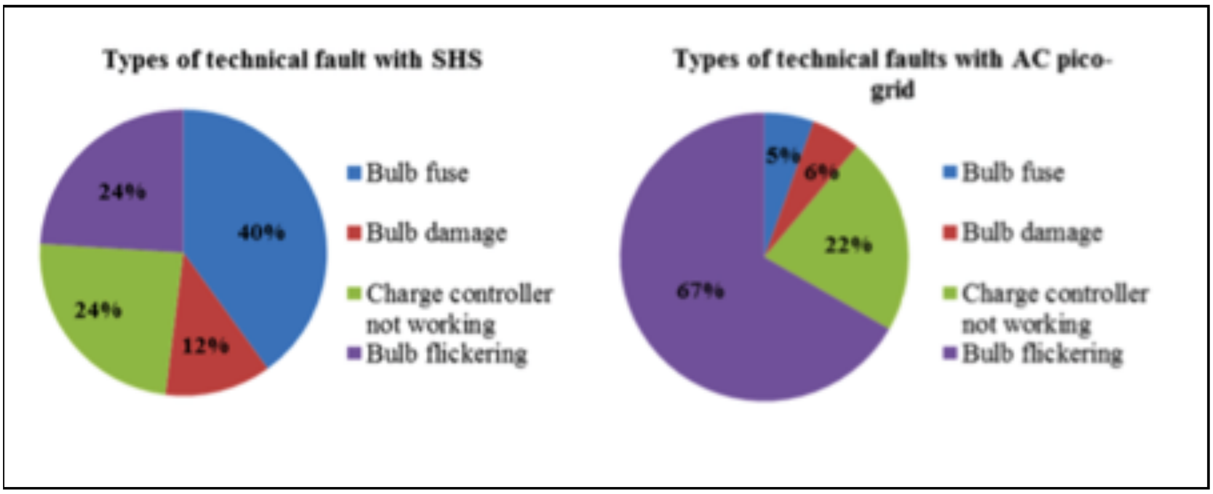


Figure 14: Technical faults indicated by survey respondents

(Source: Murali et al., 2015)

The study also covered the aspects of training and technical-know amongst the PV system users. As per the survey, about 40 percent of the rural homes with SHS indicated that they did not receive any information and training regarding the servicing, maintenance and functioning of the system. They said that they acquired the basic knowledge on the system operations from other users of the system in their village, who already had been using such systems. In contrast, around 67 percent of the SHS users in the market sector indicated that they did receive training on operation and maintenance from the agency who installed the systems in their shops. It is important to highlight that, it is the duty of the installing agency to make sure that the systems are being properly maintained and are not ruined. In addition to visiting the system holders, the agency has also provided the users with a checklist of what to do and what not to do with the systems. With regard to solar AC pico-grids, on the other hand, 50 percent of the market surveyors indicated that they had received training (619).

The financing of the solar PV projects in the Sunderbans region was also examined. The scheme under NABARD was responsible for financing the SHS installed in the surveyed rural districts. As per the NABARD scheme, along with loans, subsidies are also provided (619). For systems up to 300 Wp, a subsidy of 40 percent is provided and for systems with 300 to 1000 Wp, a subsidy of 30 percent is provided, with an interest rate for 5 years as per the regulations of the Reserve Bank of India. Under the MNRE program, the market vendors can also sell their SHS to other potential users at subsidized rates (619).

For installation of solar pico-grids, 30% of the project cost was provided by OASYS South Asia from Mlinda Foundation and rest of the amount was provided by NABARD as loan under the Joint Liability Group (JLG). Under JLG 5 to 10 households are clubbed together and the group of households apply for loan together. To open a bank account, the group is charged € 1.6 (620). This financial model has been structured in a way that after the loan has been paid the consumers become the owners of the system. Different JLGs have been provided loan by NABARD with help from PIA (Private Implementation Agency) at an interest of 10% for 5 years. After taking into account the interest and maintenance charges, the private implementing agency collects € 2.4 each month from each household and deposited with the NABARD (620). The JLG system has been successful for all stake holders as this model provides electricity to households at a rate that can be afforded by them besides making them owner of the system eventually. In markets, the individual shopkeepers are the owners of the pico-grid systems. The cost of the system is € 3.66 per Wp which includes costs on account of hardware, transportation and installation. In this case also the PIAs, collect money from the shopkeepers and pay to NABARD which extends loan at the rate of 10% interest for 5 years period. But in the market system, there is no JLS system. The monthly installment is paid by the individual entrepreneur and shopkeeper on the basis of the system capacity. Some shopkeepers who have excess energy also give paid connection to other shops (620).

The following pages of the case study examine the social, economic and health impacts of the installed solar systems, experienced by domestic and market users, in the Sunderbans region:

I. Impact on domestic users

(a) Changes in consumption and expenditure on kerosene

As illustrated in various case studies in this paper, installation of solar powered systems in rural districts has led to many positive impacts on its users. Since the installation of the SHS, the consumption of kerosene by SHS consumers has decreased from 4 liters to 3 liters (Murali et al., 2015, 621). Whereas, since the installation of the solar AC pico-grids, the consumption of kerosene by pico-grid consumers has decreased from 3 liters to 1.5 liters, as depicted in Figure 15.

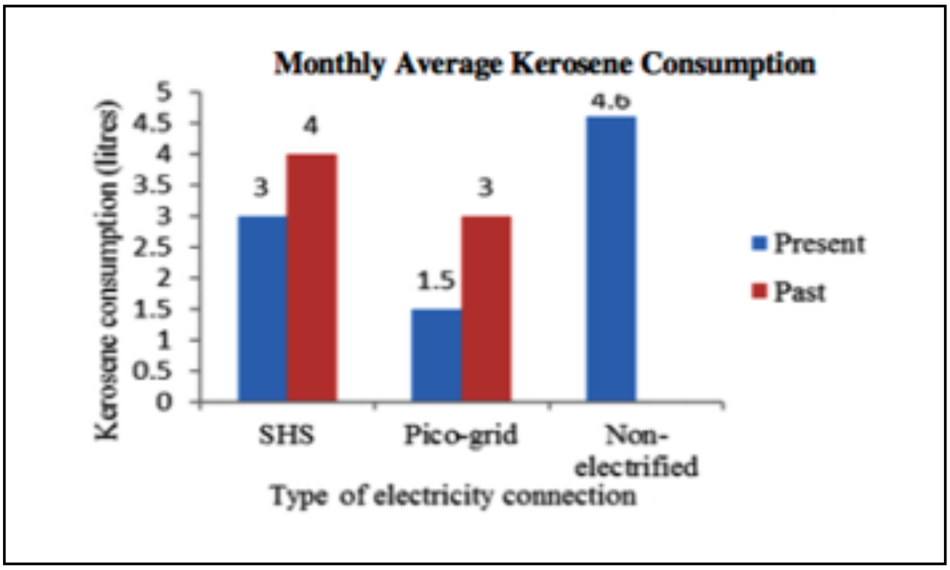


Figure 15: Monthly average kerosene consumption
(Source: Murali et al., 2015)

According to the study, the authors found that on average un-electrified rural homes were monthly consuming about 4.6 liters of kerosene. There have also been changes in expenditure trends. Since the installation of SHS, villagers started spending less on kerosene as their monthly spending fell from € 1.37 to 90 cents. The results also showed that there had been a further decrease in expenditure on kerosene by pico-grid consumers as the spending fell by about 75 percent in one month. In contrast, the un-electrified rural homes spent about € 1.79 cents monthly on kerosene, as depicted in Figure 16 (621). The study showed that even though the average spending on kerosene increased a little, as some rural homes were using both kerosene and solar power, the quality of solar power is far superior to the kerosene powered lamps. The cost per hour of light from kerosene lamps is much greater than the cost per hour of light from solar systems.

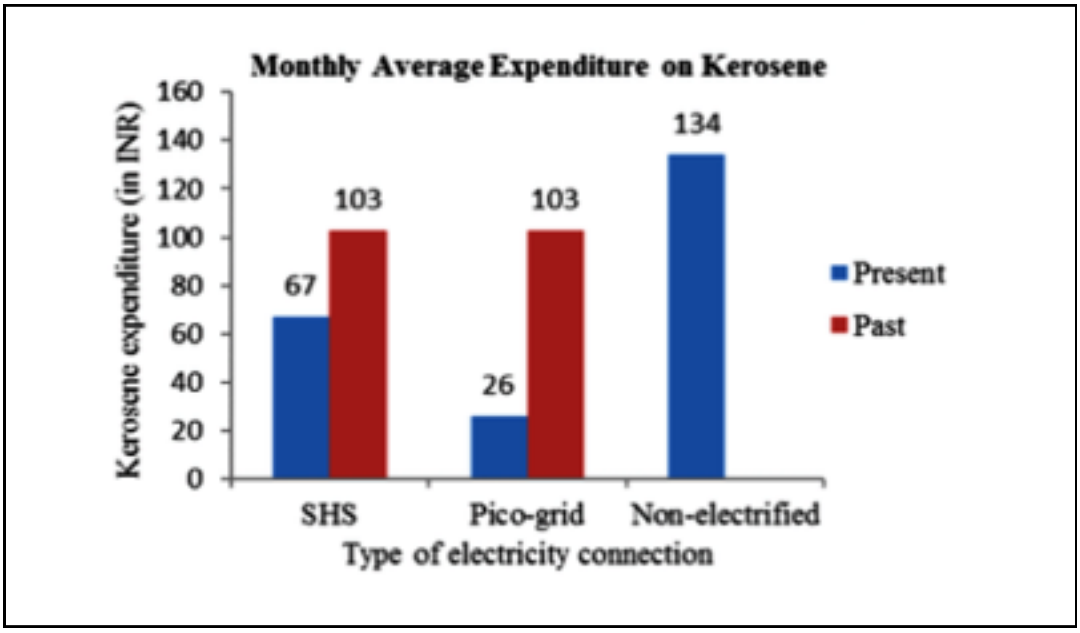


Figure 16: Monthly average spending on kerosene

(Source: Murali et al., 2015)

(b) Changes in activities after electrification

There were not many changes. While the SHS users engaged in starting tuition sessions at home, renting spaces and making handicrafts, pico-grid users engaged in fixing fishing nets (622).

(c) Impact on gender

There have been significant positive effects on gender in these rural districts. While 58 percent of the surveyed pico-grid domestic users have electricity in the kitchen, only 32 percent of SHS domestic users have electricity in their kitchen. The responses made by the SHS women-users for not having electricity in their kitchen were diverse. On one hand, some women did not think that it was possible to have electricity in the kitchen, on the other hand, some women thought that providing light to their children to help them study during the evening was more important and took precedence. They believe that as cooking only takes a couple of minutes to an hour, they can simply get the job done using kerosene lamps and devote all the solar lights to helping their children study. The study showed that 41 of the solar system users (both pico-grid and SHS users) used solar power in their kitchen. 80 percent of these respondents indicated that cooking using solar electricity was easier than using kerosene light, as illustrated in Figure 17 (622).

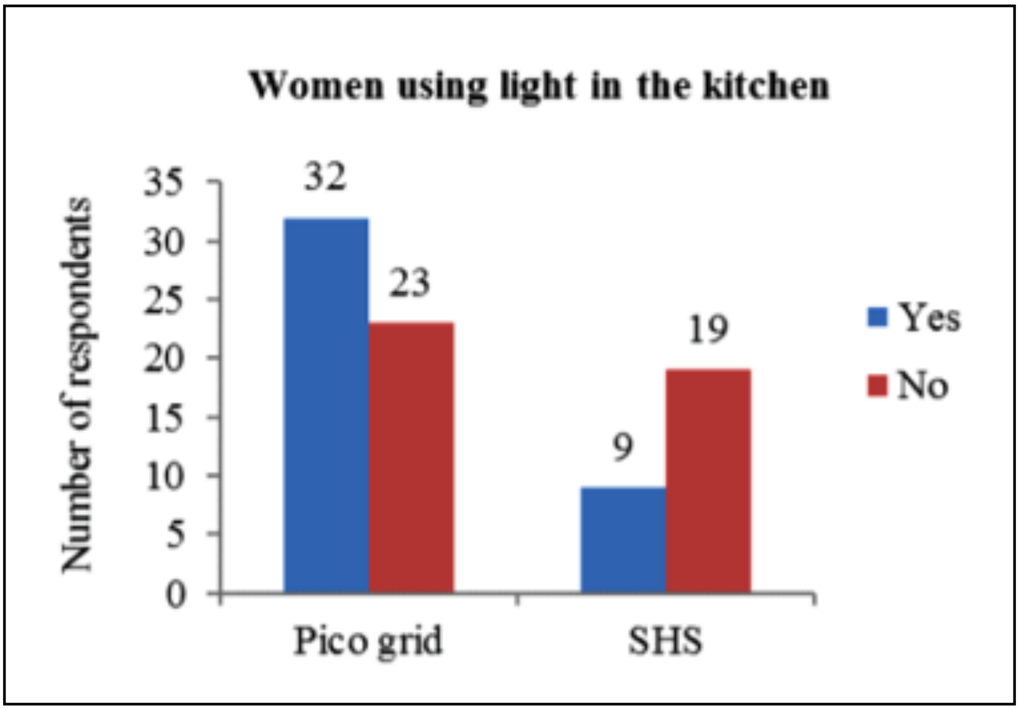


Figure 17: Use of light in the kitchen

(Source: Murali et al., 2015)

(d) Impact and changes in education

As illustrated in Figure 18, there have been changes in study hours before and after the installation of solar power systems; before only kerosene lamps were used for studying. There were not many changes seen in study hours in rural homes with SHS as most of the children in those areas studied at the village's common study center with private tutors. In contrast, there have been significant changes in the study hours of children in rural homes with solar AC pico-grids. There has been an increase in their study hours, in addition to their attendance in village study centers. The authors highlight that, the reason for this difference is due to the fact that, rural homes connected with SHS are financially stronger than rural homes with pico-grids, thus they can afford extra study sessions for their children in study centers (623).

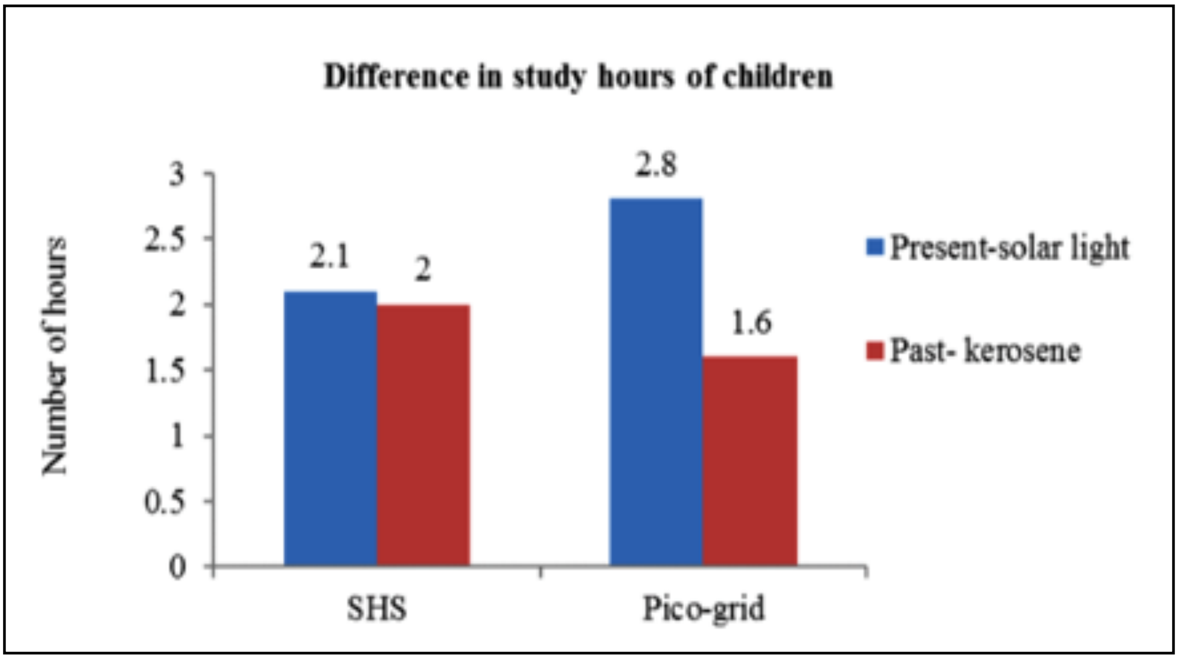


Figure 18: Difference in time spent for studying
(Source: Murali et al., 2015)

(e) Changes in health

Figure 19 illustrates the health issues resulting from kerosene consumption. When the authors conducted the survey study in February to March 2015, they asked the rural homes of they had witnessed or heard about any accidents or health issues arising due to kerosene consumption. To this, around 80 percent of the rural homes said ‘yes’ (624). There had been many accidents such as homes catching up on fire due to accidental knocking down of kerosene lamps, and children were accidentally drinking kerosene thinking that it is water. This result complements other studies conducted in India, where similar accidents due to kerosene have been reported. The old and the young are the most vulnerable groups (Jana, 2015). Due to the use of kerosene lamps in the kitchen, many issues are faced by the womenfolk. From the total 75 percent of kerosene consumers who indicated health issues, around 32 percent made regular visits to the doctor (Murali et al., 2015, 624).

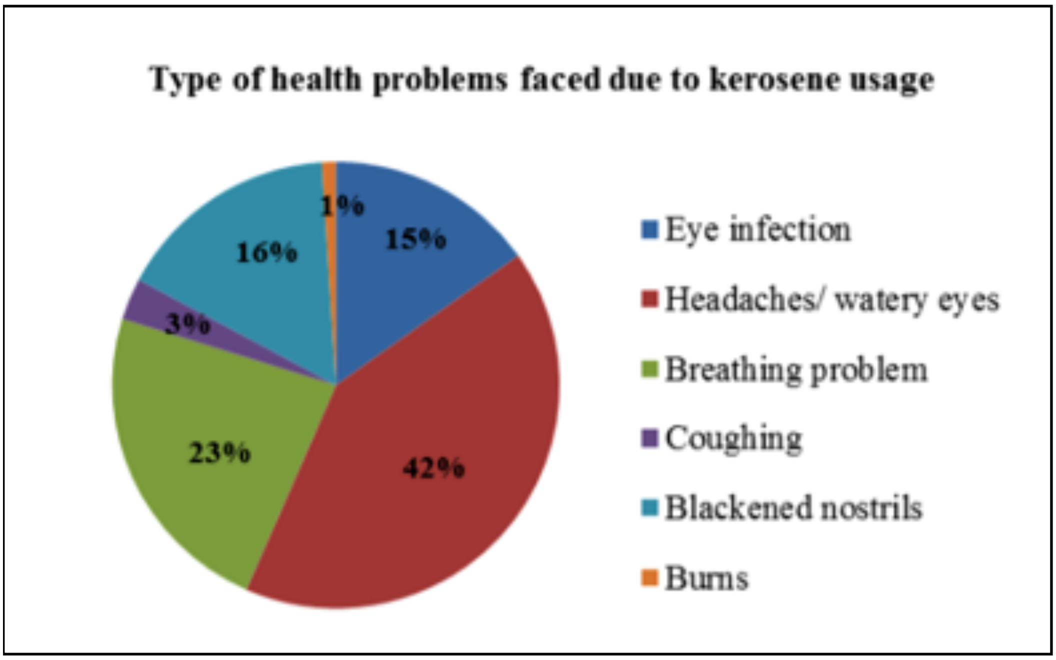


Figure 19: Health issues due to kerosene consumption
(Source: Murali et. al, 2015)

II. Impact on market users

(a) Changes in consumption and expenditure on kerosene

6 shops which were using kerosene for lighting their shops before getting connection of pico-grids were surveyed. These shops were using on an average 3 liters of kerosene in a month at a cost of € 1.90. However, after they were connected to the pico-grid, four out of the six shops said that they continued to use almost the same quantity of kerosene per month (624). The Solar Housing System (SHS) connected to 3 shops were surveyed. It was found that these shops prior to SHS connection, were using kerosene on an average of 4 liters a month at a cost of €

2.2. After SHS was made available, kerosene was used by only 2 shops on an average of 5 liters at a cost of € 2.88 per month. The reduction in the number of shops using kerosene are achievements of the SHS and pico-grids. Continued use of kerosene by some shops can be attributed to increase in business. This increase in business requires more lighting hours which is met from kerosene use. However, the amount spent on kerosene by these shops remains almost the same (625).

(b) Changes in income trends

When the shop-owners were surveyed and asked if they had experienced any changes in profit since the installation of the solar power systems, 67 percent of the SHS market users and 60 percent of the pico-grid market users said ‘yes’. From all the pico-grid market users who indicated that they had seen changes in their profit, 67 percent of them said that they attribute the change in to their monthly profit to the solar power, while 26 percent do not believe that the solar power systems were the reason for the profit (626). On the other hand, from all the SHS market users, 37.5 percent believed that solar light was the reason for the changes in their profit while the same amount believed that solar light was only partly responsible, as illustrated in Figure 20.

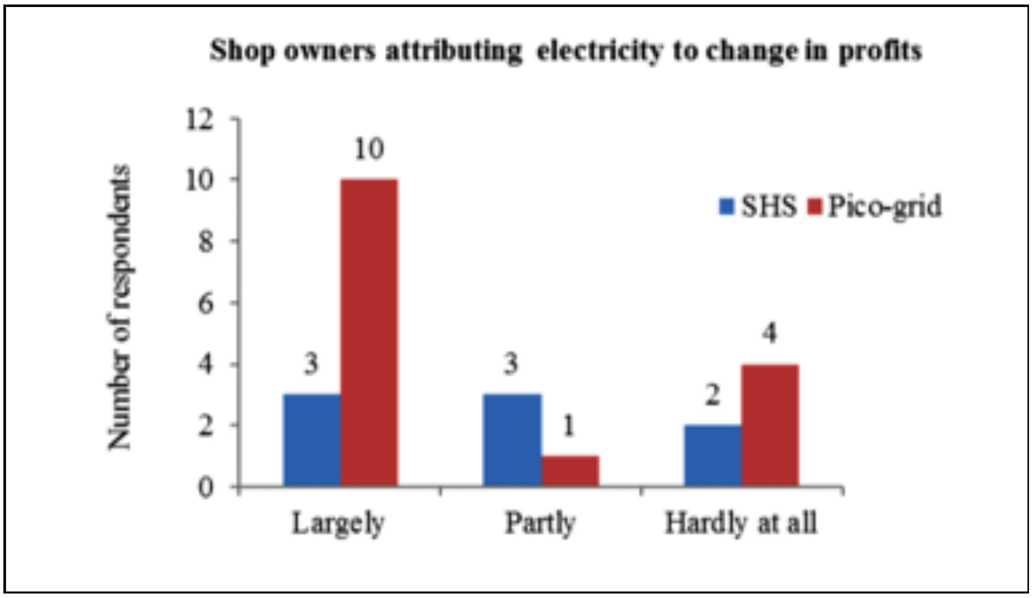


Figure 20: Market users that say solar power has changed their profits (Source: Murali et al., 2015)

(c) Future direction for appliance use

The survey-study also explored the future wants of the rural families. From the study, the authors wanted to know what changes in the use of appliances would arise if more power, through additional solar PV systems, were to be provided to the rural districts in the Sunderbans region. As illustrated in Figure 21, the pico-grid consumers sought to widen their appliance use, while, as illustrated in Figure 22, SHS market users only wanted to keep using some basic appliance (626). Pico-grids for market use are of larger size than the SHS and are of capacity ranging from 250 Wp to 2 kWp. The future appliance desires are much greater for the pico-grid consumers than the SHS consumers as the pico-grid consumers have been using various appliances, besides lighting, for a long time. They have been using fridges, TVs, fans, printers and much more. Therefore, they understand the convenience associated with modern technology and want to explore more possibilities. Whereas, the SHS consumers have only known the use of basic appliances such as light-bulbs and are content with whatever electricity they can get from their smaller systems (627).

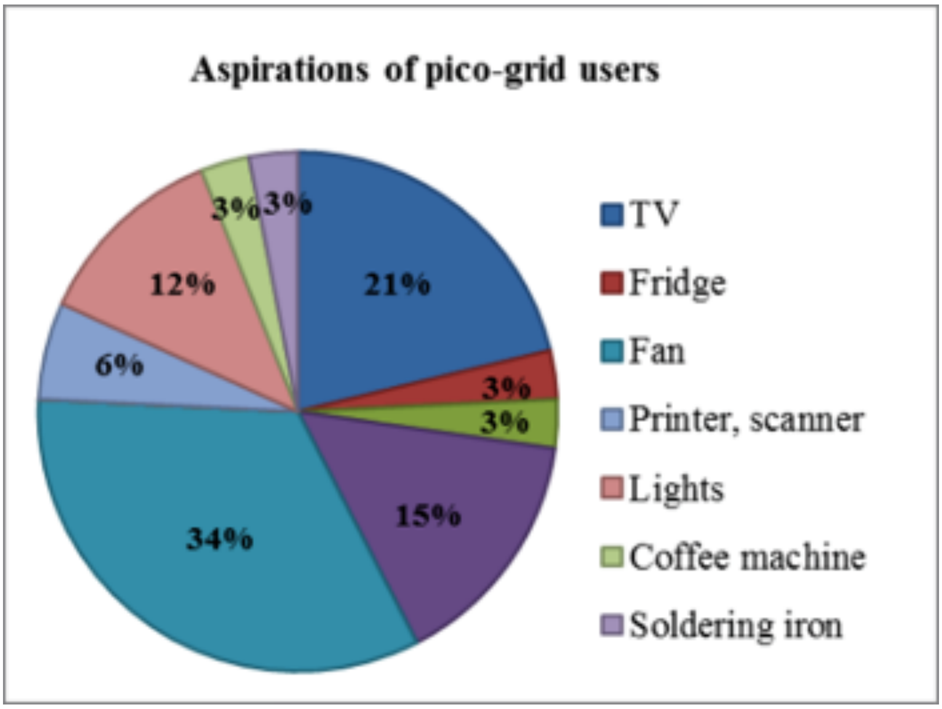


Figure 21: Future appliance wants of pico-grid consumers
(Source: Murali et al., 2015)

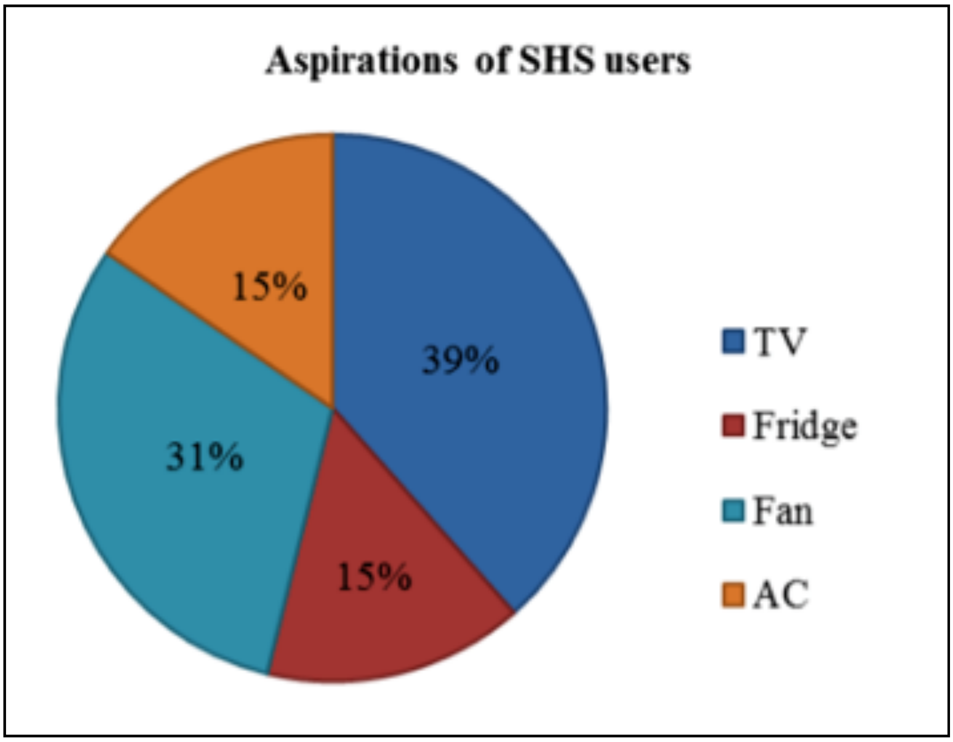


Figure 22: Future appliance wants of SHS consumers
(Source: Murali et al., 2015)

Thus, from this case study, it can be concluded that solar PV systems have had numerous positive impacts for rural districts. One of the significant changes has been the reduction of kerosene expenditure and consumption. However, as portrayed through the case study of the rural districts in the Sunderbans region, the reduction of kerosene consumption has been higher in pico-grid domestic consumers. In India, kerosene is distributed by the Pubic Distribution System (PDS) at a very subsidized rate. However, some scholars believe that it is regressive to grant subsidies on kerosene as it offers very less value financially to the rural districts (628). The reason being, kerosene quotas for domestic use are for cooking requirements whereas kerosene is used extensively by all communities for the purpose of lighting (Rao, 2012). When any community is given an option to receive quality light in a cost-effective way through financial schemes, people are more likely to buy such lighting systems. However, these rural communities have continued to purchase kerosene, distributed by PDS, to use in emergency situations, for instance, if the solar PV systems stopped functioning. This behavior is also prevalent in regions with grid connections, as they have backup generators and inverters and kerosene, to keep provide light during blackouts. The second reason is that the households getting kerosene hesitate to opt out of the government sponsored subsidized scheme. They are afraid that if they decide to opt out for this, they will be left behind in other welfare schemes in the near-future (Murali et al., 2015, 628).

The interesting thing to note about Mlinda Foundation, the agency that implemented the solar AC pico-grids in the rural districts in the Sunderbans region, is that they do not only install the systems and provide service and maintenance operations, they also want to create a sense of ownership amounts the domestic and market system holders. In these cases, after the loans were paid, the ownership of the solar power was turned to the users. The idea behind this is that, after these villagers understand how the system is managed, installed, maintained and monitored, they can continue using and installing similar systems without any support. This way, they can be self-reliant and self-sufficient. Despite the presence of Mlinda Foundation in providing initial technical and management training, they want that the main decisions about the management should come from the rural community. This will, and has proven to, create a sense of sustainability amongst the rural users and will ensure that they take proper care of these systems (628).

VI. Microgrids and Minigrids

In a report by NREL (2012), the key difference between microgrids and minigrids is highlighted. Minigrids provide AC from a locally installed network in a PV system, connected to either a single rural area or district. Microgrids, on the other hand, provide DC and are smaller in size. The Government of India and businesses use these criteria to identify both microgrids and minigrids. As per investigations conducted by NREL, around 40 percent of the energy generated was lost as a result of burglary and inefficient systems, which was and continues to buildup stress for the India's power infrastructure. India was estimated to grow economically around 7 to 8 percent every year. Consequently, this loss of energy and growing economy led to a growing demand of energy per person from 630 kWh to 1,000 kWh. At the time of the report, a 12 percent gap between demand and supply was indicated (Thirumurthy, N., et al., 2012, 1).

Due to the benefits of minigrids, in meeting energy needs in un-electrified regions, project developers are looking to install solar minigrids in Andaman and Nicobar and Lakshadweep Islands that are diesel-dependent and are not connected to the grid. Solar minigrids are a suitable alternative to generate power in remote rural districts that of not have grid connections. An added bonus is that they are independent systems and can be monitored and managed without hindering the performance of the central grid. Furthermore, minigrids provide reliable supply of power as they are distributed and any obstructions and faults in the system or supply can be easily rectified. There are also low transport and distribution costs due to proximity of the energy generation to the load (Thirumurthy, N., et al., 2012, 2)

As presented by NREL (2012), the aim of the Indian government is to install around 1,100 MW of solar minigrids under the JNNSM. The JNNSM, as explained earlier, plans to install an average minigrid system of 250 kW over 2 to 3 acres of rural land so that rural districts, without any power, can be electrified. Around € 3.96 billion is the expected cost of accomplishing the target under JNNSM. The annual target for installing solar minigrids by MNRE has been depicted in Table 6 (Thirumurthy, N., et al., 2012, 2).

Table 6: Annual Targets for Solar Mini-grid for the Period 2011-2017

Renewable Energy Applications/ years	Cumulative (likely by 31.3.11)	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	Total target for Six year period	Cumulative Total Target
Decentralized Solar PV systems-MWp	132	68	100	150	200	200	250	968	1,100

Source: Ministry of New and Renewable Energy, New Delhi

Though there are many benefits of installing minigrids, there are also some challenges to its installment that can have an impact on its performance, for instance (Thirumurthy, N., et al., 2012, 37):

i. Electricity production depends on the efficiency of the solar panels.

ii. Project costs increase because of faster battery replacements.

Though it is widely accepted that harnessing solar power is the best way to reap the benefits of renewable energy technologies in India and that decentralized solar minigrids is a great system that can be implemented to harness that energy to electricity rural homes, there are many challenges that are not allowing widespread implementation of solar minigrids in rural districts in India. The following challenges have been listed in a report by the Institute for Transformative Technologies (ITT) (2016). Firstly, compared to coal, solar power is still expensive and is a challenge that the Government needs to eliminate through incentives and subsidies. Secondly, based on the income of the rural community, they cannot afford the high electricity bills from minigrids. There is also less demand of energy in rural regions due to the lack of cheap appliances, so it does not make too much economic sense for some businesses to invest in minigrids. Thirdly, as minigrids have many components and each of them have their own capital cost, it is challenging to achieve reduced costs. Fourthly, there are technical faults in lead acid batteries, which are used for energy storage in solar minigrids. Research is being done to overcome these faults so that they can be reliable and affordable. Fifthly, “Smart meters” to monitor the electricity demand and usage is still a technology that is in the development stage. Sixthly, there are still energy losses in the minigrid system as they are dispersed and loose and do not operate in an integrated manner. Seventhly, funding for solar minigrid projects is still low but growing. As the technology is still so new, investors regard it as a risky investment. The regulations supporting solar minigrid development projects in India are still being developed (Buluswar, Shashi, et al., 2016, 1).

In addition to enumerating the challenges to minigrid development, the report by ITT (2016) also believes that the hurdles can be overcome so as to fulfill the objective of rural electrification in India. A three way method can be applied to combat the challenges, this includes technological advancements, promotion of private investments and development of supportive policies. The report highlights that developments in batteries for energy storage can be an important step in strengthening solar minigrids. The usually used lead-acid batteries can be replaced by ‘advanced’ lead acid batteries, sodium ion batteries or with a hybrid power system. An ‘advanced’ lead acid battery is simply an enhanced and improved version of lead-acid batteries. Sodium-ion batteries have been created especially for minigrids and it is cheap with a huge potential of being produced in India. A hybrid system incorporates both lithium-ion and lead-acid batteries in a control boundary (2).

The ITT (2016) report also encourages a carefully developed “utility-in-a-box” strategy. This means that a group of standardized components need to be created, along with effective metering, power collection, inverter and charge control and automatic billing techniques. The components must work efficiently with the associated batteries and other technologies. This strategy should also lead to lower costs by 10 to 20 percent. Through the use of this strategy, the rural community would be able to purchase energy-efficient appliances that would boost their energy demand. The power intensive AC motors can be replaced by DC power efficient motors in water pumps and other appliances. Therefore, in addition to developing a “utility-in-a-box” strategy, encouragement of investments from big businesses and focused policy adjustments to complement the Government's objectives, can increase cost-effectiveness and raise power consumption and demand (2).

As public-private partnership agreements (PPPs) have proven successful in large Indian cities to provide energy, they can also be adapted to meet the energy needs of rural regions in India (2). These agreements can permit the use of already existing governmental infrastructures in regions that have a grid but have interrupted power supply which can drastically lower cost of capital in minigrid development projects. This strategy can further strengthen the potential of various distributed systems, such as minigrids, to be connected to the conventional grid in the future. Similar to the Swachh Bharat Initiative, that encourages community cleanliness and responsible behavior, incentives should be developed for rural electrification, for instance, giving subsidies to rural homes that electricity their homes using renewable energy sources (2).

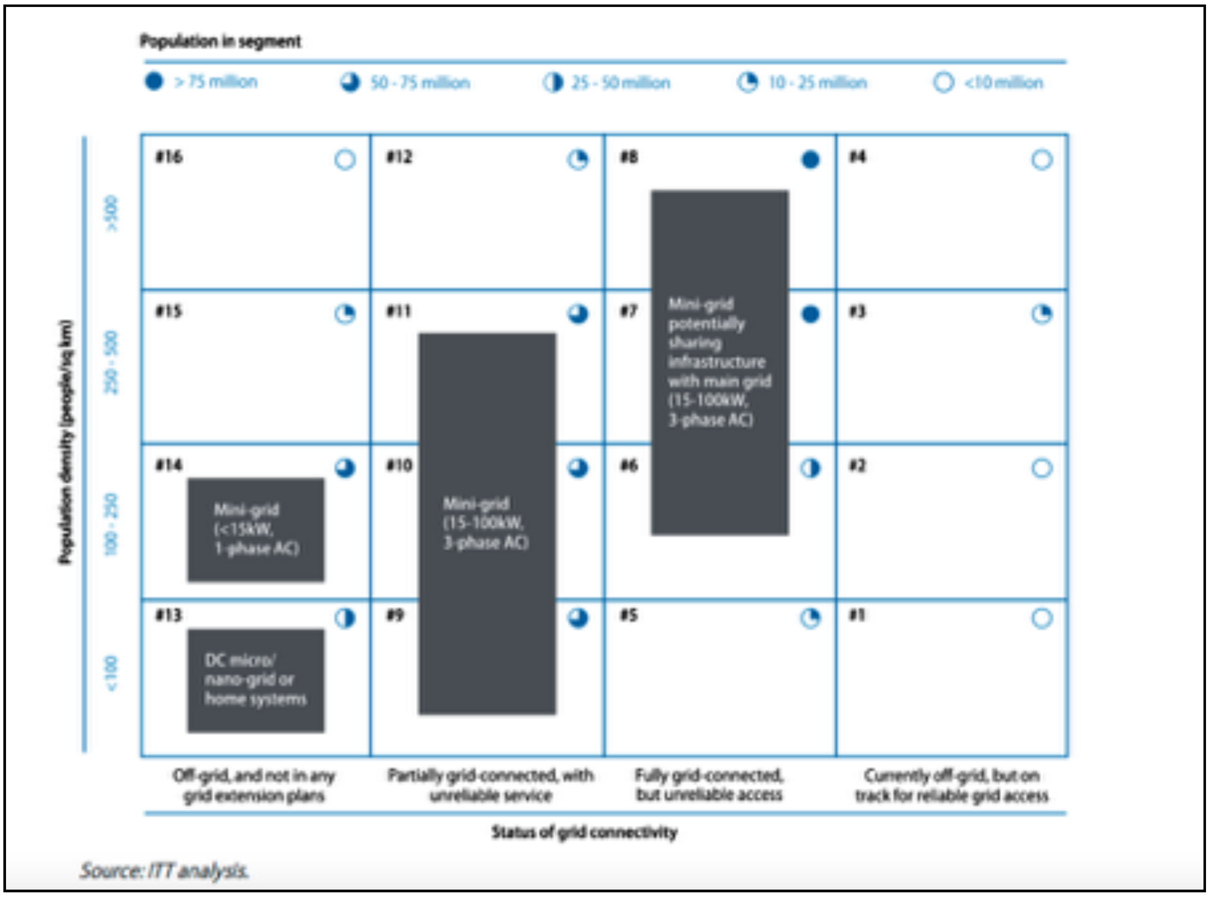


Figure 23: Different population densities in rural India and their potential for minigrid connectivity
(Source: ITT, 2016)

The Figure 23, as demonstrated in the report by ITT (2016), illustrates how various sizes of rural populations, taking into account their current and estimated access to power, can be electrified and by implementing what type of system (15). The categories of various rural population sizes have been given the number 1 to 16. Minigrid systems have been indicated as being suitable for segments 6, 7 and 8, with medium and high population density. These segments have access to the conventional grid but do not receive frequent and uninterrupted supply of power. Therefore, the minigrid systems can be implemented alongside the already present grid to meet the power demand. Policy changes need to be made so that the use of minigrids with already present infrastructure can be possible. Mini-grid systems are suitable for this segment of population, in which they can produce the electricity themselves but the current public grid is used by them for distribution of electricity in the locality. The infrastructure existing now for 3 phase AC were perhaps set up for bigger use of industries. However, for effective use of the existing infrastructure, government should make requisite changes in policy so that the shared usage of these infrastructures is made possible. It should be ensured that energy generated in a mini-grid system is used to serve the rural population rather than transmitting it elsewhere. This may necessitate cutting up of the local mini-grid from the main grid to prevent it from transmitted (15).

Segments 9, 10 and 11 represent low to medium population densities where the grid connectivity only provides power to some parts of the region. Therefore, in order to provide power to the un-electrified homes in the region, decentralized minigrid systems can be implemented. Based on the intensity of the activity and the population of the given area, the minigrid can have the capacity of 15 kW to 50 kW. Due to low rate of industrial activity, Segment 14, that represents areas with medium population density and remote un-electrified regions, can be powered by AC minigrids with a capacity less than 15 kW. These regions are so remote with less activity that only smaller systems will be able to meet the power needs of the region. Segment 13 is very thinly populated and is entirely off-grid. This segment has limited or no industrial activities. Introduction of solar home systems or DC nano-grids which are enough for LED lamps, mobile charger point and other low load usage can be useful for developments which can be long-term. This type of electrification can be termed “pre-electrification” (15). Population strata of 1 to 4, are of different population densities and are presently not connected to any grid but on course of being connected to a grid with reliable electricity supply. This of course represents a small portion of the total population and this is same for population segment number 5, 12, 15 and 16.

On the basis of above, it can be concluded that mini-grids of different sizes and configurations are suitable to provide electricity to the large majority of rural population in India who are at present without any electricity. These mini-grids can be integrated to the main grid over a period of time. After they are connected to the main grid, the mini-grids will contribute to the energy supply of the country rather than serving only the locality where they are installed (Buluswar, Shashi, et al., 2016, 16).

Similar to the Green Revolution in 1970s, the Government of India should cooperate with the State Electricity Boards and businesses towards an Energy Revolution in India. Off-grid minigrid systems, using solar PV energy, have the capability to power around 80 million homes in India, that are un-electrified (Census of India, 2011). As presented in earlier chapters, India has huge solar potential as it receives 5000 trillion kWh of solar energy per year. Furthermore, solar PV technologies have a huge potential of electrifying rural homes as they are easy to implement, install, fulfill increasing energy demand and need less interventions. Though solar lanterns are being distributed to rural homes to provide light, by the implementation of solar minigrids, the rural districts can receive ‘on-demand electricity beyond lighting’ (Chandran-Wadia, 2015). This way, there quality of life will also improve.

Besides the technological and sociological challenges, financing remains the main challenge (Chandran-Wadia, 2015). The costs are on account of the costs of the solar panels, their installations and maintenance in remote areas. 30 % of costs of such systems are subsidized by the government through the JNNSM. There is another state government sponsored program called the Decentralized Distribution Generation (DDG) which provides 90% subsidy. In spite of the subsidies, the Solar

PV minigrids have not been set up by many private developers because of non-clarity on many policy aspects.

Since more than last ten years, rural centralized micro grids are being used in India. The working of these micro grids have been evaluated from their techno economic perspectives. One of the evaluations has been undertaken by Chakrabarty and Chakrabarty (2002). They have examined the use of micro grids in an isolated and remote island named Sagardeep in the Indian state of West Bengal, from socio economic and ecological perspectives. They have also undertaken a feasibility study on the use of decentralized PV minigrids as a reliable source of electricity compared to the conventional methods. To analyze the performance both commercial and technical parameters were taken into account. It was observed that the micro PV systems offer a better performance in comparison to the conventional sources when the demand does not exceed 20 to 25 kW with a load factor of less than 30% (Chaurey and Kandpal, 2010, 2273). Therefore, there are indications that in near future Sagardeep island will see more PV microgrid installations because of its reducing costs of installation and maintenance, readily available technology, simplified operations, maximum availability of resources in remote areas and islands and environment sustainability. The analysis also observed that a nominal fee for maintenance is acceptable to the consumers. The consumers also preferred to be billed by meters than by a flat fee per connection (Moharil and Kulkarni, 2009).

6.1 Case Study: Minigrids in Leh, Ladakh

Figure 24: Leh, Ladakh, India

Source: Google Images

In a report developed by the NREL (2012), where they analyzed the data for energy demand and capacity of electricity provided by the Ladakh Renewable Energy Development Agency (LREDA) from the Leh District in the Ladakh region, they provided the technical configuration for the development of solar minigrid projects in the region. As presented in the report, the present capacity installed in the Leh District amounts to 23.14 MW, which consists of 15.2 MW power from diesel, 7.8 MW power from hydropower and 140 kW from solar power. According to the data provided by LREDA, it was estimated that the demand for power and energy in the Leh District rose at an average rate of 7% from 58.53 MW in 2005 to 87 MW in 2011 (Thirumurthy, N., et al, 2012). The energy demand grew up to 107 MW in 2014 taking into account the growth rate experienced in 2011, as illustrated in Figure 25 which was presented in the report by NREL (2012).

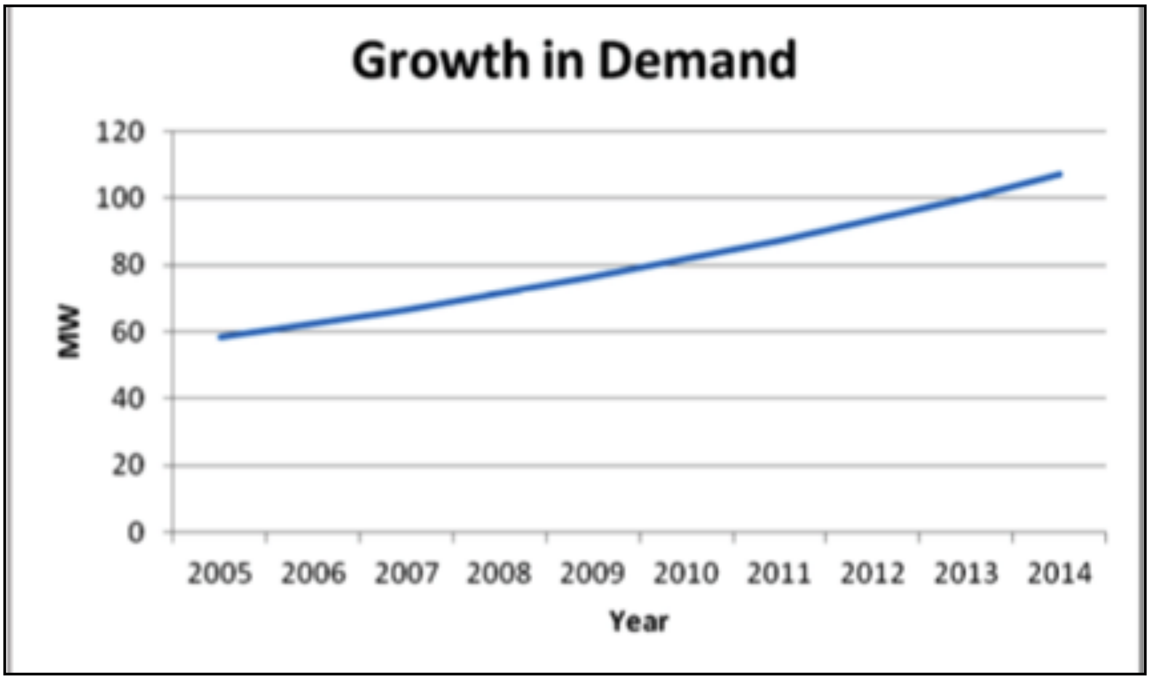


Figure 25: Projected growth in power demand in 2014

Source: LREDA

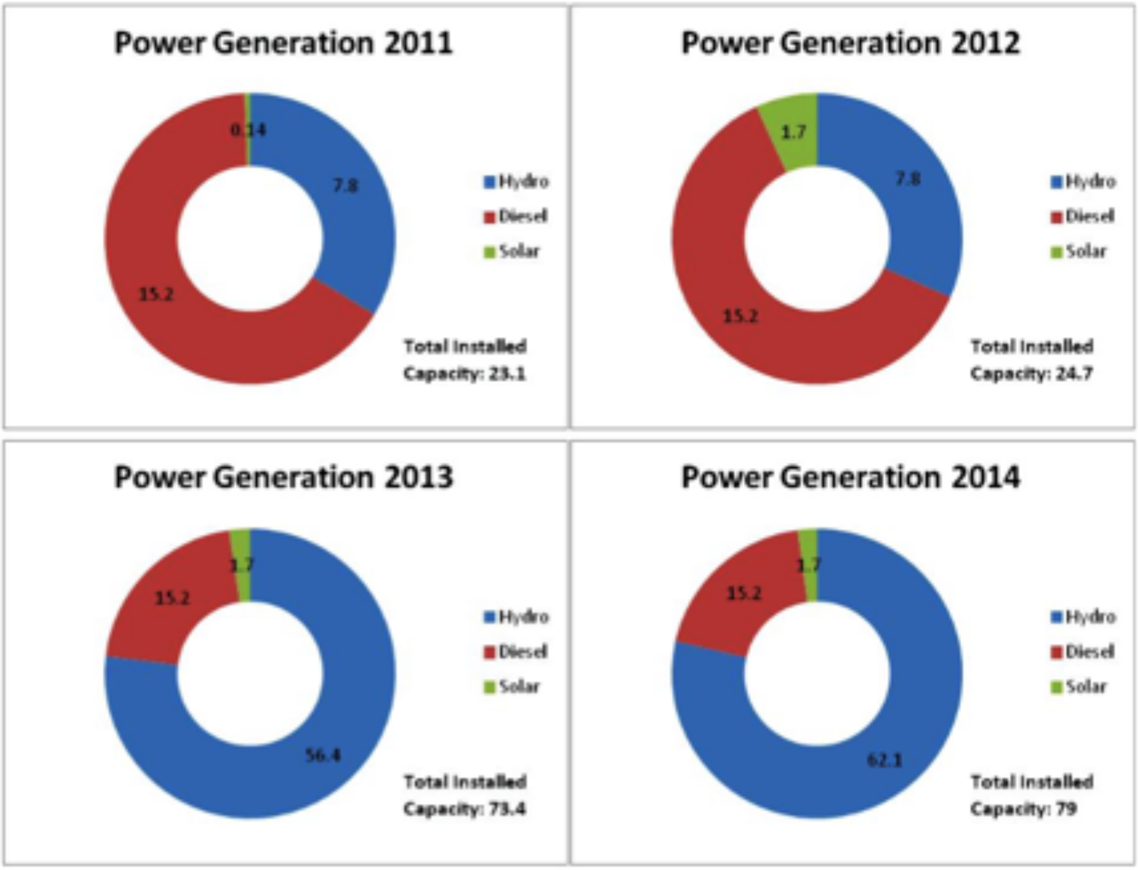


Figure 26: Estimations that were made for installed capacity for 2014

Source: LREDA

Solar powered minigrids have the strength and ability to supply the Leh District with the energy that they need, for an entire year. A Solar PV system of 250 kW which is based on NREL developed and solar insolation simulated data can generate 427,737 kWh over one year. As the JNNSM provides subsidies for minigrid projects, as per specification laid out in the Mission, a 250 kW system was chosen by the NREL in its technical configuration as that is the maximum allowed by the JNNSM. In order to store 1.2 MWh of energy with a 200 kW of power rating, a storage system of 60 kW shall be required. This is of course would base on the output of solar energy. According to the report, in order to meet the energy needs of the Leh District, around 180 to 310 systems of 250 kW needs to be built (Thirumurthy, N., et al, 2012).

It is crucial that the abundance of solar energy be exploited to develop solar technology. Solar energy systems can be a suitable alternative to create a well-networked system of local clusters of minigrids which would distribute the electricity generated. This would also be a great measure to reduce the need for a centralized power system, an expensive system that cannot reach remote regions, and will also generate energy for the population living in the remote village, such as the Leh District in Ladakh (Thirumurthy, N., et al, 2012, 1). Due to the remoteness of the villages in the state of Jammu and Kashmir, it serves all the criteria to be considered as a 'special category' state under the JNNSM and can receive large sums of subsidy under the Mission. In the State of Jammu and Kashmir, Leh district is located in the Ladakh region and is of 45,000 sq. kilometers. Leh is the largest city in the region with a population of approximately 117,000. Leh district is divided into various blocks and each block consists of several villages. Few hundreds of houses and a few businesses comprise a village (10).

According to the Ladakh Autonomous Hill Development Council (LAHDC), the governing body of the Leh District, developments have to be made to the energy sectors and the power grid so that the demand of electricity of the District can be met (Thirumurthy, N., et al, 2012, 11). Under the government of India, two programmes have been entrusted with developing the systems and establishing energy systems for rural electrification - namely, the RGGVY of the MoP and the

JNNSM of the LREDA, under MNRE. As stated in the earlier chapters, the JNNSM is responsible of various kinds of renewable energy projects to electrify rural districts. While the RGGVP deals with developing infrastructure for electrifying rural districts it also develops systems for electrifying homes and industries. Thus, a majority of the renewable energy projects in the Leh District from the Ladakh Renewable Energy Initiative falls under the supervision of the LREDA. For instance, some of those projects include hydropower, solar photovoltaics and solar thermal projects (11).

In Leh district with a 40 kW mini grid in Nyoma and another of 100 kW in Tangste, the total installed capacity is 140 kW. By Solar Home Lighting systems, LREDA has electrified more than 10,000 dwellings in 39 villages in Leh District. As the lead-acid batteries of 12 volts are no longer operational, most of these systems are not working (15). Presently in villages, diesel generators of 100 kW and 250 kW meet the electricity demand mostly during evening from 6 to 11 P.M. After the project is completed, for the summer months, electricity will be supplied to the population through newly constructed hydropower plants. However, due to the low winter temperatures in the region, the rivers will freeze which will make the hydropower plants useless. As per historic practice, the villagers used to use kerosene, liquid propane gas and wood to heat their homes. However, according to the report by the NREL, solar technology has the capacity and ability to establish energy security in the Leh District, as it is capable of fulfilling the energy demands of the villagers, throughout the year (16).

A metering system has been set up in all the homes in the Leh District by the JKPDD. They have also eliminated all the restrictions on the different load types. The villagers in the Leh District typically use their electricity to charge their phones, use their television sets and music systems, and electrify their homes with CFLs or incandescent light bulbs. Only a small number of homes operate additional appliances such as refrigerators, computers and washing machines. Table 7 shows the power supply shortage faced by various blocks in Leh district. After consultations with LREDA, it was estimated by JKPDD that in a number of blocks, electricity demand was over 500 W. However, according to a study by Ladakh Ecological Development Group (LEDeG), the load per household is around 160W.

The discrepancy in two estimates is because most of the households use minimum number of electrical appliances because of erratic power supply. Therefore, it can be safely assumed that people would use more power if it is reliable (Thirumurthy, N., et al, 2012, 16).

Table 7: Energy demand by villages in Leh District

Table 1: BLOCK-WISE DISTRIBUTION OF ENERGY REQUIREMENTS Serial No.	Block	Number of Households (source: 2001 census)	Average Connected Load Per Household (W) (source: survey conducted by LEDeG in 2004)	Required Connected Load Per Household (W)	Peak Energy Requirement for Domestic Use as Per Required Load (kW)
1	Diskit	2,305	115	500	1,153
2	Panamik	1,067	115	500	534
3	Chuchot	2,671	186	500	1,336
4	Durbuk	951	78	500	476
5	Khaltsi	2,641	115	500	1,321
6	Kharu	1,566	98	500	783
7	Leh	3,350	140	500	1,675
8	Nyoma	2,082	137	500	1,041
9	Saspol	934	186	500	467
10	Leh Town	6,580	432	1,000	6,580
TOTAL		24,147		15,166 (15.16 MW)	

Source: LREDA

There are commercial blocks mostly in Leh. However, there are also commercial establishments in the nearby area of Choglamsar and other areas like Khaltse, Diskit, Kharu, Tangste and Nyoma. These commercial establishments have load demand in addition to the domestic demand. Each of these villages has two to five shops that sell products for consumers. An increase of more than 7 percent was estimated for the loads in the following blocks: Leh, Khaltse, Chuchot and Kharu (17).

From Figure 27, one can make an inference that the electricity needs of various kinds of villages - partially electrified and completely unelectrified - can be met by developing stand-alone 250 kW solar PV systems (20). Villages with partial electrification through solar PV systems have many advantages. They have the capacity to replace the currently used diesel generators and can employ the already available T&D infrastructures (21). This way, the solar PV systems in these villages fair well and meet the energy demands of the villagers and are successful in meeting their energy needs in homes and industries. JKPDD is in charge of distribution work in already electrified villages in Leh district. As depicted in Figure 8, the electricity of 415 V generated by the generators are lowered down to 240 V before they are supplied for domestic use. The local solar PV projects can also be connected to the function grids at 415 V. Villages without any electricity would have to have extra costs as they would have to build T&D infrastructures. The cost of such projects in the Leh District is well illustrated in Table 8. All the projects seeking to electrify villages with minigrids are at an advantage as there are opportunities for them to receive subsidies for developing networks of distribution. These subsidies are provided by the RGGVY, as they support renewable energy projects for rural electrification (21).

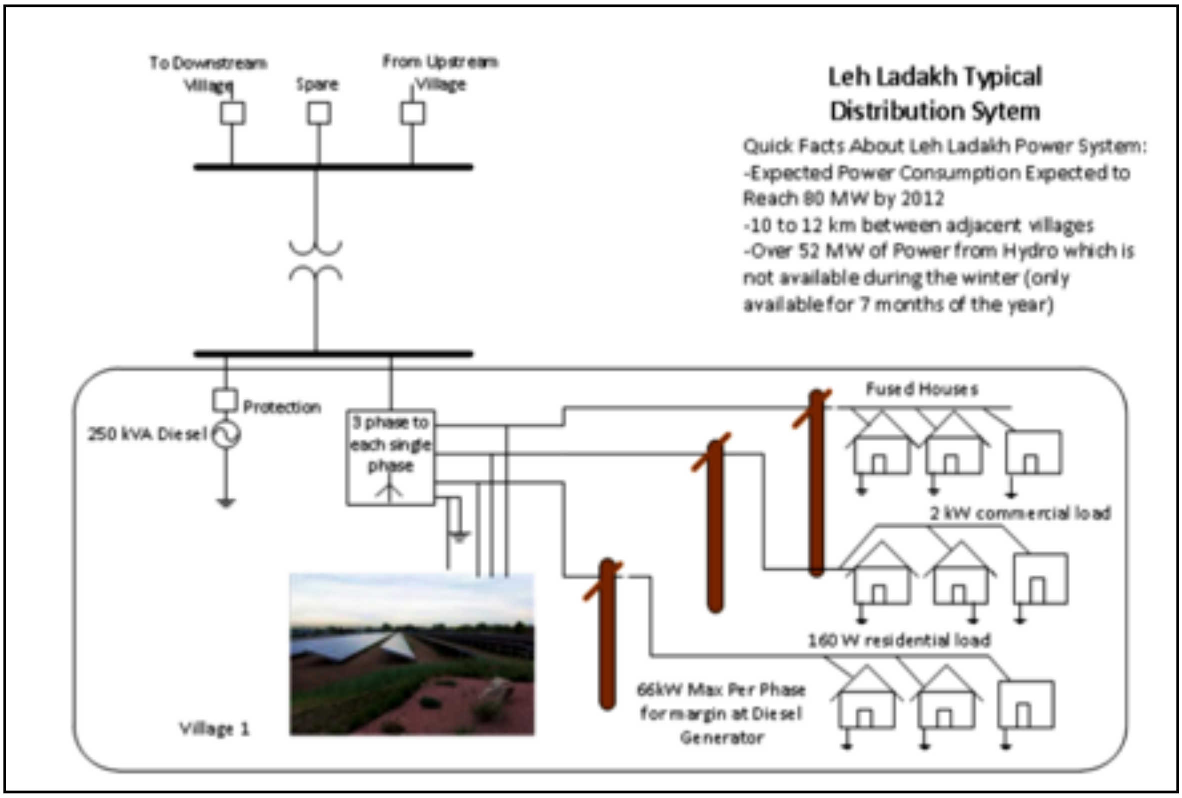


Figure 27: Technical configuration of minigrids planned for Leh District
Source: NREL, 2012

Table 8: Cost for Transmission and Distribution Infrastructure

Item of Work	Unit	Unit Cost (millions Rs)
Construction of 11/33-kV grid station	Nos.	27.6
Construction of three 33/11-kV receiving stations	Nos.	28.9
Construction of 33-kV line	km	2.7
Cost of 11-kV OH line for connecting 11-kV feeders from grid station to existing 11-Kv line on weasel conductor	km	0.5

Source: LREDA

Subsidy for mini-grids under JNNSM has been capped at 250 kW per system and that is the reason behind selecting the 250kW systems. There are many factors involved in deciding the quantity and the dimensions of the 250 kW minigrid systems that would electrify rural districts. Some of those factors include the energy demand of the rural homes and industries. While developing an unit of 1 MW, a developer may build four units of 250kW, this allows the developer to take advantage of JNNSM subsidy which is capped at 250kW per unit (Thirumurthy, N., et al, 2012, 22). Furthermore, different villages, with their own minigrids, can be connected and fined using 66 kW lines. Along the long yellow line on the map, LREDA has already approved construction of 33 kV lines. It will be much simpler for project developers to connect their green energy projects if various villages are connected using this method. Once connected and joined to each other, the reliability and the reach of the electricity, generated from solar resources, increases. This further reduces interruptions and variability in the energy supply, which will benefit the rural population (22).

With regard to batteries and energy storage, there are different varieties of batteries for grid uses (24). Lead acid batteries have advantage over other technologies in that they are low cost batteries. However such batteries have disadvantages like their shorter life and use of toxic materials in their manufacturing. Li-ion though have a longer life and high energy density are much costlier than the lead-acid batteries. According to the NREL report, lead acid and lithium-ion batteries are suitable choices for rural electrification projects in the Leh District in Ladakh. Presently, India does not domestically manufacture lithium-ion batteries and all are mainly imported. Therefore, the only available choice in India is the use of lead-acid batteries. As presented in the report, the batteries avidly used in Indian power plants are Gel, AGM and Flood Type LMLA batteries. The environmental and climatic conditions of Ladakh have an opposite effect on the battery life; Ladakh has a ‘cold desert-like environment’. Thus, it is imperative that storage rooms for batteries be constructed to protect the batteries from the Ladakh climate. This, in turn, would lead to additional expenses in the solar PV power plant projects in the Ladakh region (24).

To determine whether the energy storage of the PV system is economical and suitable for the system, the energy needed and used during the night should equal the energy stored in the battery during the sunny daytime. It would not make economical sense to install energy storage in an area, for an entire year, and not provide energy to it to charge it. Arrangements for autonomous power supply in Ladakh have been made by proper sizing of batteries of existing projects. Recognizing the importance of cost for implementing a plant, various factors such as power plant capacity and the corresponding transportability of plant components, landscape type, and land availability near the present transmission infrastructure are taken into consideration before finalizing installation of a plant (24).

An important aspect of energy storage systems that should be remembered is that there is a limit to the quantity of energy that the system can keep in storage. The energy storage device will automatically switch off when it has reached its maximum capacity, especially on days when there is maximum irradiance. Conversely, the device will also automatically switch off if it cannot charge due to days with minimum irradiance. The PV and systems require to be controlled during this period in order to maintain the quality of power (26).

Much of the energy demand of Leh is met by hydro electricity. However, during winter, the hydro electricity generation decreases considerably when the effective installed capacity is only 31.85 MW and the shortfall can be met by solar power. In summer, to meet the electricity demand an additional 28 MW of solar power would be required with the existing 1.7 MW of solar, 62.1 MW of Hydro and 15.2 MW of diesel capacity (26). In the above scenario, in winter in Leh, there would be a deficit of 47 MW, as illustrated in Figure 28 (27). This will result in excess solar capacity of 47.3 MW in Leh during summer months when hydro electric generation is fully operational, as depicted in Figure 29 (27).

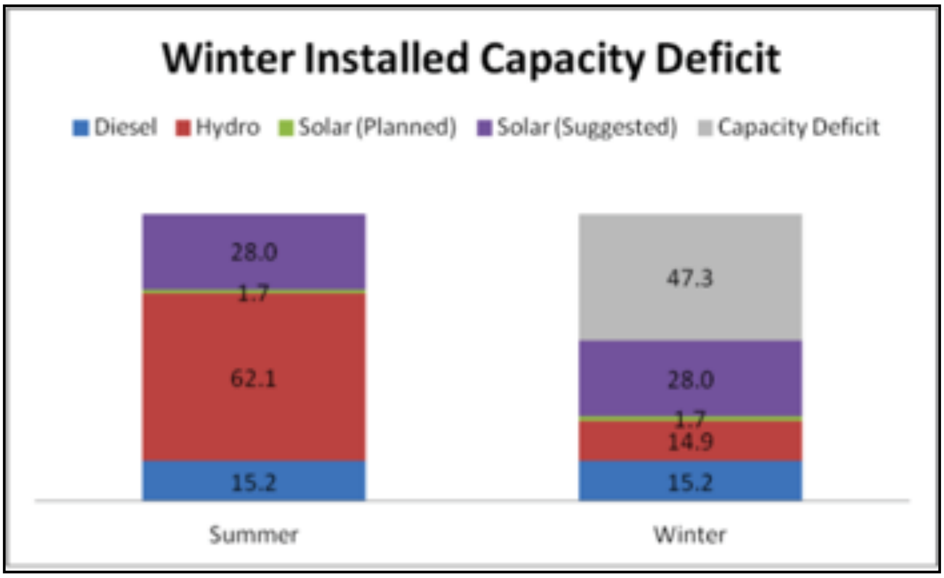


Figure 28: Deficit in winter installed capacity (MW)
Source: NREL, 2012

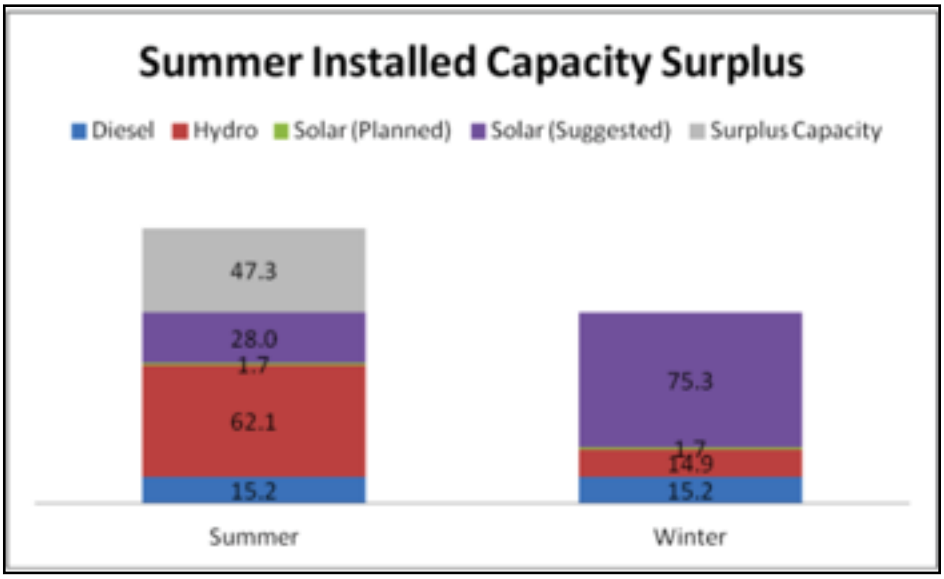


Figure 29: Surplus in summer installed capacity (MW)
Source: NREL, 2012

VII. Costs, Investments and Incentives

In the case studies presented, the different financial schemes, costs, investments and government incentives have been examined and illustrated. The details in Chapter II also portray the incentives and subsidies provided under various programmes under the Government of India and the Ministry of New and Renewable Energy (MNRE). In the following pages, we will further analyze the financial aspects and incentives to solar power and why it is suitable for rural electrification.

According to the analysis presented in a technical report by NREL, the electricity cost ranges from 0.084 €/kWh to 0.12 €/kWh. Therefore, as per these prices, solar electricity is much cheaper compared to other alternatives such as diesel, and in some cases, even cheaper to hydropower. To demonstrate, the electricity cost for diesel ranges from 0.16 €/kWh to 0.90 €/kWh and the electricity cost of hydropower ranges from 0.04 €/kWh to 0.13 €/kWh, which changes with the size of hydropower plant (Thirumurthy, N., et al, 2012).

The Government of India plans to invest € 16.2 billion by 2042 to boost the rural electrification programmes in India. The main focus of the MNRE is to electricity the remote off-grid villages. The government in partnership with regional rural banks facilitated investments, subsidized photovoltaic systems and undertaking implementation of national rural electrification programme such as Rajiv Gandhi Grameen Vikas Yojana (RGGVY. Ministry of New and Renewable Energy has provided details on eligibility, funding schemes and the process of implementation of the schemes in their booklets named "Solar Off-grid Refinance Scheme" and "Guidelines for Off-grid and Decentralized Solar Application” (Thirumurthy, N., et al., 2012, 3).

As illustrated in Figure 30, the Indian Renewable Energy Development Agency (IREDA) administers and implements the funds granted for JNNSM as per the prescribed guidelines under MNRE (Thirumurthy, N., et al, 2012, 4).

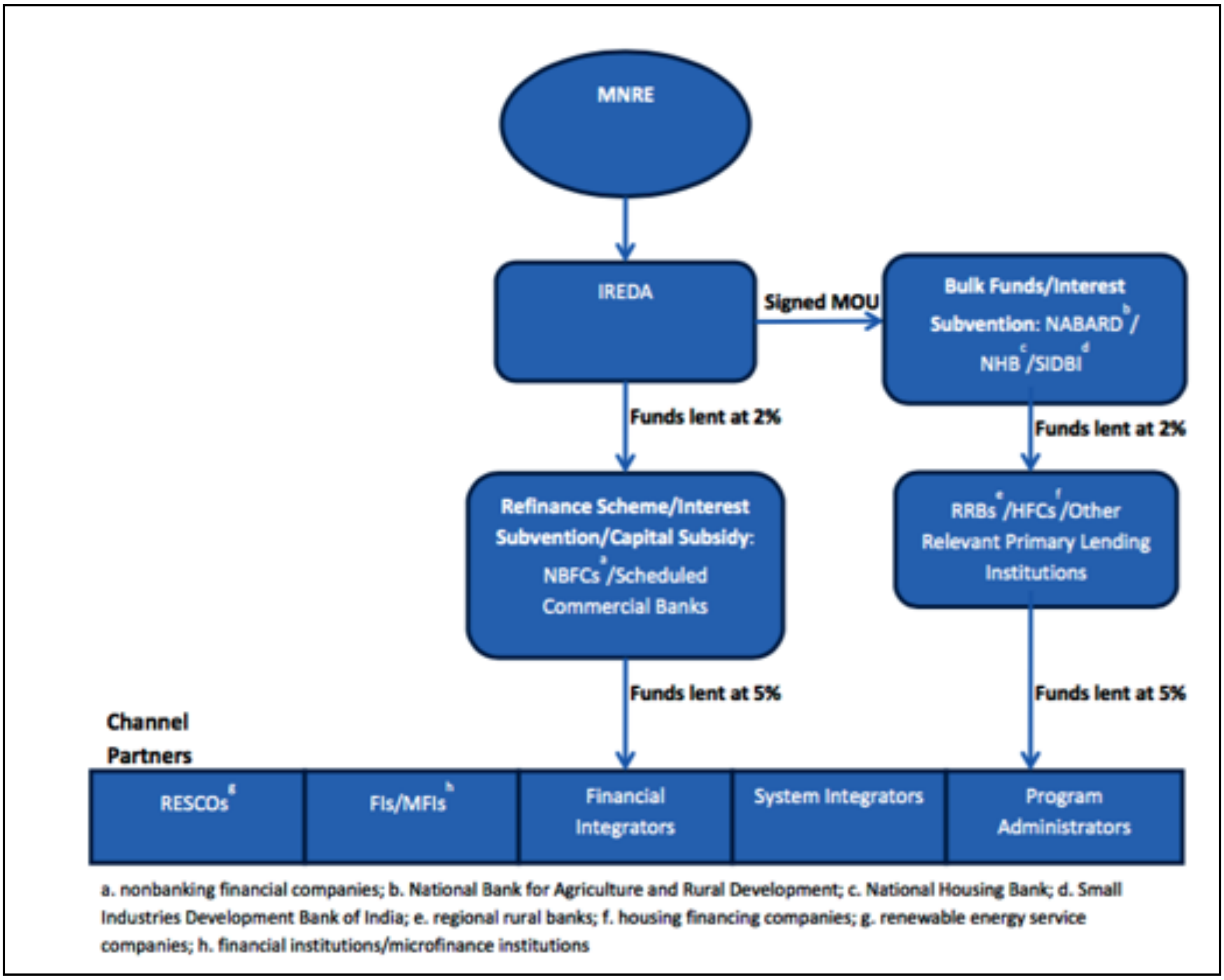


Figure 30: Funding for JNNSM

Source: IREDA

These various models of aid are under implementation. More than € 540 million of funds are donated for the solar PV projects in many developing countries, such as Asian Africa and Latin America by donors such as the World Bank and

International Finance Corporation (Grimshaw and Lewis, 2010). However, now, importance is being given in building up the financial strength of the rural community so that they do not always have to rely on direct aid to receive energy. For instance, in India, microfinance schemes are provided by the banks. Loans for buying, installing and servicing of the PV systems are provided by the Aryavart Gramin Bank of India, directed towards the rural poor. Repayment of credits works out to be less than the cost of kerosene for one month and the repayment period is spread over 5 year. The private sector also plays a role in micro financing solar projects. For instance, SELCO is an Indian company that was recorded to have sold around 100,000 SHS. It main work is to connect the solar power consumers and clients with microfinance officials, who can provide them with more information on how to receive funding. SELCO also offers 'down-payment' guarantees to aid with capital payments (Grimshaw and Lewis, 2010).

The Government of India should also take steps to offer the rural districts with affordable solar power systems that would help them with basic electricity access. The government can do so by investing in R&D and offer subsidies and further incentives to encourage solar power system installation and help out with maintenance and service costs. These incentives must favor the off-grid, remote, decentralized smaller renewable energy systems. More recommendations and the future direction of rural electrification programmes in India, will be explored further in the next chapter.

VIII. Recommendations and Future Direction

Table 9: Best practices for success of SHS program

Finance	Institutional	Technical
Affordable system price	NGOs, cooperatives	Modules
Finance for battery replacement	Service response	Structural support
Streamline of application procedure	Monitoring and supervising	Battery
Collateral and security practices	Establishing standards	Improved charge controller
Flexible repayment schedule	On-going technical training	Fixtures and lamps
Attractive guarantee	Educating	Spare parts

Source: Kamalapur, 2015

Though the use of renewable energy technologies is known to combat climate change, the shift of nations towards electricity generation based systems, especially in remote rural districts, requires vigorous training, education, development of skills and procedures, as they are not as prevalent in rural districts. Therefore, for the future sanctity of renewable energy projects for rural electrification, steps must be taken to strengthen and build the capacity of rural communities, by providing information and training from experts and other agencies, so that frameworks, political initiatives and other rural electrification programmes can be implemented.

With regard to the development of minigrids in India, a concept that was presented in detail in Chapter VI, the following steps can be taken. Firstly, suitable sections of land can be identified and added to a "land bank". This will reduce the time and cost, in the future, of finding suitable land for minigrid projects and will reduce gaps in project development. Secondly, streamlining of procedures for developing minigrid or other renewable energy projects should be a focus. This will help in creating a checks and balance system and will ensure that the services are delivered on-time and projects are handled in a safe and cost-effective way. Thirdly, projects should be developed in such a way that it attracts investments from banks or financial institutions by means of off-take agreements and clubbing of villages for providing affordable electricity, thereby increasing the number of consumers. Furthermore training and provision of incentives will encourage entrepreneurs from rural areas to augment prospects of revenue on a long term basis for investors and the electricity providers. Fourthly, to develop minigrid deployments, pilot projects on implementation of various minigrids across India can be explored so that a turn-key system's approach for a technical model which can be replicated can be developed (Thirumurthy, N., et al., 2012)

Currently, compared to non-renewable carbon-based power sources, solar technologies such as solar-thermal and photovoltaic systems cost more and are not as widespread. However, due to the analysis of researchers who argue that the planet will run out of petroleum by 2025, political instability in most of the petroleum producing countries, and the worldwide awareness of the negative effects on the climate arising from fossil fuel consumption, many businesses and market trends will, most like, favor renewable technologies, such as solar power, in the future. Another way that the potential of solar power can be boosted is through government subsidies. In the future, with technological advancements, increase in production and decrease of costs, solar technologies will be in high demand. For the success of solar power in the market, it is imperative to reach grid parity. According to this, the cost of power from conventional grids should be cheaper than or equal to the cost of solar power, without governmental subsidies.

In relation to solar power system batteries, it can amount to about 40 percent of the decentralized solar power system. Replacing batteries is an additional cost, in such systems, as the lifetime of batteries is shorter than that of solar panels. An important note to make is that there is strong relation between the efficiency of appliances and the cost of power supply in an off-grid power system. For instance, as illustrated by the experience of some German engineers in installing PV systems in developing nations, it was found that the cost of supplying off-grid solar power to one village can fall from € 31,500 to € 7,470, if the rural community use efficient CFLs and refrigerators (Grimshaw and Lewis, 2010). The positive impacts of solar power systems have been presented in various case studies and sections before. However, the most uplifting benefit of these systems is that they provide the rural communities with new income generating activities and training that helps them develop socio-economically.

Mulugetta et al. (2000), think that there is great scope to galvanize PV electrification to create a rural energy market by demand stimulation and cultivating a culture of payment for energy related services [55]. Provision of fiscal and financial incentives like tax holiday, excise duty abolition, tax-free dividend for investors and industrialists will boost the PV market, as in case of PV market in Nigeria (Oparaku, 2003). In Greece, the implementation of PV system is based on a very simplified licensing procedure and a better coordination for expeditious environmental approvals (Bakos, 2009). According to Shum and Watanabe (2008), for a successful dissemination of PV systems, the strategy should be based on market demand increase, so that cost of key components like solar cell is reduced. Another strategy is to use the flexibility of PV systems to meet the unusual requirements of users downstream (Chaurey and Kandpal, 2010, 2268).

It continues to be a challenge in finding a balance between the market-pull which is based on willingness to pay, credit availability, after sales service, system designs and donor-push strategies in terms of fiscal and financial incentives, research and development support and simplified procedures, as both these factors have contributed to the popularity of decentralized photovoltaic markets around the world (Chaurey and Kandpal, 2010, 2269). Though studies show good impacts of suitably designed customer awareness and training programmes and active participation of users in the decision making process, their role in adoption of decentralized photovoltaic systems continues to be undermined.

For popularizing the PV systems and for contributing towards innovations and financing, various financing agencies both governmental and international donors, NGOs, micro-financing agencies, enterprises and local communities have played important roles. For example in India, the National Renewable Energy Laboratory (NREL) worked with a NGO to supply SHS to around 300 rural households through easy installments. Various factors such as proper rural electrification planning with available technologies, fee for private service providers, local entrepreneurs and consumer credit sales through microfinance have facilitated growth off decentralized photovoltaic markets (2270).

PV business provides employment and income both at the demand and supply sides. The Grameen Banks in India provide small soft loans to rural poor people to buy solar systems. Biswas et al (2004) believe that Grameen Banks can also extend bigger loans to rural businesses for selling, renting and maintaining these solar systems. The case study on ESCOs giving solar systems on rent and lease is such an example (Chaurey and Kandpal, 2009). Vleuten et al (2007) in their study have highlighted the role of rural entrepreneurs to meet the basic electricity requirements of users by providing decentralized basic power infrastructure at village level. A study by Herwig (1997) on sales, employments and economic benefits indicated that sales of PV systems of US$ 100 million created more than 3800 jobs. Though the amount of electricity generated by decentralized PV system at village level is small, its impact on socio, economic and cultural developments of village communities cannot be underestimated. It will be good if the local governments and international donors integrate their development programmes on health, education and community welfare with that of photovoltaic based electrification to maximize the impacts (Chaurey and Kandpal, 2010, 2270).

For development of an integrated SHS, a different approach has been presented by Krauter (2004). He says that pre-assembly of all the components like PV module, inverter, charge controller, wiring and support structure, eases the installation and reduces the cost of installation and failures. Further, by the integration of an water tank which acts as a cooling unit and also system foundation, a considerable reduction of operating cell temperature was obtained and electricity generation increased by 9-12%. The paper also highlights the importance of a standardized approach that can be followed while finalizing off-grid electrification projects. The paper has also presented a decision making tool which outlines approaches that need to be followed during the planning and formulation of off-grid electrification projects with less budget for sustainable electrification.

Recommendations on resource mapping and GIS based rural planning models have also been provided in the paper to find out the scope and the best possible location for undertaking a project (Kumar et al., 2009).

For the selection of ratings and types of components for system designing for various applications, system optimization techniques are useful (Chaurey and Kandpal, 2010, 2271). For implementation of rural electrification projects, integrated and standardized system designs are very effective. It is essential to select components that are reliable and whose replacements are easily available, because it positively influences the performance of the system and also adds to user satisfaction. Configuration of the system to requirement of the user may lead to better acceptance of decentralized photovoltaic programmes by people (2272).

The challenge of providing electricity to all rural households has made decentralized PV systems more and more relevant. Relevance of decentralized PV systems has also become more relevant at the global level because of concerns of climate change, meeting the SDGs, education, health and employment generation. Because of above facts and the global trends, decentralized PV systems are set to find new markets. These are (Chaurey and Kandpal, 2010, 2274):

i. Providing dedicated PV systems for better healthcare, education and community services through augmentation of power supply in already electrified villages
ii. Dedicated power supply can be provided to rural business activities like computer kiosks, small shops and skill development centers which can boost local economy
iii. It can be used to improve the domestic electrification level in already electrified villages where dwellings are scattered and extension of grid is not easily feasible
iv. For use during periods of low demand like street lighting and lighting in compounds of institutions and campuses
v. Introducing basic electricity to villages which are likely to be electrified in near future and augmenting load growth subsequently to make grid extension viable
vi. Supplying portable lighting for temporary construction, excavation sites
vii. In semi-rural and semi-urban localities, charging of battery by electricity for domestic battery-inverter power back-up.

Besides the drivers of PV market, there are some emerging technologies, which are likely to add to the growth of decentralized PV systems (Chaurey and Kandpal, 2010, 2274):

(a) Emerging technologies on lighting and storage:

LED technology popularity is definitely going to bring down consumer's bill on electricity consumption and at the same time provide more lumen output per watt. This will in turn reduce the storage battery size and that of the photovoltaic module in PV lighting systems and this will result in total cost reduction. This trend will increase the cost competitiveness and reliability of PV lighting system with the use of state of art components.

The rapid progress in battery technology will augment the cost competitiveness and reliability of PV systems. For example, the Ni-MH batteries besides improving their volumetric energy densities and the life span, have also contributed towards lowering of the cost and this has made such batteries an attractive option for portable solar lanterns. Other types of batteries such as Lithium-ion ones are also being used in solar fueled lanterns. As Ni-MH and Li-ion batteries are increasingly used in equipment like portable computers, telecommunication and cordless appliances and medical equipment, advancements of technology and cost competitiveness will popularize products like solar lanterns also.

(b) Distributed generation and smart mini-grids:

The renewable energy markets in India are composed of mainly grid-connected large scale electricity generation units and also small sized off-grid systems. The new trend which is emerging involves distributed generation based smart grids which actually includes various small modular electricity generating technologies that are capable to be combines with small energy management and storage systems. The purpose is to improve the energy delivery operations for the customer. It is not essential that such systems are connected to the grid. A smart mini-grid besides generation technologies also uses advanced sensing, control and communication technologies to effectively store, manage and distribute electricity so that different set of loads are met optimally (Chaurey and Kandpal, 2010, 2275).

The capacity of a distributed generating system varies from less than a kilowatt to a few megawatts. The system can be run with a number of technological options which are based on renewable and non-renewable energy sources. Solar photovoltaic systems, biomass gasifiers, wind mills are normally used as distributed generating systems in rural areas for electricity generation and distribution. Out of the distributed generation technologies, small scale roof-top PV systems are being used in developed countries and this system is getting increasingly popular in developing countries including in India through the National Solar Mission. In India, the PV distributed generation and the roof-top PV systems have huge potential in rural and semi-urban localities where there is no constraint of roof space in houses and institutions. These systems can be used by the national schemes like DDG component of RGGVY (Rajiv Gandhi Grameen Vidyutikaran Yojana) and tail-end grid connected solar power plants (2275).

With regard to our previous discussions regarding PV water pumps, the technology can be calibrated to the needs to the Indian farmers. By combining the PV pumping technology with the irrigation styles of drip or micro-irrigation, the farmers will be able to benefit as it will lead to higher production of quality crops and will also save water (Campen, 2000, 50). With many water scarce regions in India, water conserving irrigation technologies are needed to ensure that farmers can continue with their livelihoods. PV irrigation pumps also have the capacity to irrigate lands that were once regarded as unsuitable. Furthermore, many solar power technologies need to improve their replicability, such as aeration pumps. As highlighted before, though PV refrigerators are used extensively by the health and veterinary sectors, by investing in developing this technology, PV refrigerators can also make their way to rural homes. Even though such larger refrigerators would require a lot of PV energy, which could be expensive for the rural poor to afford, there have been many case studies of refrigerators being powered successfully by hybrid PV-diesel and hybrid PV-wind technologies. Since the success of the hybrid power system has been presented in the Case Study on Uttar Pradesh, this task is within our reach.

PV technologies need to be modernized to meet the needs of agriculture, irrigation, horticulture, and fishing and also to develop packages for their use. These packages should take into consideration the quality of the surrounding ecosystem, oil, and water and should include suitable training packages (Campen, 2000, 75). Additionally, investments in R&D for the development of energy efficient and less-energy utilizing appliances, as well as hybrid power systems using diesel and wind along with PV should be encouraged and incentivized by the Government of India. Researchers should also work to develop quantity standards and create a framework to implement them effectively.

Financing of PV technologies should also be widened. PV systems should be made eligible for extending loans by Rural and Agricultural Development Banks, with the PV systems themselves can be considered as collateral. Women should have the equal opportunity to have access to credit to install PV systems in their homes and to encourage them to participate in income providing jobs. Investments from the private sector, to finance rural electrification programmes, should be encouraged. They should have also benefit from world donor programmes, soft term loans and other sources of capital (Campen, 2000, 76).

The Government of India should, in their rural electrification programmes, include the necessity of promotion and demonstration for various PV technologies in rural districts (76). For instance, the rural community can be demonstrated on how to use PV systems for drip-irrigation, electrifying farm fences, livestock watering and fishing, as it will greatly improve their life on the farm. Promotion of the use of PV technologies in the cottage industry and micro-enterprises should also be encouraged as the rural community needs to be made aware of the benefits of such systems in improving their quality of life and rate of income. In addition to financial support, the villagers also require training on how to install, operate, service, monitor and maintain solar PV systems and on how and where to implement them.

A significant effort is being made by the Government of India as they are aiming to use wastelands to install solar power plants. They are seeking to develop solar parks on wastelands. The official statement was made by the Minister of State of Power, Coal and New and Renewable Energy, Shri Piyush Goyal. As per this scheme, the development of 32 solar parks in 20 states with a capacity of 19,400 MW is underway. It was stated by the Minister that under the current solar park scheme, the government has set a target of 20,000 MW solar energy and the target for grid-connected solar power is 60,000 MW by 2022. The scheme is being monitored by the government in close cooperation with states and all stakeholders to ensure completion of all the projects on time with financial incentives and other concessions (MNRE and Tripathi, 2016, 7).

As illustrated in a report by ATKearney (2013), the capacity of solar power in India is expected to exceed 50 GW by 2022 as a result of the growing demand for power, increasing cost of carbon-based energy, and challenges in availability of conventional modes of energy. The report also estimates that the solar industry will evolve, as it reaches grid parity between 2016 and 2018, as illustrated in Figure 31. This growth story includes two chapters, the seed phase and the growth phase. In the seed phase, the government provides support to all independent solar power producers. In the growth phase, demand increase and positive economic growth results in fast industrial growth which lead to requirement of utilities of larger size. Solar energy will be considered as a feasible source of energy and will form a significant part in the conventional grid. The large scale installation, testing and successful working of off-grid and rooftop solar systems in the seed phase is expected to see huge growth of these systems in the growth phase (Kaushal, Vikas et al., 2013, 3).

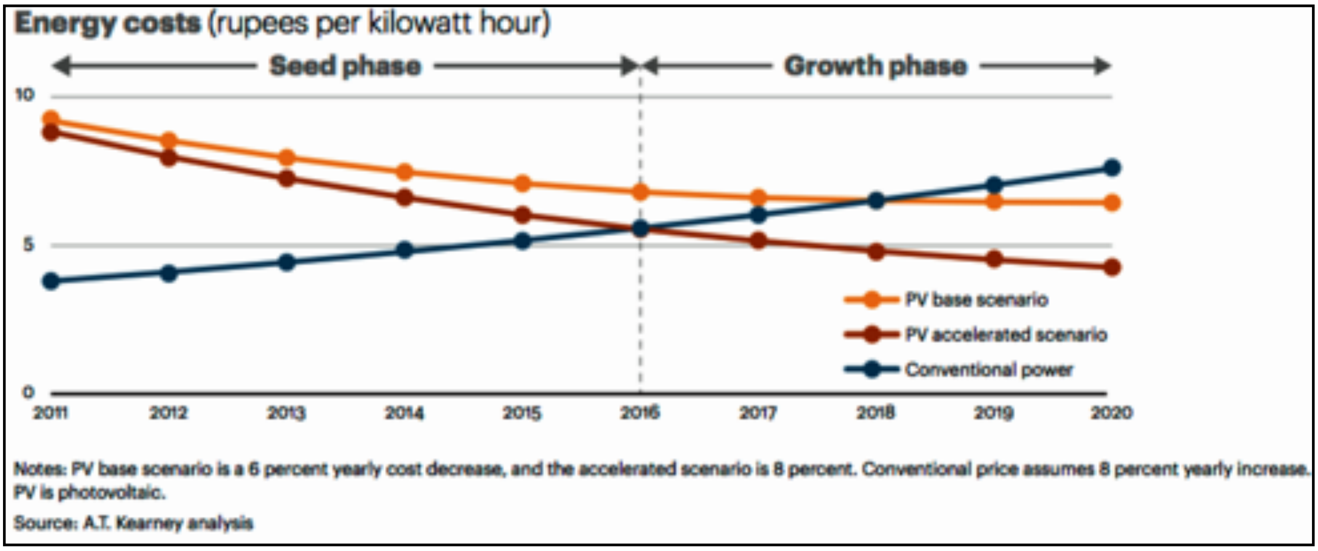


Figure 31: Estimations that solar power will reach grid parity

Source: ATKearney (2013)

IX. Conclusion

India is making consistent efforts in increasing the share of renewable energy in the power sector. Through programmes such as the Jawaharlal Nehru National Solar Mission (JNNSM), Remote Village Electrification Programme (RVEP) and other initiatives under the guidance and support of the Ministry of New and Renewable Energy of India (MNRE), the Government of India aims to create a financial supportive and sustainable environment for energy generation through abundant renewable sources, such as solar energy. As India has a great potential for solar irradiance, investing in development of solar power systems and PV applications is a step in the right direction.

As demonstrated through the case studies, the rural electrification programmes in India have had many positive effects. These rural electrification programmes all employed solar energy systems and PV systems to electrify homes and improve the standard of living. The case studies cover solar minigrids, hybrid power systems using abundant natural resources, solar AC pico-grids, and solar home systems. Some of the significant impacts has been the reduction in the consumption and expenditure of kerosene, increase of income generating activities, improvement in productive life of the womenfolk and increased rate of children attending school. The storage capacity and optimized battery size are also discussed using the ‘sizing curve’ methodology. The incentives, subsidies, funding opportunities and microfinance schemes, investigated in this paper, have facilitated the access to power by rural districts in India.

Therefore, it is evident from this study that in addition to technological support and advancements, financial and institutional aspects also play a key role in the success of rural electrification programmes. As highlighted by Murali et al (2015), policy changes need to be targeted towards strengthening solar PV projects. Furthermore, it is also important that the rural districts are self-sustaining and self-reliant. They should receive the appropriate training and knowledge on how to monitor, service and maintain the installed solar PV systems, so that further external support is not required. Another important take away from this study has been that, as extension of conventional grids to remote and hilly rural districts can be very expensive, investing and implementing solar PV projects such as solar minigrids or microgrids can be both sustainable and cost-effective. In fact, as recently as May 12, 2017 it has been reported that the cost of solar power decreased to 0.32 €/kWh and this is much less than the average price of 0.042 €/kWh being charged for the electricity generated from coal fired plants (Duttal, 2017). In rural districts where only solar PV systems cannot be implemented, hybrid power systems employing both solar and wind or solar and diesel can also be implemented to meet the power needs.

If India seeks to continue with its economic development and work towards meeting its targets in combating climate change and reducing GHG emissions, it needs to continue its efforts towards electrifying rural homes and other parts of the country using renewable energy technologies, such as solar PV systems. As argued by Cust et al (2008), remote and decentralized regions can be provided electricity and get easily connected using renewable energy systems. In order for economic development to continue, reliable access to power in all regions of the country is important, as around 70 percent of the Indian population live in rural districts.

References

Anantha A. and Chowhan P L. (1996): “Village Electrification using Renewables”. paper presented at International Workshop on Renewable Energy and Village Electrification: 2181-2186

Arun P and Banerjee R, Bandyopadhyay S. (2009): “Optimum sizing of photovoltaic battery systems incorporating uncertainty through design space approach”. *Solar Energy* 83(7):1013–25.

Arun P, Banerjee R and Bandyopadhyay S. (2007): “Sizing curve for design of isolated power systems”. *Energy for Sustainable Development* 11(4):21–8.

Bakos GC. (2009): “Distributed power generation: a case study of small scale PV power plant in Greece”. *Applied Energy* 86(9):1757–66.

Bhattacharjee, Aniruddha. (2015): “How Realistic is India's 100 GW Solar Target?" *ABC of Solar*. India Goes Solar. Web. <http://abcofsolar.com/solar-target/>.

Bhattacharjee, Aniruddha. (2015b): “Learn About the Concept of Solar Cities." *ABC of Solar*. India Goes Solar. Web.

Bhattacharjee, Aniruddha. (2015c): "Solar Energy in Ladakh is Helping (Re)Build Communities." *ABC of Solar*. India goes solar. Web. <http://abcofsolar.com/solar-energy-in-ladakh-is-helping-rebuild-communities/#>.

Bhattacharjee, Aniruddha. (2015d): “Gandhinagar’s Solar Success: Why it is Replicated in Other Cities." *ABC of Solar*. India Goes Solar. Web. <http://abcofsolar.com/gandhinagar-solar-success-why-it-is-replicated-in-other-cities/#>.

Biswas et al. (2004): “Can photovoltaic technologies help attain sustainable rural development in Bangladesh?” *Energy Policy* 32(10): 1199–207.

Buluswar, Shashi, et al. (2016): *Achieving Universal Electrification in India*. Institute for Transformative Technologies (ITT), *Achieving Universal Electrification in India*, assets.rockefellerfoundation.org/app/uploads/20160503122350/Achieving-Universal-Electrification-in-India.ITTReport.April2016.pdf.

Buragohain, Tarujyoti.(2012): “Impact of Solar Energy in Rural Development in India.” *International Journal of Environmental Science and Development*, vol. 3, no. pp. 334–338.

Cabraal R., Barnes D. and Agarwal S. (2005): Productive Uses of Energy for Rural Development. *Annual Review of Environment and Resources*, vol. 30, pp. 117–144

Campen, Bart Van, et al. (2000): *Solar photovoltaics for sustainable agriculture and rural development*. FAO, Rome, pp. 1–76, *Solar photovoltaics for sustainable agriculture and rural development*.

Cecelski, 2000: “Enabling equitable access to rural electrification: current thinking and major activities in energy, poverty and gender”; Briefing Paper prepared for a Brainstorming Meeting on Asia Alternative Energy Policy and Project Development Support: Emphasis on Poverty Alleviation and Women, *Asia Alternative Energy Unit*, The World Bank, Washington D.C.

Chakrabarti, Snigdha, and Subhendu Chakrabarti. (2002): “Rural electrification programme with solar energy in remote region–a case study in an island.” *Energy Policy*, vol. 30, no. 1, pp. 33–42. *Elsevier* , doi:10.1016/s0301-4215(01)00057-x.

Chamania S, Chouhan R, Awasthi R, et al. (2015): “Pilot project in rural western Madhya Pradesh, India, to assess the feasibility of using LED and solar-powered lanterns to remove kerosene lamps and related hazards from homes”. *Burns* 41: 595–603.

Chandran-Wadia, Leena, et al. (2015): “Prospects for Electricity Access in Rural India using Solar Photo-Voltaic based Mini-Grid Systems.” *Springer Proceedings in Energy*, Springer, Cham.

Chaurey A, and Kandpal TC. (2010): “Assessment and evaluation of PV based decentralized rural electrification: An overview.” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 8, pp. 2266–2278. *Elsevier* , doi:10.1016/j.rser.2010.04.005.

Chaurey A and Kandpal TC. (2009): “Solar lanterns for domestic lighting in India: viability of central charging station model”. *Energy Policy* 37(11):4910–8

Chaurey A and Kandpal TC. (2006): “A techno-economic analysis of solar home systems for decentralized rural electrification in India”. *SESI Journal* 16(2):1–21.

Cust, James, et al. (2008): “Rural Electrification in India: Economic and Institutional Aspects of Renewables.” *SSRN Electronic Journal*, Jan. pp. 1–36., doi:10.2139/ssrn.2760810.

Duttal, Sanjay. (2017): “Solar tariffs sink further below coal power at Rs 2.44 per unit - Times of India." *The Times of India*. The Times of India. Web. 14 May 2017. <http://timesofindia.indiatimes.com/business/india-business/solar-tariffs-sink-further-below-coal-power-at-rs-2-44-per-unit/articleshow/58641464.cms>.

Garg, H. P. (2015): *Rural Applications of Solar Energy.* Rep. Dr. H.P. Garg. Web. Global Network on Energy for Sustainable Development (GNESD). (2007): *Reaching the Millennium development Goals and Beyond: Access to Modern Forms of Energy as a pre-requisite*, 2007, ch.1, pp. 1–5.

Government of India. (2017): "JNNSM." Solar Energy Corporation of India (SECI). Government of India, 12 May 2017. Web. <http://www.seci.gov.in/content/govt_initiatives.php>.

Government of India, 2011 Census.

Government of India, Deendayal Upadhyaya Gram Jyoti yojana (http://www.ddugjy.gov.in/mis/portal/index.html#).

Government of India, Ministry of Power (http://powermin.nic.in/d-d-g).

Grimshaw, David J., and Lewis, Sian. (2010): "Solar power for the poor: facts and figures." SciDev.Net. N.p. Web. <http://www.scidev.net/global/energy/feature/solar-power-for-the-poor-facts-and-figures-1.html>.

Hahn, A., Flores Condori C., Schmidt, R. (1998): “Photovoltaic water pumps - lessons learned from demonstration and field testing projects supported by GTZ” - paper presented at the International Workshop on PV water supply, Marrakech, Morocco

Herwig LO. (1997): “Impacts of global electrification based upon photovoltaic technologies”. *Renewable Energy* 10(2–3):139–43.

Hewitt, Charlie.(2015): “Can solar microgrids bring power to rural India?” *The Energy Collective*.

Ibrahim M et al. (2002): “Demonstration of PV micro-utility system for rural electrification”. *Solar Energy* 72(6):521– 30.

IMA, India. (2006): *Solarizing India: Commercial Feasibility Analysis and an Commercial Feasibility Analysis and an Implementation Roadmap*. International Market Assessment India Private Limited, www.ima-india.com/solarising-rural-india.pdf.

India Central Electricity Authority, March 2015.

India Today, “Budget 2016: Power ministry gets Jaitley’s thumbs-up over rural electrification”, (http://indiato day.intoday.in/story/budget-2016-power-ministry-gets-jaitley-thumbs-up-over-rural-electri cation/1/608088.html).

International Energy Agency. (2015): “Projected costs of generating electricity”. Note: the levelized cost of electricity (LCOE) is the ratio of the present value of lifetime system costs (discounted at the rate of cost of capital), to lifetime electricity generation.

Jana C (2015): “Sustainable domestic lighting options for poor people—an empirical study”. *Environment Development and Sustainability* 17: 1–15.

Kamalapur, Gopalkrishna D. (2015): *Rural Electrification in India and feasibility study of solar home systems.* Rep. Department of EEE, SDMCET Dharwad. Web.

Kamalapur, G. D., and R. Y. Udaykumar. (2011): “Electrification in rural areas of India and consideration of SHS." *International Journal of Electrical Power and Energy Systems* 1: 596-601. *Research Gate*. Web.

Kandpal TC, Purohit P, Kumar A, and Chandrasekar B. (2003): “Study of selected issues pertaining to the economics of renewable energy utilization in developing countries”. *SESI Journal* 13(1 and 2):57–82.

Kaufman R, Duke R, Hansen R, Rogers J, Schartz R, and Trexler M. (2000): “Rural electrification with solar energy as a climate protection strategy”. *Renewable Energy Policy Project Report* No. 9.

Kaushal, Vikas, et al. *Solar Power and India's Energy Future*. (2013): ATKearney, pp. 1–9, *Solar Power and India's Energy Future*.

Krauter SCW. (2004): “Development of an integrated solar home system”. *Solar Energy Materials and Solar Cells* 82(1–2):119–30.

Kohli, Gayrajan. (2015): "5 Reasons To Start Using Solar Water Pumps." *ABC of Solar*. India Goes Solar. Web. <http://abcofsolar.com/5-reasons-start-using-solar-water-pumps/#>.

Kohli, Gayrajan. (2014): “Solar Water Pump Systems Can Boost Agriculture in India." *ABC of Solar.* India Goes Solar. Web. <http://abcofsolar.com/solar-water-pump-systems-agriculture-india/#>.

Kumar A, et al. (2009): “A. Approach for standardization of off- grid electrification projects”. *Renewable and Sustainable Energy Reviews* 13(8):1946–56.

Kumar A and Kandpal TC.(2007): “Potential and cost of CO2 emissions mitigation by using solar Photovoltaic pumps in India”. *International Journal of Sustainable Energy* 26(3):159–66.

Luque, A., and Steven Hegedus. (2010): Handbook of photovoltaic science and engineering. 2nd ed. Chichester, West Sussex, U.K.: Wiley. Print.

Ministry of Environment and Forest (MoEF). (2011): “Guidelines for linear infrastructure intrusions in natural areas: roads and power lines”. *National Board for Wildlife*. Ministry of Environment and Forest, Government of India.

Ministry of New and Renewable Energy, India. (2016): *Annual Report 2015-2016 of Ministry of New and Renewable Energy of India*. Ministry of New and Renewable Energy, India, *Annual Report 2015-2016 of Ministry of New and Renewable Energy of India*.

Ministry of New and Renewable Energy of India (MNRE), and Dr. Arun K Tripathi, editors. (2016): “Solar Power Plants on Waste Land.” *Akshay Urja: Renewable Energy* , vol. 9, no. 6, mnre.gov.in/file-manager/akshay-urja/may-june-2016/EN/AU-June2016-inside.pdf.

Ministry of New and Renewable Energy (MNRE). (2010): *The Remote Village Electrification Programme in India: Assessment of Experience in Odisha, Madhya*

Pradesh and Chhattisgarh, National Council of Applied Economic Research, A project report submitted to Ministry of New and Renewable Energy.

Ministry of New and Renewable Energy (MNRE). (2008):*The Remote Village Electrification Programme in India: Assessment of Experience in Assam, Jharkhand and Meghalaya*, National Council of Applied Economic Research, A project report submitted to Ministry of New and Renewable Energy.

Mukerjee AK. (2007): "Comparison of CFL-based and LED-based solar lanterns"*.* *Energy for Sustainable Development* 11(3):24–32.

Murali, Rashmi, et al. (2015): "Socio-Technical assessment of solar photovoltaic systems implemented for rural electrification in selected villages of Sundarbans region of India." *AIMS Energy*, vol. 3, no. 4, pp. 612–634., doi:10.3934/energy. 2015.4.612.

Masheleni H, Carelseb XF. (1997): "Microcontroller-based charge controller for stand- alone photovoltaic systems." *Solar Energy* 61(4):225–30.

Moharil RM and Kulkarni PS. (2009): "A case study of solar photovoltaic power system at Sagardeep Island, India". *Renewable and Sustainable Energy Reviews* 13(3):673–81.

Mondal, Manas, and Satyabrata Mandal. (2013): "Remote Village Electrification through Renewable Solar energy: a Case Study of Sagar Island, West Bengal, India." *The International Journal of Engineering And Science (IJES)* 2.1 : 201-05. Web.

Mohibullah, et al. (2014): "Rural Electrification by Effective Mini Hybrid PV Solar, Wind & Biogas Energy System for Rural and Remote Areas of Uttar Pradesh." *International Journal of Computer Science and Electronics Engineering (IJCSEE)*, vol. 2, no. 4, pp. 178–181.

Mulugetta et al., (2000): "Photovoltaics in Zimbabwe: lessons from the GEF solar project". *Energy Policy* 28(14):1069–80.

National Bank for Agriculture and Rural Development - Government Sponsored-Installation of Solar.

NDTV, "PM Modi Stresses India's Commitment for 175 GigaWatts Clean Energy Goal", 28 September 2015 (http://www.ndtv.com/india-news/pm-modi-stresses-indias-commitment-for-175-gigawatts-clean-energy-goal-1223706).

Kohli, Namrata. (2014): "The Loss of Power." *The Economic Times*.

Oparaku OU. (2003): "Rural area power supply in Nigeria: a cost comparison of the photovoltaic, diesel/gasoline generator and grid utility options". *Renewable Energy* 28(13):2089–98.

Ouwens K.D. , (2006): “Poverty alleviation and energy supply,” position paper presented at the Poverty Alleviation and Energy Supply Meeting.

Palit D (2013): “Solar energy programs for rural electrification: Experiences and lessons from South Asia”. *Energy Sustain Dev* 17: 270–279.

Pearce, Fred. (2016): “In Rural India, Solar-Powered Microgrids Show Mixed Success.” *Yale Environment 360*, Yale School of Forestry and Environmental Studies, e360.yale.edu/features/in_rural_india_solar-powered_microgrids_show_mixed_success.

Prime Minister's Office. (2015): “Powering India's Growth." *PM India*. Government of India, 2015. Web. 13 May 2017. <http://www.pmindia.gov.in/en/government_tr_rec/powering-indias-growth/>.

Purohit P. (2009): “CO2 emissions mitigation potential of solar home systems under clean development mechanism in India”. *Energy* 34(8):1014–23.

Purohit P and Michaelowa A. (2008): “CDM potential of SPV pumps in India”. *Renewable and Sustainable Energy Reviews* 12(1):181–99.

Ramachandra T.V., Jain R. and Krishnadas G. (2011): “Hotspots of solar potential in india”, *Renewable and Sustainable Energy Reviews*, 15 (3178–3186).

Rao DN (2012): “Kerosene subsidies in India: When energy policy fails as social policy”. *Energ sustain dev* 16: 35–43.

Raugei M and Frankl P. (2009): “Life cycle impacts and costs of photovoltaic systems: Current state of the art and future outlooks”. *Energy* 34(3):392–9.

Shaahid SM and El-Amin I. (2009): “Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—A way forward for sustainable development”. *Renewable and Sustainable Energy Reviews* 13(3):625–33.

Shum KL, Watanabe C. (2008): “Towards a local learning (innovation) model of solar photovoltaic deployment”. *Energy Policy* 36(2):508–21.

Singh, Bharat Raj, and Onkar Singh. (2016): “Future Scope of Solar Energy in India.” *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology*, vol. 8, no. 1, pp. 21–30., doi:10.18090/samriddhi.v8i1.11408.

Singh, Shiva Nand, and Arun Kumar Singh. “Solar (PV) - Grid/DG Green Power Supply for Rural India.” *Journal of Electrical Engineering*, pp. 1–5., www.jee.ro/covers/art.php?issue=WX1256362037W4ae29035f16c6.

Siegl, René, and ABA. (2015): *Austria-Strong Location for Environmental Technologies and Renewable Energies*. Austrian Business Agency, *Austria-Strong Location for Environmental Technologies and Renewable Energies*.

Sinha, S., 2000: “Lighting in Sundarbans: from dhibri to solar photovoltaic” - forthcoming paper.

Solar Energy Centre, Ministry of New and Renewable Energy, 2010 (http://mnre.gov.in/sec/GHi_annual.jpg).

"Solar Energy Programme." WBREDA : Department of Power and NES, Govt. of West Bengal. WBREDA, n.d. Web. <http://www.wbreda.org/solar-energy-programme/>.

"Solar Nano grids for smart village power." *Climate Parliament | Legislators combating climate change worldwide*. N.p., 18 May 2016. Web. <http://www.climateparl.net/single-post/2016/07/20/Solar-Nano-grids-for-smart-village-power>.

Srivastava, Swami Prakash, and Surat Prakash Srivastava.(2013): “Solar Energy and its Future Role in Indian Economy.” *International Journal of Environmental Science: Development and Monitoring (IJESDM)*, vol. 4, no. 3, pp. 81–88.

The Guardian, “India unveils climate change plan”, 2 October 2015 (http://www.theguardian.com/world/2015/oct/02/india-pledges-40-percent-electricity-renewables-2030).

Thirumurthy, N., et al. (2012): *Opportunities and Challenges for Solar Minigrid Development in Rural India.* National Renewable Energy Laboratory (NREL), pp. 1–60, *Opportunities and Challenges for Solar Minigrid Development in Rural India.*

Ulsrud K, Winther T, Palit D, et al. (2011): “The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems”. *Energ Sustain Dev* 15: 293–303.

United Nations. (2005): *The Energy Challenge for Achieving the Millennium Development Goals*. New York. pp. 15–49.

United Nations. (2003): *MDG Needs Assessment: UN Millennium Goals*, New York, pp. 8–17.

Van der Vleuten et al. (2007): “Putting solar home system programmes into perspective: what lessons are relevant?” *Energy Policy* 35(3):1439–51.

World Bank Development Indicators, 2015; International Energy agency.

World Bank. (2008): *The Welfare Impact of Rural Electrification: A Reassessment of the Cost and Benefits: An IEG impact evaluation*, ch.5, pp. 39– 52.

List of Figures

List of Tables