SOCIO-ECONOMIC ASSESSMENT STUDY OF DECENTRALIZED RURAL ELECTRIFICATION BASED ON SOLAR ENERGY IN RAJASTHAN

Ph.D. Thesis

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Socio-Economic Assessment Study of Decentralized Rural Electrification based on Solar Energy in Rajasthan

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by

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CERTIFICATE

This is to certify that the thesis entitled **"SOCIO-ECONOMIC ASSESSMENT STUDY OF DECENTRALIZED RURAL ELECTRIFICATION BASED ON SOLAR ENERGY IN RAJASTHAN"** being submitted by **Ms. Boola Choudhary (I.D. 2013RHS9054)** is a bonafide research work carried out under my supervision and guidance in fulfillment of the requirement for the award of the degree of **Doctor of Philosophy** in the Department of **HUMANITIES AND SOCIAL SCIENCES**, Malaviya National Institute of Technology Jaipur, India. The matter embodied in this thesis is original and has not been submitted to any other University or Institute for the award of any other degree.

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DECLARATION

I, **Boola Choudhary**, declare that this thesis titled, **"SOCIO-ECONOMIC ASSESSMENT STUDY OF DECENTRALIZED RURAL ELECTRIFICATION BASED ON SOLAR ENERGY IN RAJASTHAN"** and the works presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this university.
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- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself, jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Date: Ms. Boola Choudhary

(I.D. No. 2013RHS9054)

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ABSTRACT

Energy is an indispensable necessity for all individuals and economic development of a nation. Energy has strong linkages with the three important pillars of sustainable development i.e. economic, social and environmental which place it on priority at a global level. The majority of developments in the energy sector are required to be executed corresponding to all the phase of the growth process, e.g. energy and communication, energy and health, energy and education, etc. Consequently, energy is considered as a complementary aspect of socio-economic development. Electricity, being the foremost structure of contemporary energy is fundamental for development and is an imperative indicator of a nation’s standard of living.

Indian economy has witnessed a steady increase in energy demand with the increasing population and the rising living standards. Due to fossil fuel depletion and scarce conventional resources of energy, most of the developing nation’s including India is facing the challenge of attaining sustainable energy growth along with social-economic development without affecting the environment adversely. Diminution in reliance on fossil fuels and achieving self-sufficiency in energy, the major contributor is undoubtedly indigenous renewable energy. Therefore, it’s a need of the hour to shift towards alternative sources of energy in order to exploit and utilize energy in a sustainable manner for the collective socio-economic growth of the nation.

Access to consistent electricity persists to be subtle for enormous rural households in India, and around 45% of them remain un-electrified according to Census of India 2011. Yet those who are electrified habitually receive the very poor quality of power supplied by a grid with recurrent blackouts and brownouts. The accessibility of electricity in the remote rural, tribal and hilly regions is at stake in Rajasthan, India as the expansion of grid in such areas is not only difficult but also highly cost intensive. For such areas, the electrification by off-grid renewable technologies proves to be the better option. There exist a larger number of households that live in dark even after rising growth rate of the country. Illuminating these villages is possible by renewable energy interventions.

The rural electrification using renewable energy has been widely researched both at national and international levels. From this vast area of study the researcher reviewed around one hundred and twenty articles out of which around 50 were found appropriate for the

current study. These studies have found that there is a huge potential of solar energy in Rajasthan for rural electrification in the remote areas using off-grid technologies.

Based on the survey of the literature, the rural electrification caters an awfully important opportunity for both direct and indirect socio-economic benefits for society with a vast array of increased livelihood escorting to poverty reduction and in turn providing better resources for health and education.

The present study is a modest attempt to focus on understanding and devising strategies for effective rural electrification. Two structures of studies have been carried out keeping in mind the social as well as economic aspects of the decentralized electrification. In the first step, we assess and analyze the social impacts of existing off-grid solar PV interventions in remote villages of Rajasthan by conducting a primary survey of the rural households, comparing it with pre-electricity situations and applying different descriptive statistics and econometric tools. In the second structure, we compared the cost of grid extension to these villages with the cost of existing off-grid solar PV projects using life cycle cost analysis.

This research highlights the rural electrification situation in Rajasthan. The power situation in rural Rajasthan especially in the remote areas with tribal population and hilly terrain continues to remain poor without access to any form of electricity. As a result of this inaccessibility of electricity since decades kerosene being consumed as a chief source of lightening for un-electrified households in addition to households with the sporadic access to electricity in rural areas. Becausegrid-based electrification is not possible in few of the areas; decentralized solar PV systems have been adopted as a cost-effective approach of electrification.

This study presents the results of the socio-economic assessment of solar photovoltaic intervention namely, solar micro-grids, which have been installed to electrify selected villages in Rajasthan. The study spotlights the technical, financial, and institutional aspects along with the social impact assessment of PV based electrification in Rajasthan.

The results of the study explicate that, in most cases, the impacts of the solar PV solutions designed for electrification have been fundamentally constructive, particularly for a reduction in kerosene consumption, alleviation in education and upliftment of women and improved health conditions.

As the researcher focused on solar energy based micro-grid systems and also covered conventional grid extension, the life cycle cost of both was calculated taking two case studies. Thus, this study presents the results of an overview and survey of recent, up-to-date estimates of the cost of generating and distributing electric power from decentralized solar microgrids as well as conventional grid extension in remote and rural villages of Rajasthan.

It furthermore does a comparative analysis to utilize cross learning prospect and propose explicit boosters that could serve as input for policy appraisal and enhancement to support future electrification efforts in the region.

This socio-economic research in conjunction with technical segment underlines the dynamics between technology, economy and society and analyzes that how they are jointly stimulating and determining each other. A plodding alteration is created by such dynamics in the three tier aspects, i.e. socio-economic-technical system of people, practices, knowledge, technical devises and other elements, which require equal efforts and adjustments from the side of implementing actors as well. A range of technical and non- technical factors at various stages are discovered to be appropriate for the accomplishment, operation, sustenance and further for promoting and achieving development of the solar micro grid systems.

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LIST OF ABBREVIATIONS

AC : Alternate Current

ANOVA : Analysis of Variance

BBMB : Bhakra Beas Management Board

BEE : Bureau of Energy Efficiency

BLCL1 : Balmer Lawrie and Co. Limited.

BLCL2 : Biecco Lawrie Co. Limited

BPCL : Bharat Petroleum Corporation Limited

BPL : Below Poverty Line

CCO : Coal Controller’s Organization

CDM : Clean Development Mechanism

CEA : Central Electricity Authority

CEA : Central Electricity Authority

CERC : Central Electricity Regulatory Commission

CERC : Central Electricity Regulatory Commission

CFA : Central Financial Assistance

CIL : Coal India Limited

CMPDI : Central Mine Planning and Design Institute

CMPFO : Coal Mines Provident Fund Organization

CPCL : Chennai Petroleum Corporation Limited

CPRI : Central Power Research Institute

CSP : Concentrated Solar Power

CTU : Central Transmission Utility

DC : Direct Current

DDG : Decentralized Distribution Generation

DDUGJY : Deen Dayal Upadhyay Gram Jyoti Yojana

DG : Distributed Generation

DLC : District Level Committee

DNI : Direct Normal Incidence

DSM : Demand Side Management

DVC : Damodar Valley Corporation

ECIL : Electronics Corporation of India Limited

EDI : Energy Development Index

EDL : Economic Distance Limit

EED : Energy Economy and Development

EEZ : Exclusive Economic Zone

EIL : Engineers India Limited

GAIL : Gas Authority of India Limited

GBI : Generation Based Incentive Scheme

GDP : Gross Domestic Product

GHG : Green House Gas

GHI : Global Horizontal Irradiance

GIC : Generating Installed Capacity

GW : Giga Watt

HDI : Human Development Index

HPCL : Hindustan Petroleum Corporation Limited

IEA : International Electricity Agency

IOCL : Indian Oil Corporation Limited

IREDA : Indian Renewable Energy Development Agency

IREDA : The Indian Renewable Energy Development Agency Limited

IREL : Indian Rare Earths Limited

JNNSM : Jawahar Lal Nehru National Solar Mission

JVC : Joint Venture Companies

KJC : Kutir Jyoti Scheme

kV : Kilo volt

kW : Kilo Watt

kWh : Kilo Watt Hour

LCA : Life Cycle Analysis

LCC : Life Cycle Cost

LCCA : Life Cycle Cost Analysis

MDG : Millennium Development Goals

MNRE : Ministry of Renewable and New Energy Sources

MRPL : Mangalore Refinery and Petroleum Limited.

MW : Mega Watt

NABARD : National Bank for Agriculture and Rural Development

NAPCC : National Action Plan on Climate Change

NEEPCO : North Eastern Electric Power Corporation

NGO : Non-Governmental Organizations

NHPC : National Hydro Power Corporation

NHPC : National Hydroelectric Power Corporation

NISE : National Institute of Solar Energy

NIWE : National Institute of Wind Energy

NIWE : National Institute of Wind Energy

NLCIL : Neyveli Lignite Corporation India Limited

NLDC : National Load Despatch Centre

NPTI : National Power Training Institute

NREP : National Rural Electrification Policies

NRL : Numaligarh Refinery Limited

NTPC : National Thermal Power Corporation

NTPC : National Thermal Power Corporation

NVVNL : National Thermal Power Corporation Vidyut Vyapar Nigam Ltd
NW : Northwestern
O&M : Operation and Maintenance
OIL : Oil India Limited
ONGC : Oil and Natural Gas Corporation Limited
PFC : Power Finance Corporation
PMGY : Pradhan Mantri Gramodayan Yojana
POWER GRID: Power Grid Corporation of India
PPA : Power Purchase Agreements
PSU : Public Sector Utilities
PV : Photovoltaic
RD&D : Research, Development and Deployment
RE : Renewable Energy
REC : Renewable Energy Certificate
REC : Rural Electrification Corporation
REDB : Rural Electricity Distribution Backbone
RERC : Rajasthan Electricity Regulatory Commission
RGGVY : Rajiv Gandhi Grameen Vidyutikaran Yojana
RLDC : Regional Load Despatch Centre
RPO : Renewable Energy Purchase Obligation
RREC : Rajasthan Renewable Energy Corporation
RSPCB : Rajasthan State Pollution Control Board
RVREP : Remote Village Renewable Energy Programme
RVSLP : Remote Village Solar Lighting Programme
SAM : System Advisor Model
SEBs : State Electricity Boards
SECI : Solar Energy Corporation of India

SERC : State Electricity Regulatory Commission

SERC : State Electricity Regulatory Commission

SLCP : Short-Lived Climate Pollutants

SLDC : State Load Despatch Centre

SOLS : Solar off-grid Lighting Systems

SPV : Solar Photovoltaic

SSM : Supply Side Management

SSS-NIBE : Sardar Swaran Singh National Institute of Bio-Energy

STU : State Transmission Utility

STU : State Transmission Utility

SWH : Solar Water Heaters

UCIL : Uranium Corporation of India Limited

UN : United Nations

USDOE : United States Department of Energy

VEI : Village Electrification Infrastructure

VESP : Village Energy Security Programme

Chapter 1

INTRODUCTION

CHAPTER 1

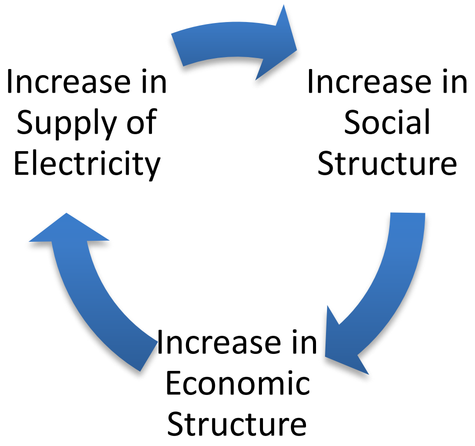
INTRODUCTION

Energy is an essential requirement in all facets of human life and has been recognized as a basic human need. It is a prime mover of economic growth and is a critical infrastructure on which socio-economic development of the country depends. It has complex linkages with the environment. In other words, energy is directly related to development; as development means growth and growth require energy. Further, it is the most efficient tool for sustainable development. Energy impinges on poverty, jobs and incomes, access to social services, gender disparities, population, agricultural production and food security, health, land degradation, climate change and environmental quality, and economic and social issues. Therefore, it must be viewed, as a means of contributing to the solution of the major global problem. In fact, thegoal of energy can be stated very simply: sustainable development.

Being a versatile form of energy, electric power is one of the most critical infrastructure sectors of the economy. Electricity, for instance, is an essential input for productive and economic activities, as well as for overall health and well-being of communities. The sources of electricity production can be classified into two broad areas: conventional sources or non-renewable sources and non-conventional or renewable sources. As observed over long stretches of time, the most utilized sources since past decades are that of conventional resources like fossil fuels. At the global level, the primary source of electricity production is coal. All over the globe and especially in developing countries, the power sector is experiencing a phase of energy crisis and environmental degradation. India is the world’s sixth largest energy consumer relying on coal for more than half of its total energy needs. Therefore, India needs to switch to renewable sources of energy mainly due to following two reasons:

1) India needs to meet the demands of increasing energy consumption substantially because of high positive correlation between energy consumption and human development.
2) A rapid depletion in fossil fuels is creating energy crisis and severe environmental degradation; thereby a rapid shift to less-polluting and renewable sources of energy will be needed to avoid the catastrophic effects of global warming.

An increase in population, accompanied by rapid urbanization and industrialization has led to an increase in the usage of fossil fuels. The present fossil fuel reserves are unable to meet the growing energy needs of the society. Energy economists opined that energy consumption is an index of economic development. For overall development of a nation, it is requisite to ensure adequate and sustained supply of energy in every sector of the economy. Thus, there is a need to look for viable alternative energy sources to meet the energy requirements (Ramaswamy & Kumar, 2009).



The above diagram makes it very clear that economic and social development forms a cyclical process with electricity consumption.

An economically sustainable system must be able to produce goods and services without polluting the environment by making use of technologies oriented towards renewable energy. An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of the non-renewable resource base. A socially sustainable system must achieve distributional energy equity and adequate provision of energy services to the society (Ramaswamy & Kumar, 2009).

Modern energy services are fundamental to all three pillars of sustainable development, i.e., social, economic and environmental. Most energy developments must be implemented in line with all the aspects of the development process, example, energy, and communication, energy and health, energy and schools, energy and roads, etc. Energy is, therefore, a complementary factor to socio-economic development. Electricity, the main form of modern energy, is crucial to industrialization and easy access to it is an indicator of a nation's standard of living (Opiyo, 2016).

Per capita, energy consumption is an index of development and economic well-being and the standard of living of the people of the country. There is a high correlation between energy usage on the one hand and development, national income, the standard of living and quality of life on the other hand. Therefore, for economic growth, an increase in energy supply and consumption becomes mandatory (Ramaswamy & Kumar, 2009). Also, electricity remains an obligatory contribution for productive and economic activities along with over-all health and well-being of a nation.

Literature also reveals the fact that the positive contribution of electricity to the Human Development Index (HDI) is the strongest for first kilo-watt hour reflecting that poorest are likely to benefit from even minimum electricity inputs in terms of meeting their basic needs (Chaurey & Kandpal, 2010).

The present chapter is divided into various sections and sub-sections. The chapter begins with a prologue to the power scenario of India; provide overview of the consumption pattern of energy in India along with the power demand-supply gap situation of the nation. At the same time, it throws light on the power scenario of Rajasthan, in particular, and the trends of power deficit in the State are also studied in this subdivision. Later, the chapter presents a brief foreword to renewable energy resources of India including the energy mix, the policies adopted by the government of India for its promotion and implementation. Finally, the rural electrification position of India and Rajasthan is also discussed in this chapter. The chapter concludes with the statement of the problem, research objectives and the importance of the study in the present context. In the end, the chapter scheme of the study is portrayed briefly.

1.1 POWER SCENARIO OF INDIA

With 1.2 billion people and the world’s fourth-largest economy, India’s recent growth and development has been one of the most significant achievements of our times. As is accepted worldwide, energy being the lifeblood of the global economy remains a crucial input to nearly all of the goods and services of the modern world. The living standards of billions of people in India and the world can be improved and maintained by stable and sustainable energy supplies at reasonable prices. It is justified to state that energy works as the oxygen to the economy. Without energy, heat, light and power neither can one run any productive activities that provide goods, jobs, and homes, nor can anyone enjoy the amenities that make life more comfortable and satisfying. With rapid development, the infrastructural and energy needs of the country have been increasing at a massive pace. Thus, the energy supplies remain insufficient, and as a result of this, about 300 million people are still not connected to the national electrical grid. Therefore, the agricultural as well the manufacturing sector which is vital for job creation and livelihood remain underdeveloped especially in rural areas of the country.

1.1.1 Power consumption in India

There has been a rapid increment in power consumption in India. The increase in per capita consumption of power (which is the indicator of demand for electricity) in India was not much in 80's but has gradually increased thereafter. The rising trend of electricity consumption in India (Table 1.1) shows that the per capita consumption of electricity was merely 176 kWh in 1980-81 which bounced to 559 kWh in 2000-01 and presently, has escalated manifold.

Table 1.1: Growth of per capita consumption of electricity in India

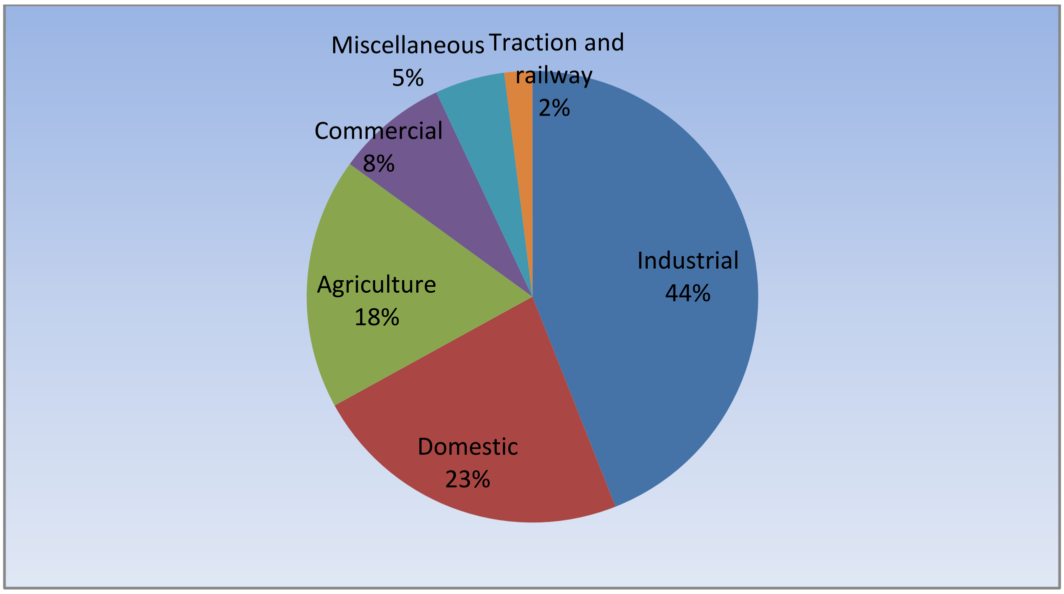
Year	**Per capita consumption of power (KWh)**
1980-81	176
1990-91	348
2000-01	559
2001-02	563.2
2002-03	577
2003-04	592
2004-05	612.5
2005-06	631.5
2006-07	671.9
2007-08	717.1
2008-09	733.5
2009-10	778.6
2010-11	818.8
2011-12	883.63
2012-13	914.41
2013-14	957
2014-15	1010
2015-16	1101

Source: GoI, Central electricity authority report 2016

It is observed that power demand and power consumption in India have bounced by more than 100 percent since 1980's till 2016 from 176 kWh in 1980-81 to 1101 kWh in 2015-16. The above data clearly reflects the significant increase in the consumption of per capita energy in India which in turn leads to rise in power demand. It further depicts the increase in generation of electricity for meeting the rising demands. The rise in consumption pattern is considered a positive element for any country as the boost in per capita consumption of electricity is a well defined and important statistic of development and growth of a country.

The living standard of people in India has gradually increased over the years resulting in augmented power consumption. This increase in consumption of electricity has been responsible for widening the gap between the demand for and supply of power, and as a result, India is presently facing uncompromising power crisis. In India, power consumption pattern highlights that the sectors like industry, commercial, traction, and railway, etc. have a high consumption of energy, but the most important and largest fraction after industry sector is occupied by domestic and agriculture needs (Figure:1.1). Agricultural sector thus presses on higher energy needs which are generally not met, in rural areas. The need for power consumption is equally important for domestic purposes and for other productive activities in the rural areas to initiate the growth process of the backward regions. Education is another one of the paramount sectors of power consumption, followed by the healthsector, especially in the rural, remote and facility deprived areas.

Figure 1.1: India's electricity consumption sector-wise during 2015-16



Source: www.mospi.gov.in/sites/default/files/publication_reports/energy_statistics_2016.pdf

On the qualityside, the electricity grid shows high voltage fluctuations and power outages in almost all parts of the country. The transmission and distribution losses are high, and the production of electricity from conventional sources does not meet the demand, thereby, generating demand-supply gap resulting in power deficits. This can be met by the high potential renewable energy sector in India.

1.1.2 Power demand-supply gap

India is going through churning power crisis issues. The power generation is inadequate. Due to country’s growth trends, the demand for electricity is rising continuously. The peak demand for electricity in India during 2002-03 was 81,492 MW, and the supply was 71,547 MW, resulting in a deficit of 9,945 MW (12.8 percent). It shot up too high in 2007-08 when the peak demand for electricity increased to 1, 08,866 MW and supply was only 90,793 MW, contributing to a deficit of 16.6 percent in the economy. This power deficit has been fluctuating throughout on the higher side though recently the data showed a drop in the demand-supply gap of electricity, which appears quite unrealistic from the ground reality in the country. The highly mounting per capita consumption, in the country, demonstrates that our nation is in the course of development, but the progression of development in India is stalled by a dearth in the power supply. The various CEA reports clearly reveal that the deficit in the demand for and supply of electricity has been continuously rising as observed in the past two decades and this has been depicted in Table 1.2.

Table 1.2: Power demand-supply gap in India since 2002-03

I	**II**	**III**	**IV (III-II)**	**V Percentage Change**
Year	**Peak demand MW**	**Peak met MW**	**Deficit/surplus MW**	**In %**
2002-03	81,492	71,547	-9,945	-12.8
2003-04	84,574	75,066	-9,508	-11.2
2004-05	87,906	77,652	-10,254	-11.7
2005-06	93,255	81,792	-11,463	-12.3
2006-07	1,00,715	86,818	-13,897	-13.8

2007-08	1,08,866	90,793	-18,073	-16.6
2008-09	1,09,809	96,685	-13,124	-12
2009-10	1,19,166	1,04,009	-15,157	-12.7
2010-11	1,22,287	1,10,256	-12,031	-9.8
2011-12	1,30,006	1,16,191	-13,815	-10.6
2012-13	1,35,453	1,23,294	-12,159	-9.0
2013-14	1,35,918	1,29,815	-6,103	-4.5
2014-15	1,48,166	1,41,160	-7006	-4.7
2015-16	1,53,366	1,48,463	-4,903	-3.2
2016-17 ***(April 2016 to January 2017)***	1,59,542	1,56,934	-2608	-1.6

Source: powermin.nic.in/en/content/power-sector-glance-all-india

Despite this in the past few years, we have been witnessing a promising growth in the generation capacity additions; there prevails a continuous electricity shortage which imposes the significant constraint on economic growth and development of our country.

However, the government of India has made remarkable efforts in reducing the power deficit but again, the rising population, scarce energy generation resources and escalating power consumption results in deficiency of power supply in the country. It remains an alarming situation for our nation which needs to be dealt with on priority and of course there exist certain corners where the sustainable sources of energy could play an important role.

1.1.3 Power scenario in Rajasthan

Rajasthan is emerging as the fastest growing state in India and is experiencing drastic changes in its demography as well as in the process of economic development. In the recent years, urbanization has been increasing at an alarming rate and in turn,has led to widening the power demand and supply gap in the state (shown in Table 1.3).

In 2002-03, the peak demand was 3,880 MW and peak met was 3,820 resulting in a deficit of 60 MW (1.5%) which shot up to 14% in 2006-07 with a peak demand of 5,794 MW and peak met of 4,946 MW. During 2016-17 (April 2016 to January 2017) the deficit was observed to be 2.5%.

Table 1.3: Demand-supply gap of power in Rajasthan

Year	Peak demand MW	Peak met MW	Deficit/surplus MW	Percent
I	**II**	**III**	$IV = III - II$	$V = \frac{I}{II} \times 100$
2003-04	4,134	4,134	0	0
2004-05	4,786	4,414	-372	-7.8
2005-06	5,588	4,850	-738	-13.2
2006-07	5,794	4,946	-848	-14.6
2007-08	6,374	5,564	-810	-12.7
2008-09	6,303	6,101	-202	-3.2
2009-10	6,859	6,859	0	0
2010-11	7,729	7,442	-287	-3.7
2011-12	8,188	7,605	-583	-7.1
2012-13	8,940	8,515	-425	-4.8
2013-14	10,047	10,038	-287	-0.1
2014-15	10,642	10,642	0	0
2015-16	10,961	10,961	0	0
2016-17 (***April 2016 to January 2017)***	10,613	10,348	-265	-2.5

Source: Compiled from various annual Load Generation Balance Report, CEA.

It is illustrated from the above table that in Rajasthan the power deficit fluctuations are very un- certain, like from around 12.7% in 2007-08 it suddenly dropped to 0 during 2009-10 and again shot up to 7.1% in 2011-12 and then gradually slowed down to 0 during 2014-15. A rise is expected in 2016-17 as an increment of 2.5% has already been noticed during April 2016 to January 2017.

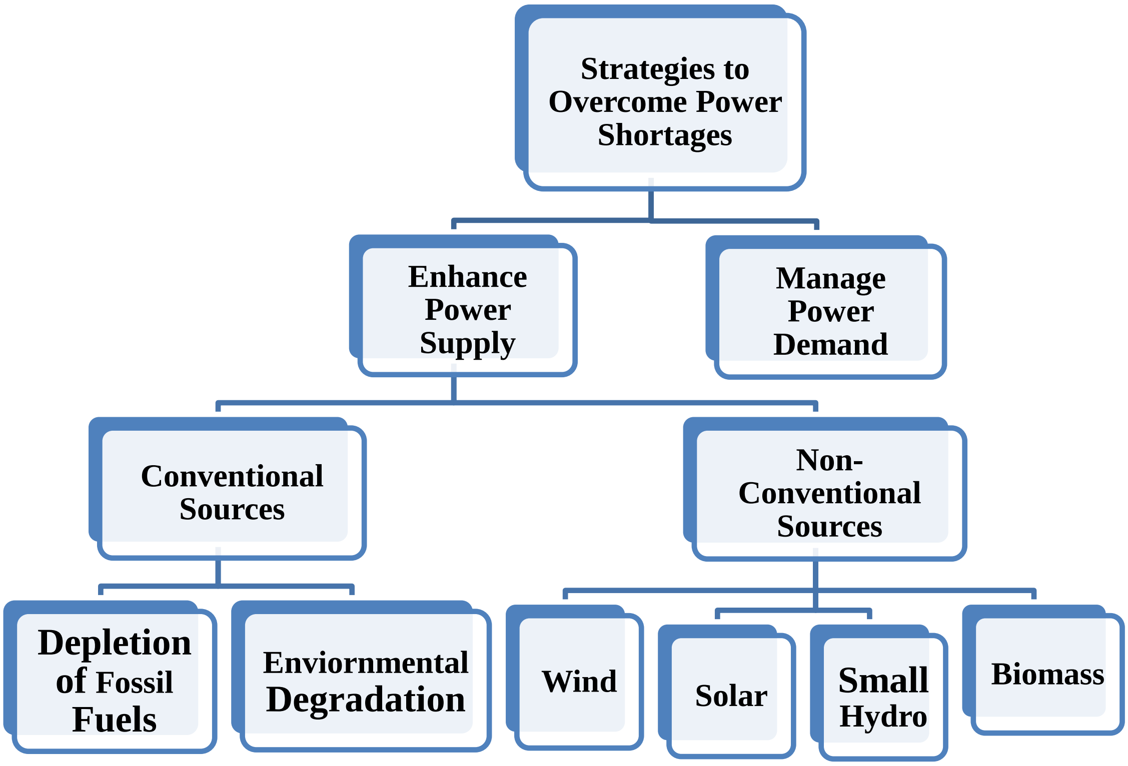
There are continuous power cuts in Rajasthan which emphasize that the deficit has dropped to 0 percent reflecting the managed demand in the State. Hence, it is important to curb the deficit to improve the power demand and supply scenario in the State.

Major power crisis in Rajasthan is witnessed in the rural areas due to the desert and remote regions. The grid connectivity to these areas is minimal or zero. The topography of such regions renders it difficult to opt for an extension of the grid for providing electricity services in the rural areas.

Thus, a high possibility for off-grid power supply is spotted there. Besides, the high transmission and distribution losses are also observed in the State, due to which the production and supply of electricity do not meet the demand of end users, and there is a loss of capital at par. Therefore, sensing the severity of the power crisis in the State and the country we need to enhance our sources of power generation and supply.

As discussed earlier, the conventional sources of energy, i.e., fossil fuel and coal are limited and knowing that we have a large potential of renewable sources of energy we need to think and strategically tap on the available alternative resources of energy for power generation. This approach can curb the power deficits as well as can help us achieve sustainable growth and development in the power sector of our country, which will further add to the country's economic growth.

Approaching towards the formulation of strategies that can curb the environmental hazards and at the same time make us sustainable and reliable in energy production we look forward to various options on demand as well as supply side management of energy. These are presented in the following chart:



Managing power demand is complicated with growing development, and also a fall in power demand will result in decreased power consumption, which is an indicator of HDI and economic growth. Therefore managing demand has limited scope, however enhancing power supply which itself is challenging but is possible to achieve. The above chart clearly shows that enhancing power supply using conventional sources will lead to depletion of fossil fuels and environmental degradation, whereas the non-conventional or renewable energy sources (wind, solar, small hydro and biomass) are sustainable and environment-friendly. It is important to note that India has an enormous potential of renewable energy resources and therefore, should increase its electricity production using available renewable resources for economic growth and development.

1.2 RENEWABLE ENERGY RESOURCES IN INDIA

As clearly seen, that for the augmentation of our economy and advancement of our society, energy is an underpinning factor which has a key role in facilitating development and sustainability. While taking into consideration the process of advancement in societies aroundthe globe, we always have a sense of the perpetual concern that policy-makers confront frequently, for instance expanding and improving access to healthcare, education, curtailing negative environmental impacts, enhancing and producing employment opportunities, and developing striking trade and investment conditions. In spite of that, at times we neglect the fact that energy encompasses all of these goals.

1.2.1 Renewable energy sources in India

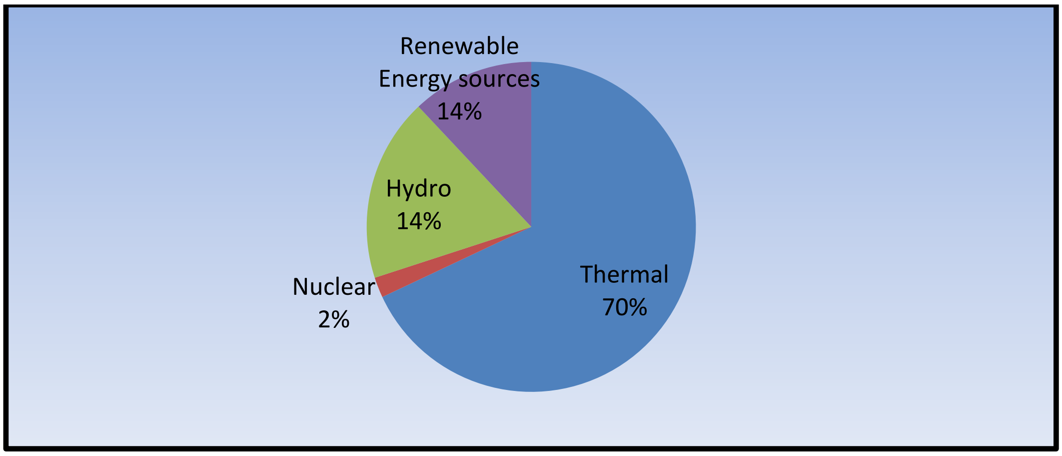
Renewable energy is increasingly a part of an economic sustainability calculation. Due to the prevailing energy crisis issues, India needs to ensure security and set larger goals to attain self-sufficiency in production of energy. There exists a considerable energy demand-supply gap in India. The primary reason for electricity shortage is an over-reliance on thermal energy from coal and gas, as shown in Figure1.2. The figure highlights that thermal energy, which is the limited, is the most common source of energy with the share of 70 percent in the total generating installed capacity (302088 MW) of energy in India in March 2016. It comprises of coal sharing the largest generation of 185172.88 MW (61 percent), gas sharing 24508.63 MW of generation (8 percent) and diesel with the capacity of 993.53 MW (1 percent) as on 31-03-2016. Fourteen percent (42783.42 MW) of the total installed capacity is generated through hydropower. Renewable energy sources share (42849.40 MW) forms another fourteen percent of the total generation capacity. The smallest portion 2 percent is generated by nuclear energy (5780 MW).

The increased competition for limited fossil resources is projected to push prices up, which would result in the increased deployment of renewable sources of energy to meet the standards of economic growth in linewith technological advancement. Renewable energy technologies are well suited to meet India's need for power in remote areas that lack grid and road infrastructure. It also helps in reducing GHG (greenhouse gas) emissions.

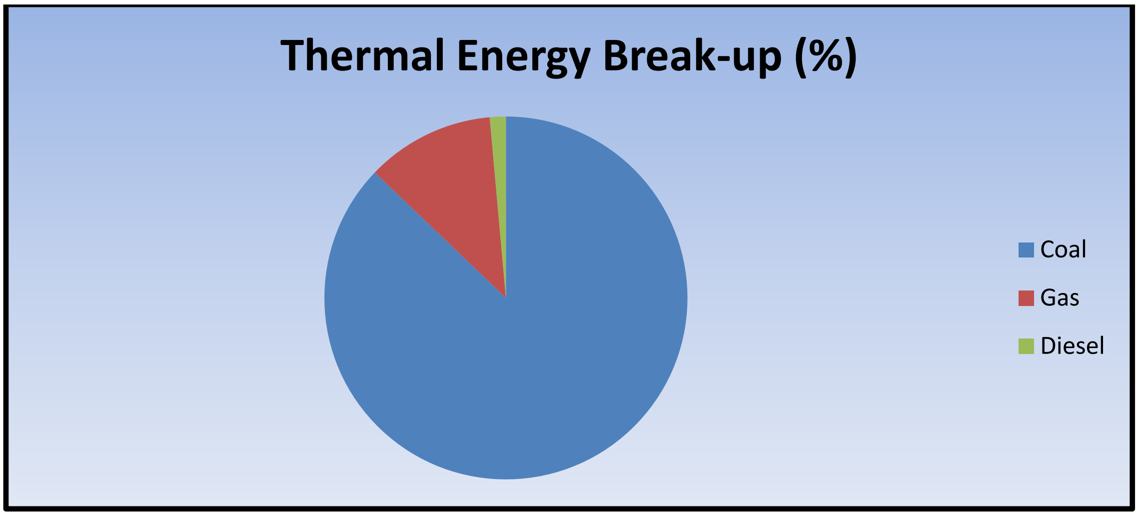
There are many sources of renewable energy like wind power, biomass energy, solar energy, energy from waste, small hydropower plants, etc. India has a great potential in renewable energy sources for electricity generation. The most utilized power in India is wind energy. Solar is an important, although currently underutilized, energy source in India with the potential to offer an improved power supply (especially in remote areas) and increase energy security in India. In many parts of India, solar energy, due to favorable climatic conditions and least seasonal variations and other constraints, is one of the best sources of electricity generation which is totally environment-friendly with zero emission potential. Solar technology is improving and advancing in India, thereby, cutting down the prices. Yet, it is not fully utilized in the country. The emission reduction potential of renewable energy sources encourages the deployment of these energy sources.

Though India has a huge potential in renewable energy resources, currently, only 14 percent of India's energy is supplied by sources of renewable energy. The dependence on fossil fuel will leave them highly exploited, and renewable sources will remain unexplored which will result in more power deficit in our country, unless strategic policies are adopted in increasing the share of renewable energy sources.

Figure 1.2: All India generating total installed capacity (302088 MW) as on 31-03-2016

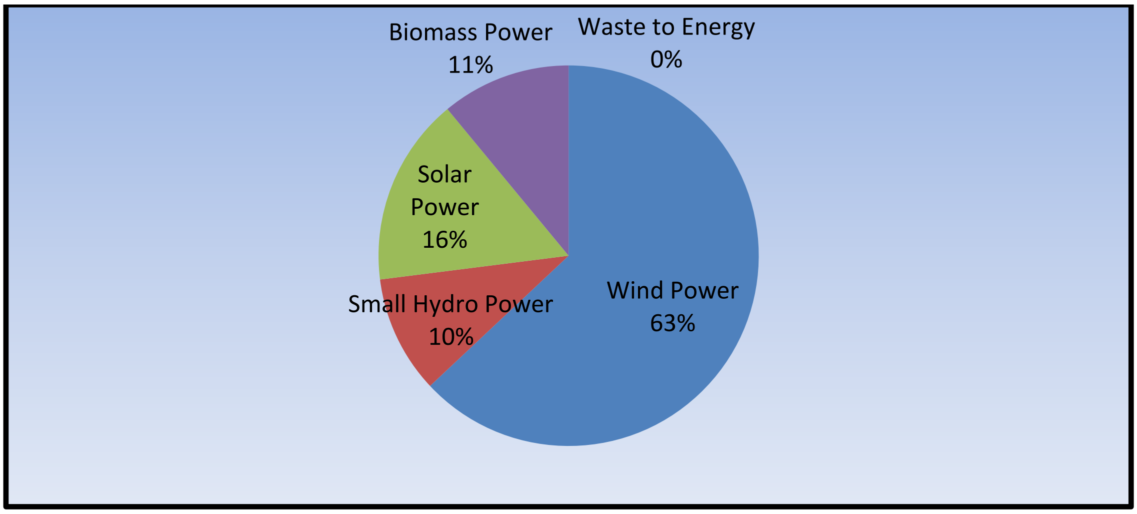


Source: www.cea.nic.in/reports/monthly/executive summary/2016/exe_summary-01.pdf



Out of 14 percent of the total installed capacity of renewable energy, solar power constitutes 16 percent of the energy mix, as shown in Figure 1.3. The total installed capacity of renewable energy sources is 42849 MW of which 26866.66 MW of wind energy has the highest share of 63 percent. Though gradual increase has been observed in solar capacity, yet compared to its potential, it lies on a lower side of the total share in energy mix i.e. 6762.85 MW (16 percent). Biomass energy constitutes 4946.41 MW (11 percent) of the total RE mix whereas small hydro share has declined to 4273.47 MW (10 percent). It is surprising and distressing to note that energy from waste prevails at zero percent of the energy mix which leaves it unproductive and degrades the environment.

Figure 1.3: All India renewable energy installed capacity during 2016



Source: www.cea.nic.in/reports/committee/nep/nep_dec.pdf

1.2.2 Renewable energy policies in India and Rajasthan

The central and state government after analyzing the growing need to shift towards renewable energy sources for power generation has initiated and implemented many policies to support renewable energy.

- ***Energy conservation act 2001:*** this act was formulated as a policy support for institutional creation to target multiple renewable energy sources and power.
- ***Government assistance for wind power development (2002):*** this policy was formulated to support wind energy through fiscal incentives, taxrelief, and loans, etc.
- ***Government assistance for small hydro stations (2003):*** this policy is to support hydropower through economic instruments, financial incentives and taxrelief, etc.
- ***Electricity act 2003:*** this is landmark legislation for reform and regulation of the plagued Indian power Sector. It also targets multiple renewable energy sources.
- ***Central financial assistance (CFA) for biogas plants (2004):*** this policy supports bioenergy and biomass for power through grants and subsidies, direct-investments, financial incentives, regulatory instruments and obligation schemes, etc.
- ***National electricity policy 2005 and integrated energy policy 2006:*** both of these policies were formulated as a policy support through strategic planning to multiple renewable energy sources.
- ***Tariff policy 2006:*** this policy was formulated to support power and multiple renewable energy sources in the form of obligation schemes, fiscal incentives, regulatory instruments, and feed-in tariffs.
- ***National action plan on climate change 2008:*** this promoted and focused majorly on solar thermal energy through regulatory instruments, codes, and standards.
- ***Solar power generation based incentives 2008:*** this policy supports solar photovoltaic and solar thermal through fiscal incentives, taxrelief, economic instruments and feed-in tariffs.
- ***RE tariff regulations 2009 (revised in Nov 2010):*** this policy supports solar, solar thermal, solar photovoltaic, wind energy, biomass, bioenergy, multiple RE sources with the help of economic instruments, financial incentives, and feed-in tariffs.
- ***National solar mission (phase I and II) 2010:*** this policy supports solar thermal, solar and solar photovoltaic through regulatory instruments, other mandatory requirements, economic instruments, financial incentives, tax relief, feed-in

tariffs/premiums, grants and subsidies, research, development and deployment (RD&D), research program.

- ***Solar cities development programme 2011:*** this policy is to promote solar energy through research development and deployment (RD&D), research program, technology deployment and diffusion, economic instruments, direct investment, funds to sub-national governments.
- ***Renewable energy certificate system (REC's) 2011:*** this policy is formulated in order to support power and multiple renewable energy sources through economic instruments, market-based instruments, green certificates, regulatory instruments, other mandatory requirements.
- ***Rajasthan solar policy 2011:*** this policy is designed to support solar thermal, solar and solar photovoltaic in Rajasthan through economic instruments, market-based instruments, green certificates, financial incentives, tax relief, policy support, strategic planning and institutional creation.

The Twelfth Five Year Plan (2012-17), also focused on faster, more inclusive and sustainable growth by promoting power and renewable energy sources through policy support and strategic planning.

1.3 RURAL ELECTRIFICATION POSITION IN INDIA

Rural Electrification is a vital program for the socio-economic development of rural areas. The objectives are to trigger economic development and generate employment by providing electricity as an input for productive uses in agriculture and rural industries and improve the quality of life of rural people by supplying electricity for lighting homes, shops, community centers and public places in all villages.

Before we study rural electrification, we need to clarify what is meant by electrification. The term electrification as such has not been defined in any of the statutes. However, the Ministry of Power in 2004-2005 defined electrified village as under:

"A village would be declared as electrified if –

a) basic infrastructure such as distribution transformer and distribution lines is provided in the inhabited locality as well as the dalit basti/ hamlet where it exists. (For electrification through non-conventional energy sources a distribution transformer may not be necessary).

b) electricity is provided to public places like schools, panchayat office, health centres, dispensaries, community centers, etc; and
c) the number of households electrified should be at least 10 percent of the total number of households in the village." (Upadhyay & Badoni, 2014)

Further, rural electrification primarily involves the supply of energy for two major programs:

a) production oriented activities such as minor irrigation, rural industries, etc.;
b) electrification of villages. (Upadhyay & Badoni, 2014)

Many policies have been implemented to achieve success in rural electrification in India; still, a large number of villages remain un-electrified in different states of the country (CEA, 2014). According to a progress report of village electrification conducted by Central Electricity Authority, Rajasthan ranks seventh having un-electrified villages in India after Arunachal Pradesh, Meghalaya, Orissa, Mizoram, Manipur and Nagaland (Table 1. 4).

Table 1.4: Progress report of village electrification as on 31-07-2014 as per 2011

S. No.	**States**	**Total inhabited villages as per 2011 census**	**Villages electrified as on 31-03-2014**	**%age of villages electrified as on 31-07-2014**	**Un-electrified villages as on 31-07-2014**	**% of un-electrified villages as on 31-07-2014**
1	Andhra Pradesh	26286	26286	100.00	0	0%
2	**Arunachal Pradesh**	**5258**	**3586**	**68.4**	**1672**	**31.6%**
3	Assam	25372	24404	96.7	968	3.3%
4	Bihar	39073	37002	95.5	1757	4.5%
5	Chhattisgarh	19567	19055	97.6	512	2.4%
6	Goa	320	320	100.0	0	0%
7	Gujarat	17843	17843	100.00	0	0%
8	Haryana	6642	6642	100.00	0	0%

9	Himachal Pradesh	17882	17880	99.99	2	0.01%
10	Jammu and Kashmir	6337	6224	98.2	113	1.8%
11	Jharkhand	29492	27142	92.1	2350	7.9%
12	Karnataka	27397	26704	97.5	693	2.5%
13	Kerala	1017	1017	100.00	0	0%
14	Madhya Pradesh	51929	50394	97.1	1535	2.9%
15	Maharashtra	40956	40920	99.9	36	0.01%
16	**Manipur**	**2379**	**2061**	**86.6**	**318**	**13.4%**
17	**Meghalaya**	**6459**	**5132**	**79.7**	**1327**	**20.3%**
18	**Mizoram**	**704**	**650**	**85.1**	**54**	**14.9%**
19	**Nagaland**	**1400**	**1261**	**90.0**	**139**	**10%**
20	**Orissa**	**47677**	**38920**	**81.6**	**8757**	**18.4%**
21	Punjab	12168	12168	100.00	0	0%
22	***Rajasthan****	***43264***	***39036***	***90.02***	***4228***	***9.8%***
23	Sikkim	425	425	100.00	0	0%
24	Tamil Nadu	15049	15049	100.00	0	0%
25	Tripura	863	837	97.0	26	3%
26	Uttar Pradesh	97813	96515	98.7	1298	1.3%
27	Uttarakhand	15745	15638	99.3	107	0.7%
28	West Bengal	37463	37461	99.99	2	0.01%

Source: CEA

Table 1.4 highlights the following facts in Indian context:

a) unavailability of electricity for rural masses,

b) low generation capacity which remains handicapped in meeting peak demand and
c) non-reliability of electricity supply, in terms of predictability of blackouts/power cuts and quality of power supply.

In spite of various attempts to achieve total rural electrification, India has not been able to do so. The initiatives taken by government for rural electrification include many schemes, from which important ones are discussed briefly.

Rajiv Gandhi Grameen Vidhyutikaran Yojana (RGGVY): RGGVY was introduced by Ministry of Power, GoI in April 2005 in order to achieve the objective of providing access to electricity to all rural households. Under this scheme 90 percent capital subsidy is provided for rural electrification infrastructure through:

- creation of rural electricity development backbone (REDB)
- creation of village electricity infrastructure (VEI)
- decentralized distribution generation (DDG) and supply system from conventional sources for villages where grid supply is not cost effective.

Remaining 10 percent are in the form of loan assistance on flexible terms by Rural Electrification Corporation (REC). The scheme inter-alia provides for funding of electrification of all un-electrified below poverty line (BPL) households with 100 percent capital subsidy.

Though, Rajiv Gandhi Grameen Vidhyutikaran Yojana encourages the use of renewable energy sources for off-grid applications in rural areas, yet, around 9.8 percent villages are totally un-electrified in Rajasthan and many villages are partially or seem electrified.

Deen Dayal Upadhyay Jyoti Yojana (DDUJY): This scheme is introduced as a replacement of the earlier scheme for rural electrification viz. Rajiv Gandhi Grameen Vidhyutikaran Yojana (RGGVY). The scheme emphasizes the strengthening of the transmission and distribution infrastructure including metering at all levels in rural areas which will help in delivering round the clock power to rural households for domestic as well as agricultural and other productive uses.

The DDUJY focuses on the following objectives in rural areas:

1. to electrify all villages of the country,

2. to work on feeder separation in order to ensure ample power for agriculture and uninterrupted electricity supply to households,
3. to improve the transmission and distribution network to ensure good quality and reliable power supply, and
4. to introduce the metering system in order to reduce the losses.

1.4 STATEMENT OF PROBLEM

Socio-economic development in rural India lags behind regardless of the high agricultural and industrial development prospects. The main factor behind the stumpy development in the country is attributed to insufficient energy sources resulting in continuous turn down in economic production. Electricity is identified as a prime indicator of the socio-economic development of households. However, dwindling accessibility to electricity, and little adoption, is a major hindrance in impelling and empowering rural households in India.

Researches have come up with alternative sources of energy to foster rural electrification and face the challenges due to low generation and weak transmission of electricity. Solar Energy has a high potential for rural electrification in India and Rajasthan. Immense studies have been conducted in this field on the technological aspect. The other side that is socio-economic and environmental impacts remains underexplored. The growing challenges of energy demand-supply gap and catastrophic climate change risks due to overuse of conventional sources of energy in the present scenario offer a window of opportunity in the form of renewable energy sources, especially solar energy for rural electrification in India. The added advantage is that the unemployment situation can also be tackled with electrification in areas without grid connections thus lowering down the transmission and distribution losses through off-grid applications.

In Rajasthan, solar energy has significant potential and is being deployed as well but largely for grid-connected systems and mainly in urban areas. Though some work has also been done in remote areas, yet, a large part of rural population remains un-benefitted. The decentralized energy generation can effectively be opted for rural electrification in Rajasthan. This technique is the area which is socio-economically feasible and remains under-researched in the State.

Research Gap:

The literature review highlights the growing need for renewable energy deployment in off-grid applications and also on grid energy supply. However, no micro study has been done in analyzing the socio-economic impact assessment of solar energy deployment through decentralized energy use in Rajasthan. Rajasthan being the state occupying the largest share of land area and solar radiation in India has a high potential for solar energy deployment for State's economic growth and sustainable development.

It is observed that there exist a large number of researchstudies that have been done on the economic and technological analysis in addition to factor analysis. Even though these investigations are profoundly meticulous and precise, still the quantitative impacts of the transformation of demand and supply structure of energy, for instance, the induction of new technologies, are yet to be considered in the studies. In contrast, there are only a few studies that integrate socio-economic effects into the analysis. In present scenario poverty, education, health, and economic dispossession are equally significant, therefore, it is obligatory to embrace these socio-economic factors in the investigation.

1.5 OBJECTIVES OF THE STUDY

The electricity production and demand-supply scenario of India and Rajasthan, along with the policies and actions adopted by the government to overcome the shortages have been investigated. Based on the problem statement discussed in section 1.4, the primary focus of this study is to analyze the use of solar energy for rural electrification in the off-grid application for the deployment of decentralized energy for rural needs in Rajasthan. Thus, the broad objective of this study was to evaluate rural electrification adoption dynamics in the study area. The objectives of the study can be stated as:

- to study the problems and prospects of rural electrification in Rajasthan.
- to evaluate the scope of decentralized electrification in rural areas based on solar energy in Rajasthan.
- to evaluate comparative cost of off-grid solar energy in rural areas vis-a-vis grid connected conventional energy cost.
- to study the socio-economic impact of existing solar based decentralized projects in rural Rajasthan.

The present research also investigates the effectiveness of solar energy electrification in the transformation of livelihood amongst the rural households and understands the people's sense of adoption and willingness to use solar technology for electrification and to examine their views for the PV Solar project stability and future maintenance.

1.6 IMPORTANCE AND CONTRIBUTION OF THE PRESENT STUDY

With accelerating development trends and high standards of living, the need for electricity generation and consumption has increased in recent years. But due to the shortage of fossil fuels and the adverse climatic changes caused by them, to shift to renewable energy for power generation is now a well established truth.

In the present scenario, the challenges of providing electricity to rural areas are manifold. Ever increasing demand-supply gap, crumbling electricity transmission, and distribution infrastructure, the high cost of delivered electricity are a few of these. Thus, renewable energy technologies for meeting basic needs of rural communities are required to be adopted. This study analyzes the deployment of decentralized solar power for remote rural communities in Rajasthan.

Hence, this study is gauged to promote and encourage the solar energy power generation, accessing the hurdles being faced by the present system to provide electricity in rural areas.

Furthermore, the assessment of the employment generation opportunities with solar implantations and a study of the social profile (health and education) of rural masses for further implementation and improvement can be promising in increasing growth trends.

Thus, the research can prove to be helpful in achieving energy policy planning for energy security of the rural and remote population.

Contribution of present study in filling the research gap:

The present research has targeted the beneficiaries of the photovoltaic solar energy projects commissioned in remote villages in Rajasthan. Thus, the findings of this study demonstrate the willingness, reception and a sense of ownership of the projects installed in the villages and revealsthe mindset of acceptance which ensures the stability of these projects. This study will facilitate both the people as beneficiaries of the projects, academicians and other energy stakeholders in the planning and implementation of the off-grid solar projects. Therefore, the study paves way by contributing to the academicians, researchers, policy makers and planners involved in the use of green energy for rural planning.

1.7 OUTLINE OF THE THESIS

The information studied, the survey and research analysis completed along with the results accomplished during the course of study is arranged in following seven chapters of the thesis.

Chapter I: Introduction

The introductory chapter furnishes an overview of the area of interest under consideration. It gives a brief introduction of all the relevant areas and topics related to the present study. It includes the problem statement, objectives of the research, importance of the study and the chapter outline.

Chapter II: Review of literature

The second chapter reviews the existing literature, national and international, obtainable on the subject matter.

Chapter III: Design and framework of present study

In the third chapter, the research methodology adopted in the study is represented. It gives an overview and framework of the research design for the primary survey and data collection, scope of the study and the statistical techniques used for analyzing the data.

Chapter IV: Renewable energy structure and rural electrification position in Rajasthan

Chapter four describes the detailed scholastic overview of the renewable energy resources and their uses along with the appraisal of the rural electrification situation in Rajasthan. This chapter presents the theoretical understanding of the research gap and statement of the problem including the comprehension of justification of objectives of the study.

Chapter V: Comparative cost analysis of grid-connected thermal electricity and off-grid solar energy in rural Rajasthan: case studies

This chapter includes the comparative cost analysis of the extension of the grid-connected thermal electricity and off-grid Solar PV technology based electricity. Two case studies in rural Rajasthan are presented and evaluated in this chapter.

Chapter VI: Socio-economic impact of existing decentralized solar based projects in Rajasthan: sample survey

Chapter five outlines the empirical evaluation of the socio-economic variables studied in sample villages along with the brief profile of the sample households. The variables include their monthly household income, monthly expenditure on fuel and electricity, household characteristics etc.

Chapter VII: Summary, conclusions and recommendations

This chapter focuses at the summary of findings and policy implications in view of the future prospects. It ascertains that life cycle cost of decentralized solar systems is cost-effective for remote areas. It analyzes that electrification through solar technologies have created a significant positive impact on the socio-economic aspects of the rural population of the surveyed villages.

The chapter concludes by highlighting the problems and loopholes of off-grid technologies proposing models for the improved operations of such projects for welfare and growth of the society. The environmental benefits have also been taken into account for cleaner, safer and sustainable India.

Chapter 2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

The hastily mounting issues of energy security due to the escalating energy demand and depleting conventional energy sources has led extensive research towards sustainable energy through renewable sources in India and the world.

Initially, a strenuous review of the literature was attempted to construct knowledge about the ‘energy boom' approach and previously accepted comprehension on the focus area. In the review process along with national publications, Intercontinental peer-reviewed journals were referred, together with the publications and project reports of institutions, universities and government bodies of international repute. At the same time, Google Scholar was consulted for web research on the subject.

In this chapter, the review of the literature has been divided into seven sections for better understanding. The first section explains the importance of energy in the growth and development of countries worldwide. The interconnection of energy services with economic growth and standard of living is highlighted in this section. In the second section, the literature includes the importance of clean and green energy sources for carbon emission mitigation across the globe. The main spotlight of this section is the shift to renewable energy sources from traditional energy sources for creating a safe environment. The third section comprises of the literature on sub-topic of the study i.e. techno-economic feasibility of solar power systems. In this, the economic aspects and cost-effectiveness along with the technological side of solar energy systems are discussed. The methods used for evaluating the economics of Solar PV technology in the existing literature are mentioned. In the fourth section, the literature related to the highlights of decentralized or off-grid technology uses is studied and understanding of the utilization and importance of the same. Moving to the fifth section, the rural electrification is taken into consideration to understand the scenario, problems, and prospects of rural electrification which is the primary concern of the present study. The research gap is reviewed in the sixth section, i.e. the socio-economic impacts of off-grid solar electrification in rural areas. In this section, the literature focuses on the positive impacts of solar energy on the rural masses. Lastly, in the seventh section, the literature is structured on the financial and organizational aspects of the effective intervention of renewable energy technologies in electricity-deprived regions.

After an extensive review of nearly one hundred and fifty articles, the researcher found that 76 papers were valuable for the present study. The studies are carried out in the area since 1990's; however effective studies came up with a boom in solar technology after the 2000s.

Table 2.1: Review of literature: classification summary

Description	***Authors***
Energy and growth	Khurana,2004, Samdarshi, 2011, Luise, 2013, Sharma.A,2011, A. Sapkota et al,2014, Rout,2011, Hammar,2014, Ahmad,2013, Nexant,2004, Palit,2015, Graczyk,2012, Nathan,2012, Reddy,2013, Molyneaux et al,2016, Jana,2015, Chaturvedi,2011 , Chaurey et al,2004
Green energy	Michaelowa,2008, Plattner et al,2013, Borah,2014, Reddy et al,2013, Sherwani,2010, Kandpal,2010, Feron,2016, Alka Sapkota,2014, Dopazo et al,2010
Techno-economic feasibility of solar energy	Purohit,2010, Ramachandra et al,2001, Sharma,2011, Timilsina et al,2011, Sahoo,2013, Purohit et al,2013, Pearce, 2014, Shrimali, 2014, Sharma et al,2012, Feron,2016, Munuswamy et al,2011, Mauleon,2015
Decentralized energy use	Neodoerffer et al., 2001, IEA,2012, Kandpal, 2010, Choragudi, 2013, Bandhopadhyay et al.,2015, Ackerman et al.,2001
Rural electrification	Kandpal, 2010, Bhandari, 2011, Trotter,2016, Panda,2007, Rehman,2012, Pachauri,2004, Khandker,2010, Modi,2005, Cook,2011, Khandker,2012, Bhattacharya,2006, Rud,2012, Cabraal,2005, Rehman et al,2013, Palit,2015
Socio-economic implications of off-grid solar electrification	Bandopadhyay,2016, Udaykumar,2011, Sriwannawit,2014, Murali,2015, Alzola et al, 2009, Choragudi,2013, Kandpal,2010, Feron,2016, Alka Sapkota,2014, Rao,2015, Palit et al,2013
Financing and institutional modeling	Chaurey,2012, Sadeque,2014, Chaurey,2011, Bandopadhyay,2016, Timilsina et al,2012 , Kandpal,2010, Girona. M. et al,2016

2.1 ENERGY AND GROWTH

(Khurana, 2004), have acknowledged that energy security concerns for India with an eye to uphold the likely sustained growth rate of 8-9% during the next decades needs to mull over increasing its primary energy supply by 3-4 times. Energy is the primemover of economic growth and availability of energy with assured quality of supply is not only the key to sustainable economic development but has a direct impact and influence on the quality of service in the field of education, health, and food security. Therefore, it is affirmative that energy is the key indicator of economic and sustainable growth.

(Chaturvedi & Samdarshi, Energy Economy and Development (EED) Triangle: Concerns for India, 2011) analyzed that economic growth, development and energy security in Indian scenario are interlinked. Thus the depleting fossil fuels become a matter of great concern for the country, and the need to shift towards renewable sources for sustainability becomes high.

(Luise, 2013) discussed the importance of renewable energy sources in energy security and supply side management of energy sector analyzing the technical and economic aspects.

(Chaurey, Ranganathan, & Mohanty, Electricity Access for Geographically Disadvantaged Rural Communities- Technology and Policy Insights, 2004) Literature also depicts the positive contribution of electricity to Human Development Index (HDI), reflecting that the poor are most likely to benefit from electricity inputs.

(Sharma A., 2011) confirms that energy is considered a principal representative in the creation of wealth and is a unique aspect of economic development. Energy is also indispensable for improving the eminence of life.

(Sapkota, Lu, Yang, & Wang, 2014),envisages that, due to the rising population and living standards, the consumption of energy in the form of electricity is also increasing speedily, which has resulted in a massive demand for energy and in turn generated a need for alternative energy resources as fossil fuels are depleting due to over-exploitation. Therefore, as a result of this, the cost of conventional energy resources also intend to raise on the other hand the cost of renewable energy starts declining with the progress in technology. The research signifies that the renewable energy is more cost effective in present scenario and it is more consistent as well as environment welcoming than the conventional energy. Besides, development of renewable energy kindles the growth of the economy, creates employment opportunities, improves health facilities, sustains energy security and provide clean atmosphere.

(Rout, 2011), elucidated that, the swift growth of any developing nation multiplies its population and boost is observed in its economy, human development index (HDI), energy development index (EDI), per capita GDP, industrialization (i.e., substitution from low yielding industry, e.g., traditional agriculture to high yielding industry, e.g., IT sector currently), urbanization (i.e., society revolution), living standard, and quality of life. This ultimately results in augmented demand for energy and elevated emissions. Therefore, it is suggested that it becomes crucial for a nation to plan its prospect requirements for energy and the emissions that it blazes into the environment for assessing its energy security through import, export, and withdrawal policy development on local stores and assets sector-wise; map and cope resources for sustainability; advance sector-wise restriction policies on local- and globalemission; sketch its ventures, look for sustainable system transformation of its energy template by adaptation of fuel mix and reorganize its technology mix for short and long terms.

(Hammar & Linus, 2014), advocated that it isn't doubtful that assess to electricity is advantageous for people including the existing users of electricity all over the world and most importantly for the people in developing regions. Although electricity may perhaps lack in stimulating complete growth on its own, still it is an exceedingly preferred service and a precondition to economic development in the long-term prospect.

(Ahmad & Mokbul, 2013), explicates that, since the entire technological and economic growth depends on the unremitting and adequate supply of energy, therefore, the distribution of energy has to be sound as the development of the nation is effectively prejudiced by the stable energy supplies. It is noticeable that due to rise in population and increased utilization has lead to an acceleration of energy consumption is in the current scenario. Furthermore, access to electricity not only reduces the energy cost and improves the standard of living but is also advantageous for other non-economic aspects of social life such as entertainment and safety, etc. which in turn results in improved quality of life.

(Nexant, 2004), discussed that energy is crucial to human welfare, and contemporary energy is vital to economic development. Specifically, consumption of electricity is exceedingly allied with income as considered by per capita GDP. However, until now in the developing nations, principally in South Asian countries like India, more than 1.6 billion people are deprived of electricity. During the evening time, the only light for them comes from the blaze of traditional fuels like wood, dung, and crop froths and at max, possibly from kerosene.

(Palit, Garimella, Shardul, & Chaudhury, 2015), discussed based on the literature, that India is primarily a rural country, with around 73 percent of the total population residing in villages. It is advised that India should provide access to electricity to its rural communities as for achieving the Millennium Development Goals (MDGs). For enhancing the all over socio-economic growth of country especially rural areas, the reasonable, consistent, and socially suitable energy services are considered to be the most important requirement.

(Graczyk & Dagmar, 2012), further contributed envisaging that energy availability is the primary objective in India's energy policy making, as practically one-fourth of the population remains deprived of admittance to electricity. This implies that the economic growth of the nation could be strengthened by guaranteeing the sufficient and steadfast supply of energy to the population of India that has high and rising demand for power. It has been observed that India has considerably high per-capita energy consumption and per-capita carbon emissions in a relationship with other nations. Therefore it is recommended that India should swell its energy supply to grant widespread access to modern energy and sustain economic growth. India's mounting reliance on foreign energy sources has stern policy implications for its energy safety. The fossil fuel based traditional energy mix along with growing carbon emissions will generate severe challenges for India's sustainable expansion.

In addition to existing literature, (Nathan & Kristle, 2012), concludes that energy drives the global economies, developed as well as developing. Though, the requirement for energy is more evident in developing nations because such nations have an exceptionally low life expectancy, high infant mortality and low literacy for the reason that the per capita consumption of electricity in these countries also remains remarkably little. Thus, it is ascertained that, along with the quantum of energy, the eminence of energy service have considerable effects on the living standard of any developing nation.

(Reddy, Kaushik, & Panwar, 2013), in lines with the available literature, further contributes pointing out that, energy is the most compelling feature in social-economic growth as well as the creation of a wealth of a country. Derived from chronological data, it is found that, admittance to energy resources and economic activities possess a strong correlation. Thus, electricity is the leading driver for the economic development of any emergent nation like India, which is thriving for a vigorous economic growth rate.

(Molyneaux, Wagner, & Foster, 2016), added, evolving social and economic advancement with the clean energy is the aim of leaders internationally. India remains a leading example of a country that is putting forth its right to nurture and produce energy access for all of its citizens. Clean energy from renewable sources is a principal component of elucidation and will be indispensable to accomplish that aim.

(Jana, 2015), said that, in the context of achieving sustainable energy access, reliable and adequate energy supply is one of the most important universal challenges. Currently for all the essential goods to which people are entitled and for productive activities, energy operates as a substantial requirement. Incompetent exploitation of energy and its mounting scarcity all over the emerging nations, make it imperative to recognize alternative energy sources and strategies. The implication of constructing stipulations for residential lighting in the rural area is undeniable given that various activities for their growth and affluence like education, literacy, crafting are fundamentally reliant on satisfactory and reasonable domestic lighting amenities.

(Chaturvedi & Samdarshi, 2011), illustrated that the position of equilibrium between the economic growth, development and energy security desires to be scrutinized in the light of the fundamental dynamics. In Indian perspective, it is evident to note that the economic growth, development, and energy security are interconnected.

2.2 GREEN ENERGY

(Michaelowa & Purohit, 2008), explains the relevance of CDM potential of solar water heating systems (SWHS) in India as they directly displace greenhouse gas emissions while contributing to sustainable development by reducing local pollutants. According to them, solar energy technologies have been developed through research and development, and some of these technologies have reached maturity and a user-friendly status. These are suitable for decentralized applications, but are not yet deployed in rural areas. They also state that small scale RE projects have significant local environmental and socio-economic benefits. In this study for installation of SWHs the values of the regression coefficients using logistic model have been estimated by regression of the time series data.

According to the various annual reports of Intergovernmental Panel on Climate Change (Plattner, Stocker, Qin, Tignor, Allen, & Midgley, 2013), fossil fuels provide more than 80 percent of all energy however the urgent need is to cut planet-warming carbon emissions. This means a fall equal to a third of present levels in coming decades is needed. Thus there is a heavy emphasis on renewable energy, such as wind and solar power, and cutting energy waste, which need hundreds of billions of dollars of investment a year.

However, many renewable energy technologies have substantially advanced showing performance and cost efficiency and a growing number have achieved technical and economic maturity, making renewable energy a fast growing category in energy supply. The report emphasizes that renewable sources are the best way to mitigate the catastrophic effects of the carbon emissions and greenhousegasses caused due to overuse of conventional sources of energy.

(Reddy, Kaushik, & Panwar, 2013) contemplated, that regardless of its importance in the generation of electricity, the exploitation of coal has shown elevated adverse impacts on individuals as well as the environment, due to unwarranted emissions of greenhouse gasses (GHGs). This leads to accumulation of massive amount of carbon dioxide which results in global warming and depletes the earth’s atmosphere. The research also laid stress on government policies to envisage the alarming situation resulting from present generation of electricity. The government of every country needs to develop such energy policies which efficiently consume the resources in a sustainable manner, with view to decreasing fossil fuels and rising prices. On the other side, environmental pollution linked with fossil fuel based power has a negative impact on the ecosystem and human health.

(Borah, Palit, & Mahapatra, 2014), elucidates that contribution of PV electrification has promoted clean energy supply and contributed to greenhouse gas mitigation.

(Chaurey & Kandpal, 2010), discussed the assessment of carbon mitigation potential of renewable energy technologies, including PV in India. Another such study gauges the breakeven value for a PV pump as an alternative and diesel replacement and has evaluated the dissemination potential of PV pumps in India. The study shows potential CO_2 mitigation by their use for irrigation pumping.

(Sherwani, Usmani, & Varun, 2010) stressed on the green energy scenario stating that solar photovoltaic (PV) module converts solar energy directly into electricity and lead to environmental benefits such as GHG and pollution reduction. The solar energy seems to be absolutely clean having no environmental collision. In this paper, the environmental impacts of solar PV based generation systems have been anticipated through life cycle assessment technique.

(Feron, 2016), advocated that the solar PV systems show advantages in terms of affluence abrogation and climate change alleviation especially in the caseof rural electrification because of their reasonably low negative impact on the environment. Contrary to this, conventional sources of energy result in major and significant negative impacts on atmosphere because along with greenhouse gas emissions they also contribute to climate change by fabricating around 1/4 of short-lived climate pollutants (SLCP) like black carbon. Black Carbon is generated not only in households during cooking and heating but also from lightning. It is anticipated that globally, roughly 500 million households use 77 billion liters of kerosene and other liquid fuels for lighting. Further, according to the literature available, it is predicted that7–9 percent of energy from kerosene oil lamp transforms to pure black carbon.

(Sapkota, Lu, Yang, & Wang, 2014), explained in their research that energy and climate change has a cause and effect relationship. The energy use pattern including the supply, transmission, and distribution of energy driven by consumers remains a predominant purveyor to climate change, which presently corresponds to around 60 percent of GHG emissions. It has been noticed that GHG emissions as an outcome of conventional energy are escalating progressively.

(Dopazo, Fueyo, & Izquierdo, 2010), anticipated that energy scheduling is principal for government organizations owing to its significance for the economy and the environment. Among the technologies to generate electrical energy, the one which is derived from renewable resources occur as one of the vital elements in the deterrence or alleviation of climate change. Therefore, it is advised that imminent studies on renewable energy potentials should be concentrated mainly on two different yet interlinked, features, i.e., the scrutiny of the chronological allocation of such resources, resulting in their cumulative technical potential distribution and the appraisal of the ecological and financial impact of non-conventional technologies.

2.3 TECHNO-ECONOMIC FEASIBILITY OF SOLAR ENERGY

According to a very relevant research by (Purohit & Purohit, 2010) using the cost-benefitanalysis, the techno-economic evaluation of concentrating solar power generation in India have been explained. According to them, resource assessment is the primary and essential exercise for solar energy project evaluation. The approach adopted by them for estimation of electricity generation from the projects is through comparison of direct and indirect normal radiations at locations of the new site and the projects. Hence, electricity generation figures are estimated on the basis of an actual site related data, whereas project cost could be presumed similar in the new site. They analyzed the Clean Development Mechanism (CDM) benefits by using Life Cycle Analysis (LCA).

(Ramachandra, Jain, & Krishnadas, 2011) identifies that India has a huge solar potential in order to meet the rising energy demand which would lead to socio-economic progress of the country. The techno-economic feasibility criteria of solar systems for choosing the best system for the identified area for implantation have also been studied. The research explains the future prospects of solar power in India along with the organizational and social aspects related to solar power generation in the country.

(Mauleon, 2015), adopted the levelized cost of energy method for comparing the cost of different types of technologies as this method is commonly used by industries.

(Sharma A. , 2011), analyses the global scenario of solar power generation throwing light on the potential, technology and policy framework to support the solar growth in countries. It has been observed that solar technology has grown at a very fast pace in recent times resulting in cost reductions. However, India has not adopted the solar system power generation techniques despite being one of the nations with highest solar potential. The leading countries with developed solar technique adoption are U.S, Germany, Spain, Italy and even China has become a competitor. There exist an immense scope and availability of solar energy in India with reduced technical cost to fill the energy demand-supply gap and move towards economic and sustainable development.

The research questions like the barriers that prevent solar deployment? What policies have been introduced to boost solar market? Have they produced desired results, etc. and the techno-economic analysis of competitive solar energy with fossil energy counterparts including the analysis of cost reduction and environmental benefits have been discussed in detail (Timilsina, Kurdgelashvili, & Narbel, 2012) by using levelized cost method, taking into account all the associated variables. The study also discusses the policy instruments and their impact on the solar energy power generation and the policy challenges. Solar energy development under the climate change regime has also been analyzed.

According to the research conducted by (Shrimali & Sahoo, 2013) the effectiveness of domestic content criteria had been extensively analyzed for India's solar mission which helps to explain the competitiveness of the Indian solar market.

(Purohit, Purohit, & Shekhar, 2014) explained the vast potential of Concentrated Solar Power (CSP) technologies in Northern India, especially in Rajasthan taking into account the resource assessment and availability and central/state policy framework for promoting CSP in India. According to them, mechanisms like feed-in-tariff can provide long-term and assured security to investors. The study has used life cycle assessment for identifying the cost of energy produced by renewable technologies. To estimate the energy yield over the locations in NW parts of India they have used the System Advisor Model (SAM). SAM includes energy performance models for all CSP technologies along with grid connected solar PV.

(Sahoo & Shrimali, 2014) throw light on the potential of solar energy in India, various types of solar power generation and the resource requirements and performance feasibility of solar power systems in India. The deployment of the domestic content requirement is also discussed in detail with special reference to Jawaharlal Nehru National Solar Mission (JNNSM).

Another study by (Pearce & Alafita, 2014) analyzes the costs, risks, and uncertainties of solar photovoltaic by cost flow analysis. Securitization of solar PV has been analyzed for its growth under this study. It identifies the policy interventions to reduce risk and has explained the importance of Power Purchase Agreements (PPAs) in penetration of solar energy.

(Sharma, Tiwari, & Sood, 2012) claims that solar energy is an indigenous and distributed source of energy that has the low marginal cost of generation and is significant for reducing reliance on imports for solar energy can enhance supply thus can boost energy security and can moderate fuel price instability. The study suggests that in India the development of solar energy technology can be a valuable tool to stimulate regional economic advancement, predominantly for the underdeveloped states, having excellent perspective for mounting solar power technique which is an unlimited and clean source of energy.

(Feron, 2016), stressed upon the economic side of electrification proposing that for sustainable electricity solutions cost-effectiveness is the main aspect which seems difficult for direct current (DCs) due to limited financial sources. On the contrary, in case of scattered population with low per capita consumption of electricity off-grid PV systems are observed to be more cost-effective.

(Munuswamy, Nakamura, & Katta, 2011), visualizes the cost of renewable energy resources based off-grid power generation to vary on the lines of the cost of input components. In order to electrify the rural health center, the efficacy of cost of off-grid power generation in comparison to electricity supplied by grid relies on the cost of power generation from grid source and the distance of the rural health center from the nearest power substation. There exist a break-even distance, that divides the cost efficiency of grid electricity and the electricity generated by decentralized renewable sources.

2.4 DECENTRALIZATION ENERGY USE

(Neudoerffer, Malhotra, & Ramana, 2001) emphasizes that even though a lot have been done by the government for rural electrification, there is a high need for amendments and formulation of policies for decentralization of energy. Decentralization needs ample participation of the local population for making them energy self-sufficient. The study highlighted that there are a variety of social-cultural as well as economic and access-related factors contributing to low or zero electrification in rural areas. These include lack of access to information, low awareness regarding energy and environmental issues, poor managerial skills, and technical know-how. According to them, non-governmental organizations can play a proactive role in facilitating and organizing participation based on the close rapport they share with local communities. They stressed that only a few NGO's are working on the rural energy problem and there is a dearth of information and training for NGOs on rural energy. They emphasized that real development is a time-consuming process. Historical examples from the developed world remind us that development efforts such as rural electrification were not achieved overnight.

According to (IEA, 2012) in 2008, over 400 million people in India, including 47.5 percent of those living in India’s rural areas, have no access to electricity. Because of the remoteness of much of India’s un-electrified population, renewable energy can offer an economically viable means of providing connections to these groups.

The challenges of providing electricity to rural households are manifold. Ever increasing the demand-supply gap, crumbling electricity transmission, and distribution infrastructure, the high cost of delivered electricity are a few of these. There is an urgent need to overcome these hurdles of development and growth. (Chaurey & Kandpal, 2010) states, that PV technology is one of the best among several RE technologies that was adopted globally as well as in India for meeting basic electricity needs of rural areas that are not connected to the grid. They discussed in detail the barriers and challenges to the deployment of decentralized energy and institutional approaches to support the energy penetration in remote areas. They have used life cycle cost method to evaluate and compare the energy technologies for decentralization. To evaluate environmental impact estimation of CO_2 mitigation potential of individual PV system is done along with energy payback time and life cycle analysis of PV technologies. They emphasize according to their research that, from the life cycle energy use and GHG emission perspectives, the PV system is a good choice for power generation.

Another significant study carried out by (Choragudi S., 2013)analyzes the off-grid solar lighting systems for India's sustainable and inclusive development goals by using a multinomial logit model. This study discusses the trends and patterns of Solar Off-grid Lighting Systems (SOLS) diffusion. For this, a household level analysis is done in rural areas. The factors determining the rural household conditions and the market/supply factors are analyzed through multinomial logit model.

(Chaurey & Kandpal, 2010), points out that adoption of decentralized PV systems prolong to be destabilized although there is sufficient research demonstrating the positive consequence of adequately deliberated and allocated consumer understanding and training programs, their active involvement in decision making procedure and aspiring explicit socio-economic payback of PV systems to them.

(Bandhopadhyay & Palit, 2015), explained that due to the rising energy demand-supply gap and limitation of grid extension to provide electricity to rural areas, renewable energy based decentralized generation systems are now coming up for electricity supply, termed as off-grid supply.

(Ackerman, Anderson, & Sodder, 2001), defined distributed generation as the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the consumer site.

2.5 RURAL ELECTRIFICATION

According to (Chaurey & Kandpal, 2010), the population growth is outpacing the expansion of the grid network, particularly in rural areas. The developing countries are finding economic, financial and infrastructural difficulties in achieving complete grid-based electrification. Stand alone small capacity PV systems are hence, perceived as one of the lower cost options for rural electrification. The governments in many developing countries often supported by the multilateral/bilateral funding adopt them for this purpose. According to them, the main areas of technical assistance had been in policy formulation, education and training, and strengthening and building institutions for research, development, and application of solar energy technologies.

Adding to this (Bhandari & Malhotra, 2011), observes that some of the developing countries has initiated country level programmes focusing on solar cell research and development, system design and pilot demonstration of PV applications in various sectors such as water pumping, remote meteorological stations, maritime and railway crossing, rural television and telephone equipment, seismological detection, refrigeration, low power rural industrial applications, etc.

(Trotter, 2016), envisages that a rise in rural electrification is coupled with growth in literacy rates by advancement in-school and domestic education amenities. It has also been linked to improving nursing care. Moreover, it has been instituted to augment employment, principally among women, facilitate supplementary agricultural and non-agricultural income generating activities, and expand rural productivity. Wherever corresponding rigid and flexible infrastructure is present, access to electricity is usually accepted to result in positive health, education and income upshots. Electrification rates wander considerably.

(Panda, 2007), talked about the ascendancy of rural electricity systems in India and stated that the rural electrification programs have largely chased a supply-led approach. Further, (Rehman, et al., 2012), indicated the demand–supply gap for electricity in rural India.

(Pachauri & Spreng, 2004), while discussing about poverty due to energy crisis, envisages that lack of electricity and the unskilled use of devices is a reason for scarcity of energy in rural households of India. (Khandker, Barnes, & Samad, 2010), discussed on the concern of poverty, provoked the question of whether the prerequisite of energy services leads to economic development or economic development leads to a boost in demand for energy. The paper appraises the association between energy and poverty in India.

In this context, (Panda, 2007), adds that both the reliable and circuitous amalgamation of the utility's service delivery system, with income-generating prospects for consumers, can promote access. (Modi, 2005), portray modern energy service as a catalyst for the accomplishment of the UN's Millennium Development Goals. (Cook, 2011), recommends that while the increased focus on rural electrification has highlighted its correlation with dynamic use and poverty alleviation, progress in rural areas in terms of electrification has been partial.

On similar lines, (Khandker, Samad, Ali, & Barnes, 2012), advocates that the impact of electrification on incomes are proportionate, while (Bhattacharyya, 2006), suggests intensifying the productive use of electricity for the economic and financial feasibility of rural electrification projects in India. The author finds that conventionally in rural households, electricity is only used for lighting and hence, it does not emerge as a primary energy requirement at the household level. (Rud, 2012), finds that in India, the need for electricity to operate electrical pump sets has created a demand for electricity and the consequent extension of the grid network in several states. (Cabraal, Barnes, & Agarwal, 2005), add that productive use for energy must take account of health, education, and gender flanking expansion of incomes. They further add that the program for the productive use of electricity has been relatively flourishing in the area of irrigation.

(Palit, Garimella, Shardul, & Chaudhury, 2015), illustrated that, traditionally, the altitude of electrification was considered as a proportion of electrified villages (with grid extension to some point contained by the revenue periphery of a village, irrespective of whether any family unit is being connected or not), not as a proportion of electrified households. Thus, presenting the stumpy household electrification levels in many states.

(Rehman, Paatero, Poudyal, & Lahdelma, 2013), further, envisages that rural electrification is an indispensable component in stimulation of the social and economic progress of any neglected rural inhabitants. Notwithstanding, according to the reports of International Energy Agency it has been observed that globally around 1.3 billion people are deprived of access to electricity, from which 85 percent resides in rural areas. While taking into consideration the grand significance of electricity, the international community has been strongly highlighting the utmost requirement of expanding and developing modern energy services (including electricity) for the residents of developing nations to eliminate poverty and attend to other economic, social and environmental concerns. In lines with the institutional architecture, financial and policy structure rural electrification characteristically establishes additional challenges than urban electrification due to its discrete attributes. Few of the general traits which craft rural electrification as more complex than urban electrification are the less number of connections per kilometer of the grid line, the low level of utilization, the lack of manufacturing load, the diverse landscape, and the lack of stimulus for private investors. Regardless of these challenges, few developing nations have been more successful in granting electricity to their rural populations.

2.6 SOCIO-ECONOMIC IMPLICATIONS OF OFF-GRID SOLAR ELECTRIFICATION

A set of research studies (Bandyopadhyay & Palit, 2016) conducted on off-grid technologies observe that there are certain inherent advantages of off-grid electrification to the rural masses.

Research studies (Udaykumar & Kamalapur, 2011) claims that electric lightning directly improves the quality of life. It allows children to study in the evening and women to gain some precious time for them or to extend income generating work into the evening hours. According to the researchers, it was found that rural electrification improves agricultural productivity and is essential for several rural activities. It enhances the social and economic infrastructure development by all means. Solar systems have enormous potential for contributing to social upliftment, sustainable development and raising local living standards of the rural poor.

(Sriwannawit, 2014), emphasized upon various economic advantages of off-grid solar systems including cost reduction and income generation. The study further showed benefits on social factors like health improvement, increased literacy, women empowerment etc.

Income generation activities like small and medium enterprises flourished after electrification and the number of hours devoted to such activities increased significantly according to the study.

Research (Murali, Malhotra, Palit, & Sasmal, 2015) indicates that deployment of solar off-grid options can help to bridge the gender gap. In this study, impact on women empowerment was studied using descriptive statistics comparing the situation before electrification.

(Alzola, Vechin, Camblong, Santos, Sall, & Sow, 2009) established a relationship between electricity cost and paying capability of the communities based on the analysis of rural electrification needs. It depicted the feasible options of payments for rural poor.

(Choragudi S., 2013) recognized, that the attribute that evidently differentiates successful and unproductive innovation is whether the technology meets the requirements of the particular users. In the developing countries, indicators of users' needs are often sought all the way through surveillance of people's behavior towards similar products, through particular market surveys or through the signals provided by the market or price mechanism. It is different for the rural electrification technologies as there are no overt demand signals are present. Consequently, we mull over an array of economic, societal, positional and demographic features that signify the acceptance of the household.

(Chaurey & Kandpal, 2010), deliberates that the electricity services imparted by micro decentralized PV systems at household and village level perhaps be diminutive in quantum, but their influence on the socio-economic-cultural progress of rural communities cannot be overlooked. It is thus imperative for local government and international donors to synchronize the deliverance of an assortment of developmental programs (like as education, health, community. (Feron, 2016), discussed that according to the existing literature energy has been vital for evenhandedness from gender perception, thus was incorporated in the UN Millennium Development Goals. The importance of electrification of the individual domestic units is significant not only because it is important for the collective welfare of the society but also because women are the chief consumers of residential electricity. As women need to hold the trouble of gathering biofuels (which leads to physical fatigue and a considerable loss of their time which they could use for other productive activities), the girls are deprived of attending schools as they are bound to stay back home to help their mothers accumulate biofuels. Further, it is observed that without access to electricity, women stays deprive of information using telecommunication on modern family planning, their rights, and empowerment; at the same time the major hazard and drawback is the exposure of women to the indoor air pollution. Consequently, it is advised that PV based electrification could be intervened for supplementing the stimulus in cooperation.

(Sapkota, Lu, Yang, & Wang, 2014), elucidates that access to energy is an elementary need as it is linked with the necessities of life such as health care, literacy, clean water, clean environment, employment and agricultural activities which in turn reflects the social welfare of any nation. Further, it should be noted that rural communities devote more than 6 hours a day in activities like gathering wood and water, cooking, etc. this time could be saved and used in productive activities by the availability and use of modern energy services.

(Rao & Pachauri, 2015), keeps a view that due to the sluggish intervention of modern energy in rural areas, the gender concerns have yet not been alleviated appropriately, therefore we fail to infiltrate the gender facets of rural masses. On the other hand, it is observed that in the energy deprived sections the allotment of responsibilities and power associations within domestic units and societies especially in developing zones, persuade the acceptance and advantages of modern energy services. These sections are surrounded by large communal, cultural and institutional structures that help to comprehend the broad perspective under which they perform. It is inevitable to note that in order to ensure the security of women and that they harvest best out of the modern energy transitions for their welfare, and to promote the intervention of such technologies it is essential that the relation of women with energy paucity is unambiguously contemplated in these remote deprived areas. Consequently, amid the underlying social profits of energy alterations, the one allied to women’s social eminence and welfare are suggested to be focused by researchers.

(Imai & Palit, 2013), have used descriptive statistics for the analysis of social impacts decentralized rural electrification. Further, the methodology used was based on survey method and interviews and was analyzed using t-statistic particularly paired-t- test.

2.7 FINANCING AND INSTITUTIONAL MODELING

(Chaurey, Krithika, Palit, Rakesh, & Savacool, 2012), in their research examined the role of partnerships to address the challenges faced during the delivery of energy in the context of innovation in technological, institutional and business models. The public-private-partnership model of 3P and pro-poor public-private partnership model of 5P have been focused in this study.

Further, (Elahi, Rysankova, Sadeque, & Soni, 2014) documented in the study conducted in Bangladesh that for off-grid programs, extensive micro-finance institution network is a key to successful deployment. Sustainable financing schemes could remove the problems of installation and maintenance of the system.

(Chaurey & Palit, 2011), discussed the business models used in villages for delivery of off-grid solar electricity. The most common amongst them in India are found to be consumer financing, leasing, the fee for service and village energy committee. Still, it is observed under several studies that major financing is being done by foreign aid and installation is done by NGOs in India.

(Chaurey & Kandpal, 2010), laid emphasis on rural electrification development tools to plot the resources with the desires and available expertise, fee-for-service delivery models relating private sector and local entrepreneurs and microfinance aided consumer credit sales to seem to be facilitating the growth of decentralized PV markets.

Literature (Bandyopadhyay & Palit, 2016) indicates that the lack of institutional support remains the major failure of off-grid technologies for poorrural masses. Positive linkages have been observed between the institutional structure and electrification; therefore, strong institutional architecture and financial support could lead to the effective intervention of solar technology in rural areas.

(Timilsina, Kurdgelashvili, & Narbell, 2012) deliberates that in recent years phenomenal growth has been experienced by solar energy due to two main reasons: firstly, as the advancements were observed in technology the cost also reduced. Secondly, due to the supportive government policies helped in better utilization of renewable resources. The study analyzes the technical, economic and policy aspects of solar energy development and deployment. The study states that solar energy has been benefitted by many policies like fiscal and regulatory incentives, including tax credits and exemptions, feed-in-tariff, preferential interest rates, renewable portfolio standards and voluntary green power programs in many countries. Along with these incentives the emerging carbon credit markets are flourishing and are expected to present additional inducement to solar energy deployment; though, it is also clear that the scale of encouragement provided by the accessible carbon market contraptions, such as the Clean Development Mechanism of the Kyoto Protocol is restricted. In spite of the enormous technical potential, the development of solar energy technologies still has to trounce some technical, financial, regulatory and institutional barricades. It is advised by the researchers that the prolongation of policy incentives is essential in future decades to sustain and augment the expansion of solar energy equally in developed as well as developing nations.

(Girona, et al., 2016), suggested that technology specific tariffs would comparatively be more pertinent to maintain the appropriate technology in the diverse off-grid regions relying on the available natural resources. Further, it is advised that a revision of the tariff based on technology specific tariffs and an improved capital subsidy design could create a center of attention for national and international investors by providing a rate that envelops the menace of the investment.

To conclude, the extensive and comprehensive survey of literature (Table 2.1) paved way to identify the research problem and gap in the existing studies and extend the present research to unexplored domains.

Chapter 3

DESIGN AND FRAMEWORK OF PRESENT STUDY

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DESIGN AND FRAMEWORK OF PRESENT STUDY

The present chapter will present theoretical structure of the study based on review of the literature. This chapter explicates the key features, variables, and relationships among theories or models and provides a conceptual synopsis. The conceptualization facilitates us to answer the research questions of the study. It commences with a sketch of the methodological framework employed to aim the collection of data. The implementation of an array of methodologies was a fundamental ingredient for the accomplishment of the objective of developing a scalematched approach, where data from diverse specialties can be amalgamated.

The various sections of this chapter include the problem statement, objectives of the study, research design, data structure and sampling frame and the statistical techniques employed in the study.

In order to meet the objectives of the study, the researcher implemented a research strategy, consisting of a mix of qualitative and quantitative methodologies and a wide range of data sources. The research process was divided into five main stages: literature review, general study, pilot study, sample survey and specific case studies. The research and theoretical framework was established to guide and control the review of the literature and empirical studies. The empirical studies were organized in two steps: pilot study and sample survey. An analysis and synthesis of the information gained was carried out progressively at all stages of research. The source of primary and secondary data is referenced in the discussion. However, in some cases, the information presented is the product of researchers own experience and observation prior to and during the study, and as such it is not specifically attributed to asource. A detailed discussion of research and methodology are included in this chapter.

The theoretical framework of research included renewable energy resources viable for off-grid rural electrification, the rural electrification barriers in the remote areas of Rajasthan and the potential socio-economic aspects of the off-grid solar electricity for rural regions in the State. The different components of the framework helped to identify the propositions to be tested, guided the analysis and geared the research to answer the research questions.

3.1 ILLUSTRATION OF THE PROBLEM

In India increasing population resulted in a majority of people being devoid of electricity which is attached with a broad inconsistency in rural electrification in the country. Along with the observed rise in overall growth of the country, the growth of rural electrification in India is surprisingly very low, and this poor growth could be endorsed to:

a) relatively more speedy expansion of rural population that resulted in slowing down the velocity of escalation in electrification;
b) de-electrification of villages, which signifies the very poor or no supply of electricity to the concerned villages, however, these villages remain electrified in records. This trend is commonly observed in the state of Rajasthan; and
c) the other organizational and institutional barriers that neglect the remote areas for electrification.

It is witnessed that in the policy globe the robust preference is given to the central grid. Therefore, generally, inducements are inclined to be offered to expand electrification through grid connections. However, despite many incentives and impetus provided for grid electrification, in rural communities, the household electricity rate prolongs to stay squat. This is principally due to the verity that even though the central grid may have previously penetrated a large number of villages but still they have not yet reached all households. It may be easier to trace an electric grid line near or in a village, but it is hard to know that there might not be any electricity service connected to all the households. It is affirmed by the data that India has 97.4percent (CEA, 2015) of villages covered through grid supply, while connection levels of rural households are perched around 74 percent (IEA, 2015). Therefore, to be more specific, in other words, the electrification rates that are considered at the village level are not accurately measuring the actual household electrification level which is relatively more crucial. The actual percentage of electrified household is thus not reflected in the village centric measures of evaluating electrification rates, and thus rural villages remain unexplored, un-electrified and underdeveloped. Along with this, it is also observed that there are many villages where grid system is in an extremely poor order and exemplified either by lopsided flow or no flow of electricity for long durations (Debajit Palit, 2016). Moreover, there are numerous obstructions to substantially attain electricity connection even though the village is officially connected to the grid.

Yet another main and an important reason that accounts for the number of un-electrified villages is the remoteness of such villages and their geographical topography. There are several villages that are quite remote to provide access to electricity and also the hilly or uneven scattered terrain makes it more difficult for the grid to reach such villages. The extension of the grid to these remote rural communities is highly capital intensive, thus infeasible. For such deprived villages access to electricity is like a dream come true as they have not seen light since decades. Darkness is their culture, and thus the development of these individuals is in the dark. There is a high possibility of obtaining electricity access for these villages by decentralized renewable energy technologies and illuminating live of these billions of people.

The above-discussed research problem establishes several research questions which can be examined with the assistance of the composition of the important objectives in the context of the desired study.

3.2 RESEARCH QUESTIONS

The research questions provide the main argument and focus of the study. An investigation of the experiences of local communities, both in overall study and in specific cases, highlights the poor social and economic infrastructure of the rural populations that remain void of access to electricity and thus offers the researcher the scope to find answers to the questions raised in this study.

In the current study, the decentralised solar power and rural electrification research is focused towards the way electrification by decentralized solar power systems has benefitted the social and economic life of the households.

This research study intends to respond to the subsequent research questions:

1) Have the decentralized solar energy micro-grids improved the social structure (education, health, income, communication, information, entertainment) of the rural population?
2) How have the women of such communities perceived it and what is their involvement in the procedures? Does electrification intervention have promoted the empowerment of women in rural areas?
3) What factors support the intervention of off-grid technologies for rural electrification? Are these affordable, reliable and cost effective?

4) Will the proposed technique for electrification of remote areas be viable in all cases in Rajasthan and India?
5) What policies could be adopted at the state and national front for better acceptability and sustainability of these off-grid electrification techniques?

3.3 OBJECTIVES OF THE PRESENT STUDY

The study accomplished primarily aims at conducting a comparative analysis of the solar off-grid technology employed in rural electrification and grid connected thermal electricity which could be supplied by extending the central grid for rural electrification. This study is first of its kind in this renewable technology in Rajasthan and is prepared to provide strong evidence on sustainability and non-sustainability factors of different models that have been employed for the dissemination of the technology and its significant social impact on the life of rural masses. This study intends to form a framework for rural electrification regarding policy, socio-economic, technical and financial parameters.

The chief objective of the study is **“to perform the socio-economic assessment of decentralized rural electrification based on solar energy in Rajasthan.**" In addition to the principal objective the research study further endeavors to ascertain various associated objectives of the study acknowledged as follows:

1) To access the problems and prospects of rural electrification in Rajasthan.

This objective is to examine the rural electrification status of Rajasthan and to identify the barriers in the path of electrification, further identifying possible solutions for the same.

2) To evaluate the scope of decentralized electrification in rural areas based on solar energy sources in Rajasthan.

Under this objective, the researcher intends to explore the potential of off-grid solar energy for providing accessibility to electricity for deprived rural populations in the State.

3) To compare the cost of off-grid solar energy in rural areas vis-a-vis grid connected conventional energy sources.

This objective aims at comparing the life cycle cost of the existing off-grid solar project in a village and the life cycle cost of extending the conventional central grid to the same village. This is carried out via two case studies.

4) ***To study the socio-economic impact of existing solar based decentralized projects in Rajasthan.***

This objective aims at analyzing the impact of existing off-grid solar projects on the social and economic structure of the rural population examining the pre-post situations. This is based on the analysis of primary survey data.

5) ***To provide policy suggestions for sustainable rural electrification in the State and country.***

This objective aims at presenting recommendations for future prospects of renewable energy growth and attaining affordable, acceptable and sustainable rural electrification.

3.4 RESEARCH DESIGN

The research design is a complete sketch that directs towards the techniques and methods for accumulating and investigating the essential information. To carry out the study on an analysis of solar micro grid systems, a framework has been developed. The framework comprises of the social, financial and institutional aspects. The solar micro grids were analyzed concerning each of the aspects of the framework to provide a well-built understanding on its association with the socio-economic upliftment of the rural population. The preferred research design is based on the fulfillment of the two key objectives of the research study, i.e.

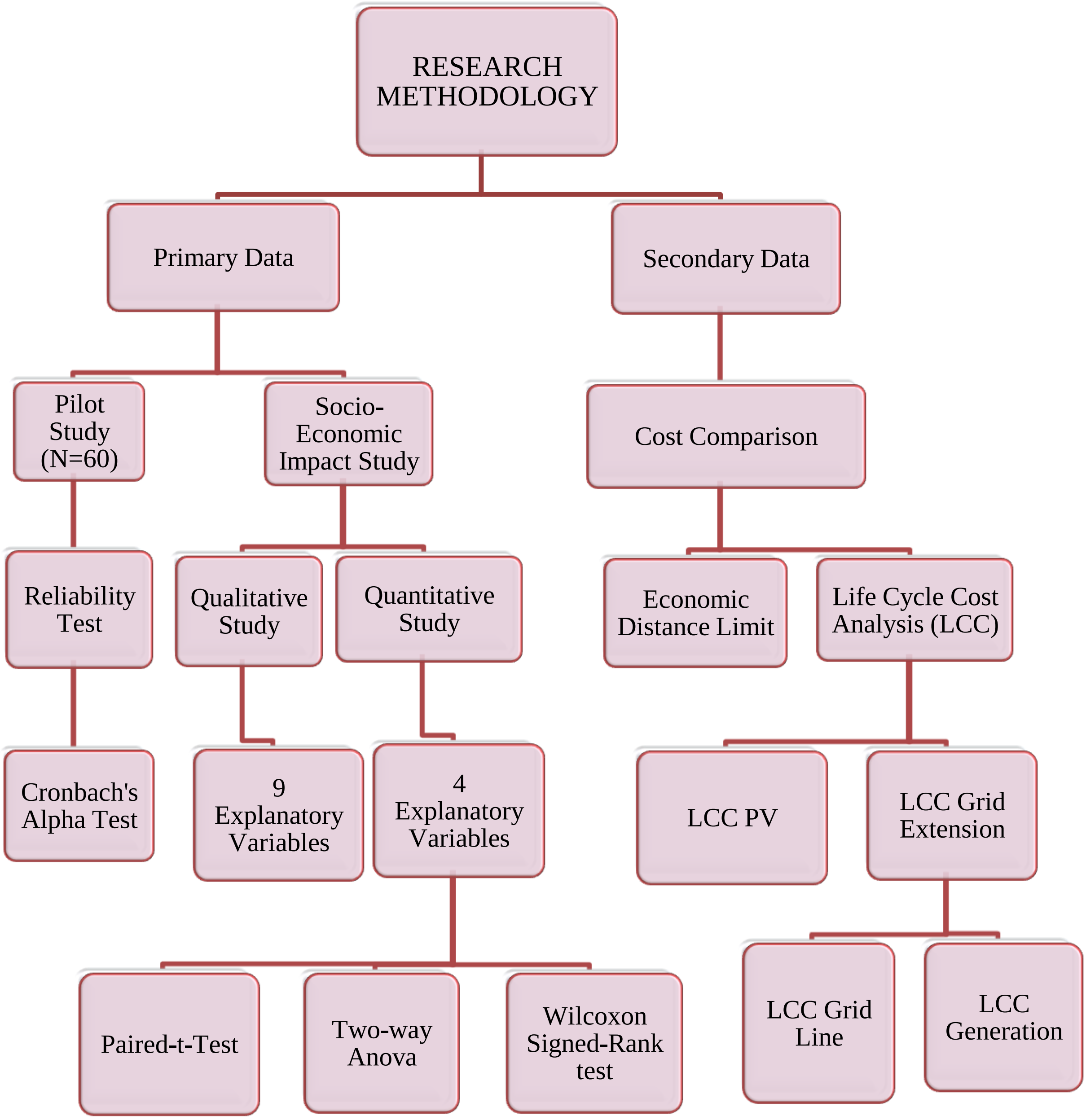
a) To compare the cost of off-grid solar electricity with the cost of grid-connected thermal electricity in rural Rajasthan.

b) To analyze the socio-economic impact of existing decentralized solar electrification projects in rural Rajasthan.

To study the first objective ***case study method*** based on ***secondary data*** is used and for the second objective ***survey method*** is adopted which is based on ***primary data collection***.

The detailed structure of research methodology adopted for the analysis of the data in the present study is demonstrated in figure 3.1.

Figure 3.1: Research design flowchart



3.5 SURVEY RESEARCH

3.5.1 Selection of study areas

The methodology used for identifying the study area under the survey method is *Multi-stage cluster sampling*. In the first stage, 4 zones namely northern, eastern, southern and western of the State were taken. Subsequently, districts were selected from each zone (on the basis of the number of un-electrified villages in each district of the respective zones). Thus those districts were selected from each zone which has a poor rate of household electrification.

From each district, the village clusters (un-electrified or poorly electrified) having solar micro grid system for electrification was selected. These systems are disseminated by various agencies and institutions for electrification in the village (as per the secondary data from agencies such as Rajasthan Renewable Energy Corporation, Rajasthan Electricity Regulatory Commission, and various NGO's).

In the next stage, villages having least 20 households electrified through solar lighting technologies are selected from each cluster in a district.

From selected villages all the households electrified by decentralized solar PV systems finally were surveyed. As the universe/ population itself was small, it was not feasible to take samples out of it for a reliable study. Thus, the universe itself is the sample in the final stage.

3.5.2 Villages identified

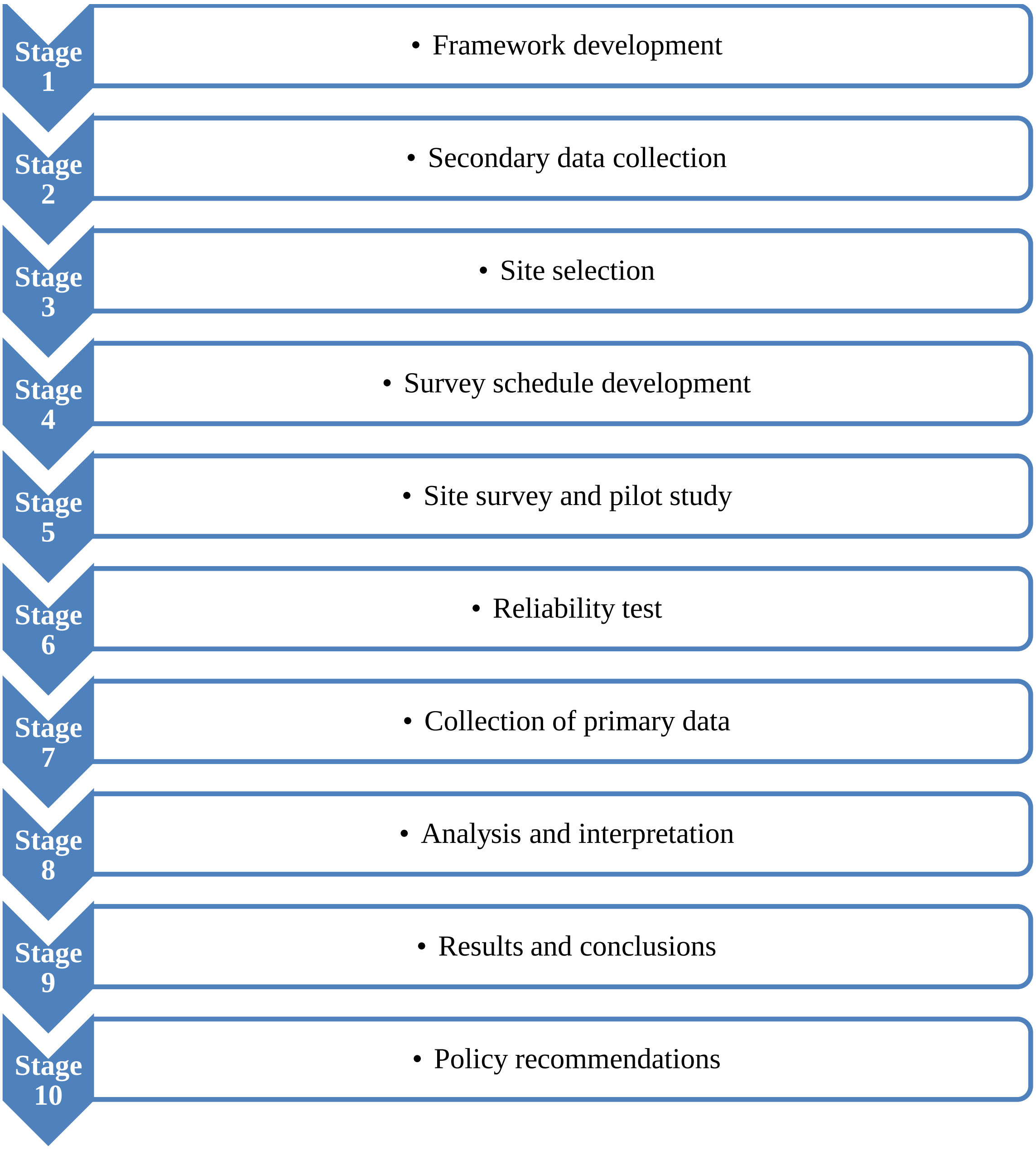
The districts and villages identified from Rajasthan for the study are as follows:

Pratapgarh	**Kota**	**Barmer**	**Baran**
Upla Kota I	Kohli Pura	Meghwalon ki Dhani	Jeswa
Upla Kota II	Khanpuriya		Kunda
Gangat Phala I	Keshopura		Gajron
Gangat Phala II	Damodarpura		Kaswathana
Nichla Kota			

The identified districts and villages to conduct the survey represent the described zones of the State: Pratapgarh district represent the southern zone, Barmer district covers the western zone and Kota as well as Baran districts represent the south-eastern zone. The northern and eastern zone remains excluded because based on the available secondary data we could not trace any decentralized solar technologies in these zones required for the fulfillment of the study.

The work plan for survey research can be portrayed in figure 3.2:

Figure 3.2: Research work plan



The survey research instrument i.e. the questionnaire was developed. The validity and reliability of the questions of the final questionnaire is based on existing literature, 20 expert opinions (both academicians and industry experts) and a pilot study comprising of 60 respondents (10 percent of the survey). The final questionnaire format for the household survey is provided in Annexure I.

Besides the stakeholders other than households like electricity board officials, financial institutions, solar installers, NGOs were also interviewed during this research at the time of data collection.

3.5.3 Reliability test

The reliability test was done twice; initially, it was done on the pilot survey to check the validity of the questionnaire and later it was done on the entire data of the primary survey.

Cronbach’s Alpha was applied to check the reliability of the pilot study. Cronbach’s alpha is a standard measure of internal consistency (a measure of reliability). It is used to determine how much the items on a scale measure the same underlying dimension. It is most commonly used when we have multiple Likert questions in a survey/questionnaire that form a scale or subscale, and we wish to determine if the scale is reliable. A higher value of Cronbach’s alpha, generally greater than 0.7, constitutes a good level of internal consistency. Cronbach’s alpha is computed by correlating the score for each scale item with the total score for each observation (usually individual survey respondents or test takers), and then comparing that to the variance for all individual item scores:

$$\alpha = \left(\frac{k}{k-1}\right)\left(\frac{1-\sum_{i=1}^{k}\sigma_{yi}^{2}}{\sigma_{x}^{2}}\right)$$

where, k refers to the number of scale items;

σ_{yi}^2 refers to the variance associated with item i;

σ_x^2 refers to the variance associated with the observed total scores

Interpretation of the Cronbach's Alpha

The resulting α coefficient of reliability ranges from 0 to 1 in providing the overall assessment of a reliability measure. If all of the scale items are entirely independent of one another (i.e., are not correlated or share no covariance), then α = 0; and, if all of the items have high covariance, then α will approach 1.For a good reliability, methodologists recommend a minimum α coefficient between **0.65 and 0.8**; α coefficient that is less than 0.5 is usually unacceptable.

The α coefficient of the scales of the pilot study conducted came out to be 0.796 (**α = 0.796**). It lies in the acceptable range. Thus, it signifies that the questionnaire and the results of the pilot study are valid and reliable.

3.5.4 Study tools

The study is exploratory in nature, as it attempts to find out the socio-economic impact of rural electrification on households in Rajasthan. The information and empirical analysis for this study came from a series of in-depth, structured/semi-structured interviews conducted at household levels in 570 households. A comprehensive survey schedule has been used for interviewing the stakeholders related to the microgrid. The stakeholders that are interviewed in the study are NGO entrepreneur, local operator, and end-users (household members). Household impact survey was carried out to understand the socio-economic impact of solar electrification on households in rural areas. The primary questions covered relate to general household information, energy, time, productive use, social capital, health issues, education, own perception and economy. Data is collected at individual, household and community level.

3.5.5 Data analysis methodology

The questionnaire developed was used to capture the indicators describing the socio-economic impact of solar electrification on the selected parameters for the study. The study is designed to assess the difference between two related groups having a within-subjects factor. The within-subjects design is a condition where all the cases undergo two conditions, which is pre-electrification and post-electrification in the present study, to gauge the impact on respondents. The households without electricity serve as a control for the study. The questionnaire is divided into nine sections viz, household profile, information on household electricity and fuel uses, household attitude on energy options, impact on livelihood and income, impact on upliftment of women, impact on health, impact on education, training programs and affordability and willingness to pay for solar energy systems. The responses to the questionnaire are measured on 5 point Likert scale and few questions which are based on frequencies. Most of the respondents were the head of the households (male), and few of them were women. A pilot test of the questionnaire was carried out in the Upla Kota Village and slight modifications of the questionnaire were made on the basis of the pilot test. As in any other survey, the attitudes of the respondents during the participation of the survey and their lack of memory may have an effect on the reliability of these results. The analysis of the primary data is quantitative in nature.

Through this study, the researcher intended to understand the socio-economic effect of the electricity intervention on the studied households by comparing the pre- and post-intervention. Therefore, in the present analysis, based on the survey, we chose to represent the data on demography, training programs and affordability and willingness to pay for solar energy systems through tabulation and graphs. For the quantitative analysis of sections of information on household electricity and fuel uses, household attitude on energy options, we used a separate statistical test for each dependent variable, as it was not possible to club them to get an overall score, apart from graphs and tabulation wherever necessary. In the case of impact on the livelihood and income, impact on upliftment of women, impact on health, and impact on education, dependent variables were considered jointly, and statistical tests were applied for the quantitative analysis, apart from graphs and tabulation wherever found suitable.

The sections on the household profile, information on household electricity and fuel uses, training programs and affordability and willingness to pay for solar energy systems has been presented through tabulation and graphs. These four sections of the study consist of descriptive data which describes the demographic profile of households, their fuel consumption pattern, views on training programs and willingness to pay for solar systems.

One of the objectives of the study is to compare and analyze the effect of solar electrification on the social and economic aspect of the households with the pre-electrification scenario on same variables. Since, it’s a pre-post study which tells us whether there is any significant difference in the variables (income, upliftment of women, health and education) after the intervention of electricity for the selected households. In order to statistically analyze the data collected through the primary survey, the researcher has applied statistical tools like Wilcoxon signed-rank test on variables based on Likert scale ranking, paired-samples t-test and two-way ANOVA on the overall score of variables like income, upliftment, health and education.

Wilcoxon signed-rank test

The Wilcoxon signed-rank test is used to determine whether the median difference between the two related groups (i.e., the two conditions) is statistically significant. It is a nonparametric test equivalent to the paired-samples t-test. The respondents are either the same individuals tested on two occasions or under two different conditions on the same dependent variable. For the present study, we have applied Wilcoxon signed-rank test to test the objective that whether there is a difference between dependent variables amongst households based on the use of solar electrification.

Null hypothesis

There is no significant difference between dependent variables amongst households based on the use of solar electrification.

Alternative hypothesis

There is a significant difference between dependent variables amongst households based on the use of solar electrification.

To test the null hypothesis, a study was designed using a sample of 570 households. The dependent variables which couldn't be clubbed together to form an overall score or those which are based on the Likert scale were measured in terms of sub-questions. The independent variable being manipulated was Effect of Solar Electrification, which had two related groups: Before Electrification and After Electrification. These two related groups were the two conditions that the sample of 570 households was exposed to a control, where there is no electricity and a treatment, where electricity is provided.

Paired t-test and ANOVA

The dependent variables/questions under the sections: impact on livelihood and income, impact on upliftment of women, impact on health, and impact on education represents the indicators for these overall variables and hence, were considered jointly by clubbing their scores. The questions under each section represent an underlying construct for each variable, which is the overall effect on livelihood, upliftment of women, health and education. It was anticipated that the differences in each dependent variable separately would be small, or responses might not be available for each question, but if it is possible to consider the dependent variables together, they might be able to distinguish between groups. This means that only by combining the differences in the dependent variables between the levels of the within-subjects factor it will be able to find a statistically significant difference between these levels. Hence, the researcher was interested in the effect of the dependent variables like livelihood, upliftment, education and health as a whole. Consequently, the dependent variables under the sections were considered jointly. For statistical analysis, parametric tests, viz, paired-samples t-test and a two-way ANOVA on the overall scores of these variables were applied.

Paired-t-test

The paired-samples t-test is used to determine whether the mean difference between paired observations is statistically significantly different from zero. The respondents are either the same individuals tested at two-time points or under two different conditions on the same dependent variable. In the current study, paired-samples t-test is used to understand whether there exist a mean difference in overall scores of livelihood and income, upliftment of women, education, and health before and after solar electrification, being two related groups. It requires certain assumptions to be true.

The null hypothesis (H_0) for a paired-samples t-test is:

H_0: The populations mean difference between the paired values is equal to zero

(i.e., $\mu_{diff} = 0$)

H_A: The populations mean difference between the paired values is not equal to zero

(i.e., $\mu_{diff} \neq 0$)

Two-way ANOVA

The primary reason for running a two-way ANOVA is to establish whether there is an interaction effect between two independent variables, sometimes called a two-way interaction effect. An *interaction effect* occurs when the effect of one independent variable on a dependent variable is different at different levels of the other independent variable. Stated in another way, the effect of one independent variable on a dependent variable depends on the level of the other independent variable.

In the currentstudy, a two-way ANOVA was executed on the post-electrification responses to depict an interaction effect between education level and occupation and between occupation and monthly income. The reason for opting two-way ANOVA is that the researcher aspired to analyze the effect of education along with occupation and occupation with monthly income in order to observe whether there is any combined effect of both the independent variables on the views of households post electrification. This interaction effect is used to draw an inference about whether the effect of education level on the dependent variables livelihood, upliftment, health and education (jointly through overall score) is different for various categories of occupation for households and effect of occupation on dependent variables is different for various categories of monthly income, respectively. This implies that we are comparing simple effects or, more commonly, simple main effects. In general, a simple main effect is the effect of an independent variable on a dependent variable at a particular level of another independent variable. The interaction effect was studied to arrive at a conclusion about whether these simple main effects are statistically significantly different. Hence, an interaction effect could be considered to be a test of whether there are any differences in simple main effects.

3.6 LIFE CYCLE COST ANALYSIS

For the first objective of cost comparison based on the literature review the ***Life cycle cost analysis*** is employed under which the life cycle cost of off-grid solar electricity is compared with the life cycle cost of grid connected thermal electricity.

For this comparison the researcher has studied two cases where the off-grid solar system is available, and no grid connection has reached till date. This part of the research is based on the secondary data which is provided by the implementing organizations **A** and **B** *(due to confidential reasons the identity of the organizations is hidden as desired by them)* for the solar off-grid systems in the two cases. Secondary data related to estimating the cost of extending grid to the two studied villages was taken from State utility companies' sources. In this cost benefit analysis has been done using long-term marginal cost of power generation.

Furthermore, a concept of ***Economic distance limit*** is introduced, and values of economic distance for extension of the grid are calculated and suggested for policy recommendations. (Mahapatra & Dasappa, 2012) the economical distance limit (EDL) is a metric whose calculation gives implications that are similar to break-even analysis. It is computed by taking into account the life cycle cost of solar photovoltaic system and the distance at which this cost and the life cycle cost of grid extension match. Thus, this concept is established to calculate the maximum distance economically feasible for extension of grid to the village load centre from nearest power substation. This is important to attain the economic viability of rural electrification projects.

Chapter 4

RENEWABLE ENERGY STRUCTURE AND RURAL ELECTRIFICATION POSITION IN RAJASTHAN

CHAPTER 4

RENEWABLE ENERGY STRUCTURE AND RURAL ELECTRIFICATION POSITION IN RAJASTHAN

Millions of people in rural areas in developing countries, still lack access to secure and consistent energy. Access to energy is as essential to human welfare as clean water, agricultural productivity, health care, education, job creation, and environmental sustainability (UNDP, 2005).

In broad-spectrum, energy use has a positive effect on the standard of living, but it is indispensable to note that research has also discovered the cause-effect relationship between energy consumption and climate change (Fredricks, 2009). Therefore, to boost energy access for rural communities without causing an adverse impact on the environment is one of the major sustainability challenges. Furthermore, the exhaustion of natural resources and an altering climate have raised the burning issue of energy security, particularly in developing countries such as India (Chandler, Schaeffer, Dadi, Shukla, & Tudela, 2002).

In developing countries such as India, the conventional use of biomass fuel in the rural households and the imported petroleum fuels has resulted in high carbon emissions. These traditional practices are required to be substituted by energy efficient technologies, which can guard natural resources and reduce carbon emissions. Consequently, if traditional fuels are not swapped with affordable and competent alternatives, they will continue to affect the environment negatively and also the livelihoods of communities who rely on them for their income and endurance.

At the same time, climate change adaptation technologies and practices, diverge between individual communities and countries and depend upon access to financing and technological knowledge (Smit, 2001). Alternative and enhanced renewable energy technologies can offer opportunities for communities, to acclimatize their lifestyles to the shifting climate. Thus, it is required to appraise and estimate existing energy systems, and guarantee that societies can adjust to climate change impacts.

In the present chapter, section one portrays the growth in renewable energy sector. In section two, potential of solar energy is discussed. Section three discusses about the rural electrification scenario in Rajasthan. In section four, structure of Indian power sector is discussed. Section five portrays the institutional structure of power sector in India. The organizational structure of Indian renewable energy sector is discussed in section six of the present chapter. Section seven shows the organizational arrangement of energy sector. In section eight, the design of decentralized solar PV is explained and section nine gives the conclusion of the chapter.

4.1 RENEWABLE ENERGY TECHNOLOGIES

Renewable energy sources are resources that are persistently permeated by nature and obtained directly or indirectly from other natural evolutions and mechanism of the environment. This is majorly inclusive of the electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources and biofuels.

In India solar energy is more feasible for remote rural electrification over the conventional sources of energy on the basis of the comparison in the table below:

Table: Comparison of different sources of power generation

Particulars	Thermal	Solar	Wind
Site	Generally located near the load centre but other factors are important to deal with such as land requirement, ash disposal, transportation, distance from populated area, and availability of coal.	They are generally located in areas with huge solar radiance. Other factors involved are distance to load centre, transportation facility, availability of barren land, population density etc.	The factors responsible for site selection are geographical and topographical conditions, areas with high wind velocity, voltage stability.
Cost a) Capital cost per kW in INR b) Fixed cost per annum (interest on capital, depreciation, taxes, insurance, as percentage of initial cost) c) Variable cost per unit made up of i) Cost of fuel ii) Transportation of fuel iii) Maintenance cost	a) INR 3-4 Crore/ MW for sub-critical and INR 5-7 Crore/MW b) Fixe costs are less, around 25% c) Variable costs are much higher for such plants ranging from 2.8 INR per unit to 3 INR per unit	a) INR 0.53 lakh/kW (CERC capital cost norms for FY 2016-17) b) Around 20% c) Variable costs are very less compared to the capital cost. Only operation & maintenance costs exist that too about 1.3% of capital cost, escalated at 5% per annum	a) INR 0.62 lakh/kW (CERC normative capital cost for FY 2016-17) b)Around 20% c) Variable costs are very less compared to the capital cost. Only operation & maintenance costs exist that too about 2% of capital cost, escalated at 5% per annum

Transmission liability	Very high in the case of mine head stations	Medium to high depending on location of PV array field. Very less for rooftop power plants	High because of remote locations
Gestation period	5 to 6 years	Few months	6-12 months
Simplicity and cleanliness (environment)	Causes air pollution. Disposal of ash is another problem.	Simple to install and clean source of power. No immediate effect on environment except the issue of disposal of exhausted PV modules	Clean source of power. No environmental pollution while operating.
Field of application	Used as central generating stations to supply base load	Bulk generation sources as solar farms for inter-state transmission or as distributed rooftop generators	Bulk generation sources as wind farms for inter-state transmission of power
Space	Huge space requirement. Area is a factor of size, number of units and other storage infrastructure. Around 400 – 500 hectares for a 2 unit 660 MW super-critical plant, for example.	4 acres of land required for 1 MW crystalline technology based PV power plant	12 hectares of land required per MW at 50 m hub height for sites with 200 W /m^2 wind power density
Auxiliary consumption	8% to 9% (CEA, 2012)	0.25% of gross generation	1%
Viable plant size	A minimum of 200 MW unit size is financially viable	From 100 kW as rooftop generators to 500 MW	Suitable for MW scale wind farms as each turbine is of minimum 1 MW size

Source: *Compiled from CEA Report 2012 and MNRE officials via email.*

4.1.1 Growth of renewable energy sector

There has been a substantial boost in the country’s renewable energy capacity over the last decade. The total capacity installed of renewable energy resources in India was 10,252 MW as at the end of the10thfive-yearplan (i.e. on 31.03.2007) and which grew up to 24,920 MW at the end of 11th plan (i.e. on 31.03.2012). Further grasping the unswerving growth, the installed capacity of renewable energy sources bounced up to 42,849.38 MW as on 31.03.2016. The installed capacity and the development trend of India’s renewable power plants since last decade are shown in Table 4.1 respectively. It is clearly noticeable from the given table that wind power is being tapped the most in the country as compared to the other renewable resources. Also, solar energy has a low share of installed capacity even though it has a towering potential.

Table 4.1: Installed capacity of grid-connected renewable power plants (As on 31.03.2016)

Renewable energy source	**Installed capacity in MW**
Solar Power	6,762.85
Wind Power	26,866.66
Bio-Power & Waste Power	4,946.41
Small Hydro Power	4,273.47
Total	**42,849.38**

Source: *National electricity plan, 2016, CEA*

Even though both wind and solar energy have a huge potential in the country still solar has a little share of installed capacity as compared to that of wind. Therefore, much energy could be extracted from solar power technologies in India and especially in Rajasthan, as Rajasthan is considered as a hotspot for solar energy.

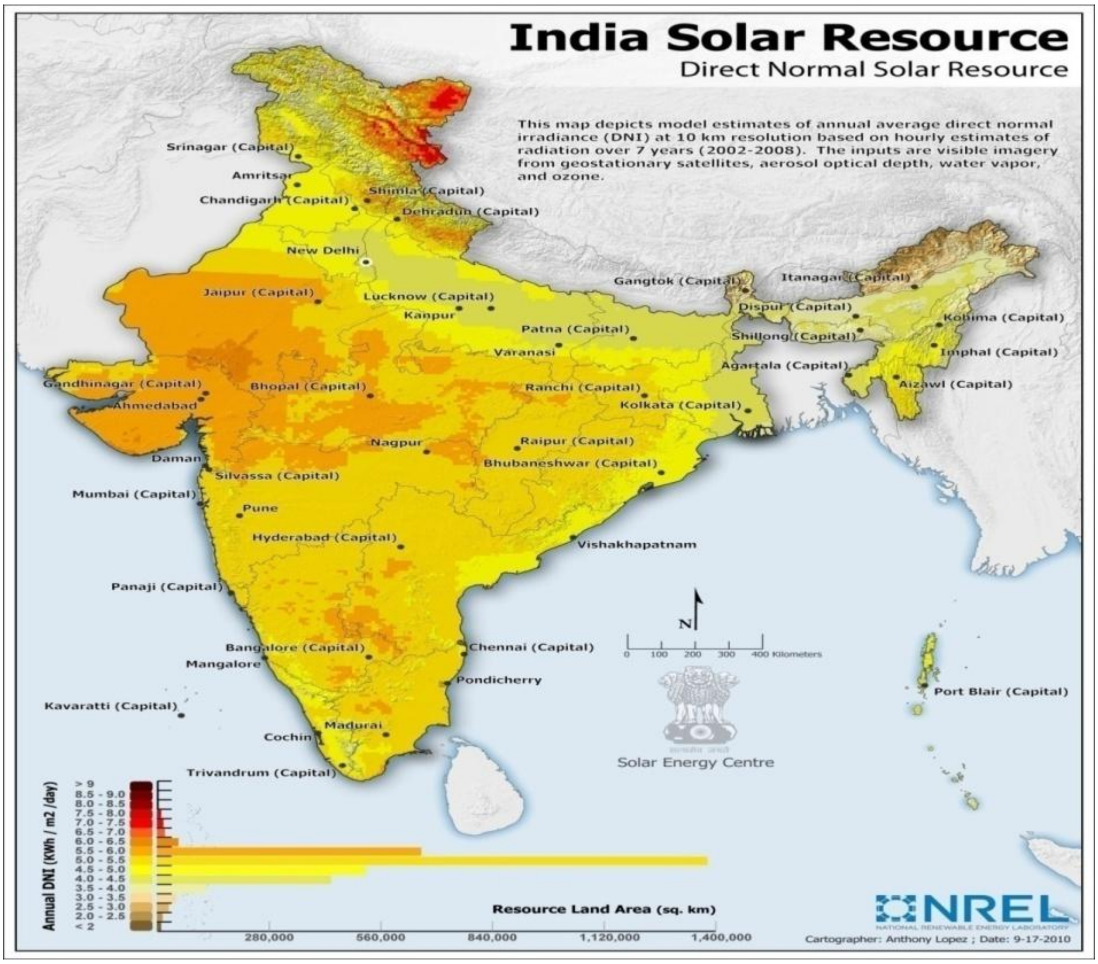
4.2 SOLAR ENERGY POTENTIAL IN RAJASTHAN

With its prime location in the equatorial sun belt of the earth, India is gifted with an abundance of solar energy resources. Hypothetically, with about 300 clear sunny days in a year, India receives solar energy comparable to over 5000 trillion kWh per year (MNRE, 2011). Depending upon the location, the daily average incidence of solar energy over India fluctuates from 4 to7 KWh/m2 (Purohit & Kandpal, 2005a).

Figure 4.1 presents the direct normal incidence (DNI) over India. It is important to note that the Northwestern (NW) states like Rajasthan and Gujarat receive maximum DNI over India. According to United States Department of Energy (USDOE), Rajasthan receives the second largest amount of solar radiation in the world. The DNI over Rajasthan diverges from 1800 KWh/m^2 to 2600 KWh/m^2 while on the other hand, Gujarat receives an annual DNI between 1800 to 2000 KWh/m^2 (NREL, 2012). Regardless of its huge potential, in India solar energy is the least harnessed of all renewable energy sources so far.

Rajasthan is the largest state of India and around 2/3rd part of the State is desert and semi-desert area with scanty rainfall and plenty of sunshine. The state is deficient in conventional power resources such as coal, hydro, etc. Rajasthan being a state rich in sunlight has a vast potential of solar power generation claiming with highly sufficient required resources. The state has a desert land of around 2, 000, 00 sq km, and the land required to generate 10,000 MW is less than 400 sqkm. Thus we can say that 2 percent of desert land can generate more than 100 GW. The state receives more than 325 sunny days, with average DNI upto 4.5-6.5 kWh/sq m/day. Rajasthan is one of the highest solar radiations receiving state in India, as depicted in Figure 4.1.

Figure 4.1: Direct normal incidence (DNI) over India



This map depicts model estimates of annual average direct normal irradiance (DNI) at 10 km resolution based on hourly estimates of radiation over 7 years (2002-2008). The inputs are visible imagery from geostationary satellites, aerosol optical depth, water vapor, and ozone.

Source: http://www.mnre.gov.in.

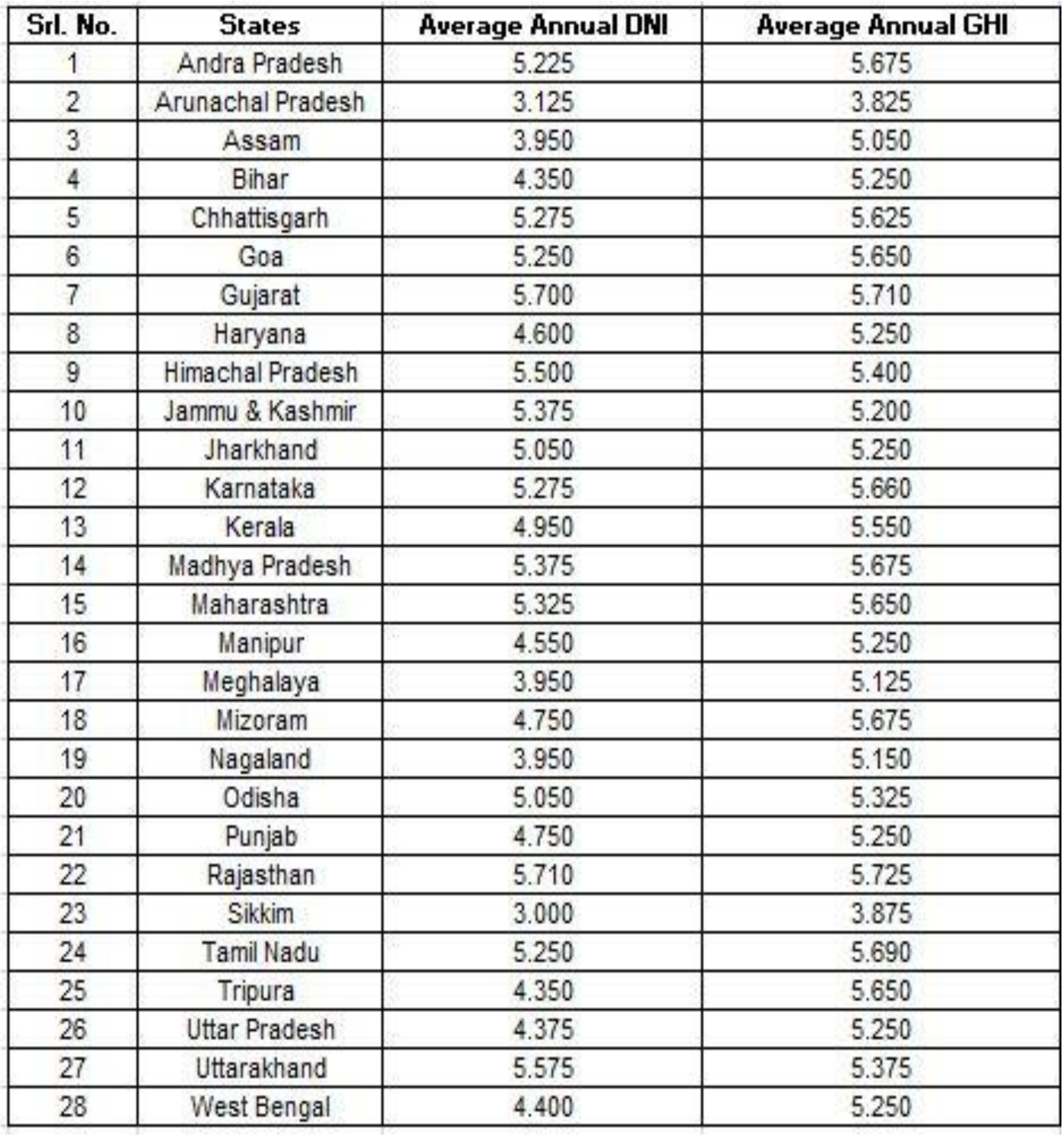
4.3 RURAL ELECTRIFICATION IN RAJASTHAN

Rajasthan, being the largest state of India covers around 10.4 percent of the geographical area of the country but remains highly scarce in the availability of the conventional energy resources like coal. Water resources are also limited in the state; the hydropower potential of the two perennial rivers Mahi and Chambal has been extracted at a large scale. Therefore, in terms of power generation from the conventional sources, Rajasthan is confronting two unique challenges: first, there is a scarcity of water resources so not much hydropower projects could be installed for power generation. Second, due to limited coal reserves, coal is required to be transported from other states, which adds to the cost of generation as the transportation alone contributes to around 50 percent of the cost of energy production.

Although, as compared to others states, Rajasthan is blessed with highest solar radiation as shown in Table 4.2; yet, solar power in Rajasthan remains underutilized in many areas especially for rural communities.

The districts in Rajasthan which receive maximum solar radiation are also not able to sufficiently utilize it because of ignorance towards the sector. In Table 4.3 we can see the annual solar radiation of each district in Rajasthan. It is inevitable to note that most of the rural households in the highest solar receiving districts are devoid of access to electricity. For such remote and rural households, off-grid solar systems could be the best option for illuminating their villages as well as life.

Table 4.2: State wise annual radiation [DNI-GHI] of India (KWh/m^2/day)



Srl. No.	States	Average Annual DNI	Average Annual GHI
1	Andra Pradesh	5.225	5.675
2	Arunachal Pradesh	3.125	3.825
3	Assam	3.950	5.050
4	Bihar	4.350	5.250
5	Chhattisgarh	5.275	5.625
6	Goa	5.250	5.650
7	Gujarat	5.700	5.710
8	Haryana	4.600	5.250
9	Himachal Pradesh	5.500	5.400
10	Jammu & Kashmir	5.375	5.200
11	Jharkhand	5.050	5.250
12	Karnataka	5.275	5.660
13	Kerala	4.950	5.550
14	Madhya Pradesh	5.375	5.675
15	Maharashtra	5.325	5.650
16	Manipur	4.550	5.250
17	Meghalaya	3.950	5.125
18	Mizoram	4.750	5.675
19	Nagaland	3.950	5.150
20	Odisha	5.050	5.325
21	Punjab	4.750	5.250
22	Rajasthan	5.710	5.725
23	Sikkim	3.000	3.875
24	Tamil Nadu	5.250	5.690
25	Tripura	4.350	5.650
26	Uttar Pradesh	4.375	5.250
27	Uttarakhand	5.575	5.375
28	West Bengal	4.400	5.250

Source*: C-WET*

It can be clearly interpreted from the above table that Rajasthan has the highest solar radiation in India.

Table: 4.3: DNI assessment of Rajasthan

Location (Rajasthan- Districts)	**METEONORM Daily (KWh/m^2)**	**METEONORM Annual (KWh/m^2)**
Ajmer	6.10	2227
Alwar	5.35	1951
Banswara	5.42	1979
Baran	5.68	2073
Barmer	5.53	2018
Bharatpur	4.99	1822
Bhilwara	6.07	2217
Bikaner	4.61	1682
Bundi	5.74	2095
Chittorgarh	6.11	2231
Churu	5.23	1910
Dausa	5.73	2019
Dholpur	5.05	1844
Dungarpur	5.33	1947
Ganganagar	3.78	1380
Hanumangarh	3.94	1437
Jaipur	4.38	1600
Jaisalmer	5.14	1876
Jalore	5.66	2067
Jhalawar	5.71	2084
Jhunjhunu	5.39	1969
Jodhpur	5.67	2070
Karauli	5.48	2002
Kota	5.61	2049
Nagpur	5.79	2114
Pali	5.74	2094
Partabhgarh	5.61	2049
Rajsamand	6.15	2244
Sawaimadhopur	5.95	2171

Sikar	5.93	2163
Sirohi	6.05	2210
Tonk	5.72	2087
Udaipur	5.76	2103

Source: (Sharma, Sharma, Mullick, & Kandpal, 2015)

The above table throws light on the truth that Rajasthan has enormous accessibility to solar radiations in all its districts and is sufficiently rich and able in harnessing its solar potential to attain sustainability in energy sector particularly in the decentralization of energy in rural areas (Choudhary & Sharma, 2014).

The state lags behind in electricity generation through conventional sources of energy due to their scarcity. It has resulted in rapidly rising power crisis in the state. Though the government has been dealing with the problem by bringing up many policies and schemes like JNNSM, Solar Policy 2011, etc. still due to lack of power generation through conventional energy sources and underutilized renewable sources there are frequent power cuts and blackouts faced in the urban areas and some villages still remains un-electrified in Rajasthan.

Rajasthan is bestowed with around 2, 08,110 km2 of desert land, which constitutes about 60 percent of the total area of the state. Attractively, Rajasthan receives high solar radiation ranging from 5.5 to 7.0 kWh/ m2. Also due to scanty rainfall in the area, the sunshine days are more and good around 325 days in a year (Sukhatme & Nayak, 1997). And in the western regions like the Thar Desert, it generally extends up to 345-355 days in a year (Singh, Singh, Chaurasia, & Singh, 2005).

Therefore, it is inevitable to state that, solar energy has high potential in Rajasthan. This can help in generating electricity through the grid as well as off-grid solar power plants especially in the remote and un-electrified areas of the state.

4.4 DECENTRALIZED SOLAR PV DESIGN

There are three primary groups of technologies acceptable that convert solar energy into useful forms of consumption i.e. solar photovoltaic, solar thermal power and concentrating solar power.

Solar photovoltaic

Solar PV technologies comprise of semiconductor or other molecular devices called photovoltaic or solar cells that transform sunlight into direct current (DC) electricity. PV modules consist of multiple cells assembled on a common platform, connected in series and sealed in an environmentally protective laminate. If the power provided by one PV module is not enough, then multiple modules are linked together to form an array to supply power ranging from a few watts to many megawatts. In addition to the modules, other components (for example, inverters, batteries, charge controllers, wiring and mounting structure) may be required to form a complete PV system.

The off-grid solar PV systems for rural electrification are generally in the form of standalone or micro-grid solutions.

4.4.1 Micro-grid

Microgrids are systems of local generation and distribution of electricity using local single grid infrastructure that can operate in island/remote mode or can be integrated with utility grid if required.

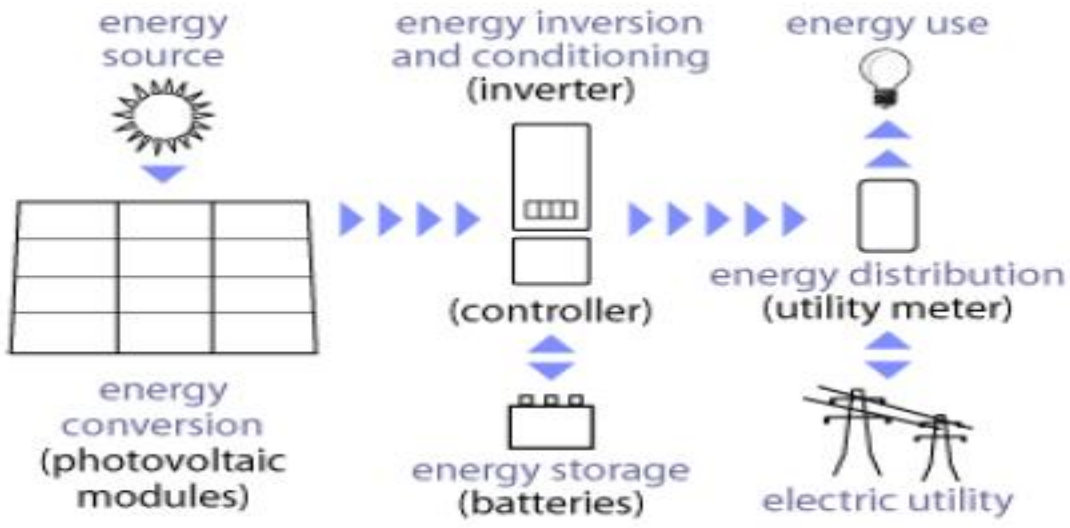
Technically, micro grid refers to a set of Distributed Generation (DG) sources, control systems and loads that can independently supply the power required for the consumers in secure condition with high reliability.

In microgrids, the local control systems are designed such that they could accomplish the stability of the system under critical situations and errors like upstream network outages. At the same time, reduce the level of power generation; short-circuit in the feeder, etc., along with preventing the power supply cut-off to the consumers (Kahrobaeian & Mohamed, 2015).

4.4.2 Major system components of off-grid solar PV

Generally, following components are included in decentralized solar PV system depending on the functional and operational requirements. The major components thus included are DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and sometimes the specified electrical loads (appliances). The complete schematic PV system is shown in figure 4.2 separately if we connect it to the grid.

Figure: 4.2: Schematic solar PV micro-grid for macro level use



a) PV modules – it converts the sunlight instantaneously into DC electric power.

b) Inverter – it converts DC power into standard AC power for use in the houses, synchronizing with utility power whenever the electrical grid is distributing electricity.

c) Battery - stores energy when there is an excess coming in and distribute it back out when there is a demand. Solar PV panels continue to re-charge batteries each day to maintain battery charge.

d) Utility meter - utility power is automatically provided at night and during the day when the demand exceeds the solar electric power production.

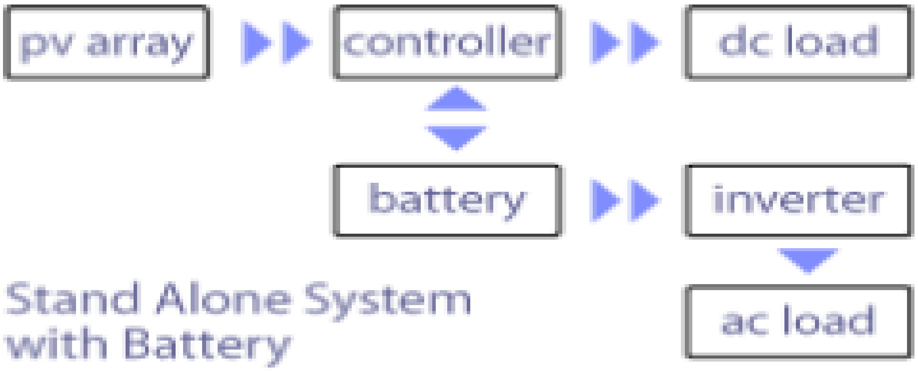
The utility meter spins backward when solar power production exceeds house demand, allowing you to credit any excess electricity against future utility bills.

e) Charge controller - prevents battery from overcharging and prolongs the battery life of the PV system.

Besides, an assortment of the balance of system hardware; over current, surge protection and disconnect devices, and other power processing equipment are the associated components used in this technology.

The schematic solar PV micro-grid, when used only for remote areas distributed directly to households, is shown in figure 4.3.

Figure: 4.3: Schematic solar PV micro-grid for micro level use



4.5 CONCLUSION

Renewable energy resources have a great scope in India to be utilized for power generation and as an alternative to the existing conventional sources of energy which are rapidly depleting. Further, particularly in Rajasthan (the solar hub or hotspot of solar energy), solar energy has a huge potential for generation of electricity both at the micro and macro level. Especially for rural electrification of the remote villages in the state, the solar off-grid technology could be utilized as it is available in plenty and is the most viable option for electrification in remote areas.

Solar micro-grids are also found to be feasible to electrify large rural communities as the power could be distributed to households by a very simple. This system comprises a single cable extending to the household from the battery bank. Further, if used at the macro level, the extra power generated could be transferred to the main grid, if available.

The government has been doing its bit in increasing the number of electrified households still the extension of the central grid is not feasible in the villages and hamlets that are extremely remote. For such regions in Rajasthan, decentralized solar systems could be the best and the most viable option.

Solar power is a vital element for the social as well as economic upliftment of the villages. In Rajasthan, the hotspot of solar potential, the decentralized solar technology could illuminate many dark households. Solar pumps could be beneficial for agricultural uses to the farmers. It could be the beacon light of hope in the dark household of the villagers.

Chapter 5

COMPARATIVE COST ANALYSIS OF GRID CONNECTED THERMAL ELECTRICITY AND OFF GRID SOLAR ENERGY IN RURAL RAJASTHAN: CASE STUDIES

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COMPARATIVE COST ANALYSIS OF GRID CONNECTED THERMAL ELECTRICITY AND OFF GRID SOLAR ENERGY IN RURAL RAJASTHAN: CASE STUDIES

Energy is a fundamental requirement for the growth and development of the economy of a country. The supply of electricity to remote areas through conventional methods has become unattractive and in some cases, rendered nearly impossible by the high generation cost, expensive centralized management system, especially for small loads, and high transmission and distribution losses. According to the findings of majority of researchers (Mahapatra & Dasappa, 2012), socio-economic conditions of the rural region of a country can be enhanced by successful rural electrification. The provision of electricity as an ingredient for various productive activities like agriculture and small rural industries by rural electrification programs lead to income generation and security supports economic development and facilitates to improve the quality of life of the rural population as is also proved by this study (Chapter 6). As per the census report of 2001, a large percentage of the population in India resides in rural areas which are deprived of access to reliable energy (Census, 2001).

It has been noted that, for remote areas, the cost of grid extension is increasing remarkably while the same for solar photovoltaic PV systems is approaching global competitiveness comparatively (Liming, 2009). At the same time, it is true to say that electrification of remote rural areas is comparatively more capital intensive than that of urban areas. Few of the primary aspects that contribute to high cost of rural electrification are: lower load demand, lower rates of capacity utilization, high cost of power utility lines, and high maintenance cost.

The cost of central grid extension fundamentally depends on the distance of the load center from the nearest power utility substation. The investment required for the delivery of electricity depends on the load demand, transmission and distribution losses, and electricity generation cost. Therefore, most of the rural electrification programs based on the extension of the central grid (conventional energy delivery model) prove to be uneconomical and thus become unattractive due to the low load demand, long distribution lines, and inherently high transmission and distribution losses. It is important to mention that despite strong social and economic objectives to raise the status of rural India, the rural electrification programmes have not been satisfactorily successful in terms of uplifting the living standards of the rural people (Bhattacharyya, 2006). The adoption of solar photovoltaic systems to fulfill the user needs in the form of off-grid or distributed standalone power supplies has gained momentum owing to the technological development in the recent years. At the same time, the cost of fossil fuel based power generation is increasing gradually (Muneer, Muhammad, & Saima, 2005). Consequently, for rural electrification, the decentralized usage of renewable energy sources will become more economically feasible and efficient (Banerjee, 2006).

Furthermore, it is observed that one of the major reasons behind the global warming resulting in climate change is the exhaustive use of fossil fuels. Hence, for the need of conserving the limited fossil fuel resources and mitigating the adverse impacts of climate change, the employment of decentralized renewable energy based systems has become an obligation. Solar photovoltaic systems have proved to be the most promising technologies for rural electrification by many research studies. As conventional power supply through extending grids is not economically feasible for remote areas, the availability of energy supply based on decentralized renewable energy sources is the most significant social benefit of their deployment in the remote areas (Nouni, Mullick, & Kandpal, 2008).

As experienced and recorded, the power supply and quality through the conventional grid in remote villages is remarkably poor and unreliable. Contrary to this, the overall social and economic growth of the remote villages could be ensured by the consistent electricity supply based on renewable energy systems (Chakrabarti & Chakrabarti, 2002). Generally, for rural households, the minimum load demand is based on power consumed for domestic requirements such as lighting in the home, fans, television, and drinking water supply. Apart from this, the load demand is contributed by health centers, education centers, street lighting and small-scale industries in villages. Solar photovoltaic is one of the most feasible options for rural electrification based on the decentralized supply of electricity as they can be used in off-grid form (separated from the grid) for viable electricity supply application for remote rural areas in developing as well as developed nations (Mahapatra & Dasappa, 2012).

The socio-economic and environmental benefits along with the economic feasibility of decentralized photovoltaic systems for rural electrification have been evaluated in several studies. Though the existing literature in the direction of identification of the appropriateness of renewable energy systems in preference to grid extension is inadequate, (Nouni, Mullick, & Kandpal, 2008) have computed the electricity cost for remote areas located at different distances. Based on the calculations, it was concluded in their study that the renewable energy based systems could be economically desirable than the grid extension for supplying electric power in remote areas.

This chapter focuses on comparing the cost of the electricity supplied from decentralized solar photovoltaic systems with grid extension based rural village electrification in remote villages of Rajasthan. The approach of study involves a relationship between the cost of electricity from a solar energy system and the economic distance limit (EDL) from the nearest utility power grid sub-station using the life-cycle cost (LCC) analysis. The EDL is the distance at which the LCC of the solar energy system (Rs/kWh) matches the LCC of grid extension (conventional energy sources) (Mahapatra & Dasappa, 2012). This analysis is intended to calculate the most favorable economic distance for grid extension in remote areas taking into account the two cases studied during the research. The data used for the analysis is derived from commonly disseminated case studies on power generation systems. The life cycle cost analysis is based on the secondary data collected from the organizations **A** and **B** that have deployed the standalone solar energy systems in their respective villages taken up as case studies for solar off-grid system. Data for the cost of extending centralized grid was collected from the state utility companies and from various reports of the Central Electricity Regulatory Commission (CERC).

Section one of the chapter describes the properties of solar photovoltaic systems for off-grid electrification along with the design details. Section two gives a brief about grid-connected systems for rural electrification. Section three discusses in detail the LCC of solar PV system and economics involved in it with all the components. In the next section, the LCC of grid extension with all components involved is discussed. Section five explains the concept of EDL and its applicability in remote rural electrification. In the next section, the case studies are discussed with the results. In the last section, conclusions drawn are discussed and suggestions are made for think tanks.

5.1 SOLAR PHOTOVOLTAIC SYSTEMS

Generally, sizing of a solar photovoltaic system depends on the number of households and the average power demand of each household. According to the load demand, the system capacity for both the cases has been designed to be equal to 25 kW. As an example, the general technical features of a PV system and the design parameters are shown in table 5.1. With an increase in operational hours, the system size also increases resulting in an increase in the capital cost of the entire PV system. Accordingly, taking into account the marginal electricity needs of the rural population, the operational hours are kept to a minimum duration required for the households. The costs that are considered for the analysis include~~s~~ the capital cost (inclusive of complete PV system modules, batteries etc), the cost of operation and maintenance (O&M) and cost of replacement of the battery. In the present research, the decommissioning cost or the salvage value has not been considered. When compared with the other renewable energy sources, the deciding factors for cost-competitiveness of solar photovoltaic systems are the capital and recurring cost in addition to the technical performance. It is true to say that, the initial capital cost of the solar photovoltaic system is higher than the other renewable energy systems like biomass gasifier and conventional sources of energy, but the moderately lower cost of operation and maintenance and negligible or no fuel cost makes the photovoltaic systems advantageous and attractive over other energy systems.

Table 5.1: Typical photovoltaic system design details

Solar radiation	5.5 kWh/m^2/day
Typical load operation hours (daily)	6 hrs
Solar modules	
Module rating	75 Wp
Nominal DC bus voltage	120 V
Peak current	62.5 A
Battery	
Capacity of each battery	12 V, 600 Ah
Depth of discharge of battery	75%
De-rate for temperature	0.90
Charge controller	
From PV Array	90–200 V DC, 110 A max
From auxiliary source	230 V,1-phase, 50 Hz, 40 A max
Inverter	
Each inverter rated capacity	7.5 kVA
Input voltage	120 V DC nominal
Output voltage	1 phase, 50 Hz, 230 V AC
Type of inverter	Pulse width modulated
Efficiency	92% max

Source: (Mahapatra & Dasappa, 2012)

5.2 GRID-CONNECTED SYSTEMS

In almost all the countries, developed as well as developing, the most favored technique of providing electric power is by installing coal or hydro based centralized power plants, and for delivering the electricity, transmission lines are laid and extended from the generation point to the load center(Nouni, Mullick, & Kandpal, 2008). The cost incurred in extending the grid is dependent on the distance of the load center from the nearest existing power substation, on the load demand, the transmission, and distribution losses along with the power generation cost. Cost appraisal for extension of the grid is calculated by aggregating the 11 kV or 33 kV (or a combination of both depending on the load) transmission lines cost and the cost of 11 kV/0.4 kV substations.

Although thermal power plants are the cheapest form of electricity generation, the grid extension for rural areas is disadvantageous due to huge transmission and distribution losses (both technical and non-technical like theft and pilferage), low load demand in the villages and the high cost of extending the grid. Despite the fact that the grid is claimed to be available, the power quality is still extremely poor. In both the studies, the availability of power through the grid is considered to be for 6 hours in a day for a comparable analysis.

5.3 LIFE-CYCLE COST ANALYSIS OF THE SOLAR PV SYSTEM

According to (Kolhe, Kolhe, & Joshi, 2002), the life cycle cost is an important factor for comparison of the energy alternatives in order to finalize the best source of energy to be adopted for rural electrification. The components included in the life cycle cost analysis of solar PV systems are the initial capital investment (C_0), the present worth of operation and maintenance costs (OM_{PV}) and the present worth of the battery replacement cost (R_{PV}) as shown in equation (1). This represents the fundamental expression for the monetary component of LCC in INR which, when divided by the annualized electricity generation units, gives the LCC in INR/kWh.

$$LCC_{PV} = C_0 + OM_{PV} + R_{PV} \quad (1)$$

The initial capital investment C_0 comprises of the cost of PV array, DC/AC converter, the cost of batteries, controller and battery charger, miscellaneous items (electric cables, outhouse, etc.), transportation and installation, etc.

5.3.1. Operation and maintenance costs

Operation and maintenance costs comprise of taxes, insurance, maintenance, recurring costs, etc (Kolhe, Kolhe, & Joshi, 2002). It is usually stipulated as a percentage (say m) of the initial capital cost. All operating costs are escalated at a rate e_0 and discounted at rate 'd'. The O & M for a lifetime of N years is given as in equation (2):

$$\mathrm{OM_{PV}} = \mathrm{OM_0}\left(\frac{1+e_0}{d-e_0}\right)\left[1-\left(\frac{1+e_0}{1+d}\right)^{N}\right] \text{ If, } d \neq e_0 \{2(a)\}$$

$$\mathrm{OM_{PV}} = \mathrm{OM_0} \times N \text{If, } d = e_0 \quad \{2(b)\}$$

where, $\mathrm{OM_0}$ is taken as:

$$\mathrm{OM_0} = m(C_0) \quad (3)$$

5.3.2 Battery replacement costs

The cost of replacement of battery (R_{PV}) is a function of the number of battery replacements (v) over the system lifetime, without taking the salvage value of replaced batteries. It is denoted by:

$$R_{PV} = C_b\, B_e \sum_{j=1}^{v}\left(\frac{1+e_0}{1+d}\right)^{Nj/v+1} \qquad (4)$$

Or is calculated as the total cost of batteries divided by the life of batteries, which is given by:

$$R_{PV} = \frac{Cost\ of\ Batteries}{Life\ of\ Batteries}$$

The cost of delivered electricity supplied by the solar photovoltaic systems is evaluated by life cycle cost analysis (LCCA). As mentioned earlier, the LCC is estimated by taking into account the capital cost, present worth value of operation and maintenance cost, component replacement cost, and others. The total carbon trading benefits are also included in the calculation to add the environmental cost and benefits. The input parameters for LCC analysis of solar PV are mentioned in table 5.2. (Kandpal & Garg, 2003). The LCC of solar energy is calculated by dividing the system's total costs incurred by the total output of energy generated during the system's lifetime. The LCC (INR/kWh) for solar photovoltaic systems is calculated by using equation (5):

$$LCC_{PV} = \frac{C_{PV} + C_B + (C_{PV} + C_B) \times \beta \times P(d,n) + C_R \times P(d,n_1) - C_C \times P(d,n)}{L \times h \times n}$$

(5)

$$C_C = (L \times h \times n \times C)$$

where,

C_{PV} is capital cost of solar photovoltaic system excluding battery (Rs.)

$C_B$is capital cost of battery (Rs.)

$\beta$is fraction of capital cost for operation and maintenance of the system (%)

C_R is component replacement cost (Rs.)

h is annual operation hours (hours)

$n_1$is life of a specific component (years)

n is the life of the complete system (years)

P is present worth factor

d is the discount rate (%)

C_C is annual carbon benefit (Rs.)

C is carbon emission benefit (kg/kWh)

L is the system capacity (kW)

Note: *Carbon emission benefit is calculated by multiplying the grid emission factor (Kg/kWh) with carbon trading cost (Rs/tonne) (CEA, 2011). Hence, carbon emission benefit Rs/kWh) =0.53 (Mahapatra & Dasappa, 2012) {0.81 kg/kWh×650 Rs/tonne} (IPCC, 2015).*

Table 5.2: Input parameters for solar photovoltaic systems

PV system cost	Rs/kW$_p$
Life of the PV system	Years
Life of the battery	Years
Operational and maintenance cost	(%) of capital cost
Carbon dioxide emission factor	Kg/kWh
Carbon trading price	Rs/tonne

5.4 LIFE CYCLE COST OF GRID EXTENSION

The cost of grid extension is primarily dependent on the distance of the village/load center from the nearest power substation or existing grid point, the cost of operation and maintenance and the distribution transformer cost. Further, the cost of electricity distributed/delivered at the village mainly depends on the electricity generation cost, transmission and distribution losses, load demand and grid line cost. Thus, the life cycle cost of grid extension collectively is dependent on life cycle cost of electricity generation at the village load center and the life cycle cost of grid line at the village load centre from the nearest existing grid point. The input parameters used for the analysis of LCC for grid extension are shown in table 5.3. (Mahapatra & Dasappa, 2012)The expression used for calculating the LCC (Rs/kWh) of grid extension can be written as in equation (6):

$$LCC_{GE} = \frac{LCC_{gen} + LCC_{grid} \times X}{L \times h \times n} \tag{6}$$

where,

$$LCC_{gen} = t_{gen} \times L \times h \times \left(\frac{1}{1-\delta_{t\&d}}\right) \times P$$

$$LCC_{grid} = C_{grid} + C_t + (C_{grid} + C_t) \times \beta \times P$$

$$P = \frac{(1+d)^n - 1}{d \times (1+d)^n}$$

where,

LCC_{GE} is life cycle cost of grid extension (Rs/kWh)

LCC_{gen} is life cycle cost of electricity generation (Rs/kWh)

LCC_{grid} is life cycle cost of grid line (cable/transformer) (Rs/km)

X is distance from the village load centre to the existing grid point (km)

L is load demand (kW)

h is annual operation hours (hours)

d is the discount rate (%)

n is the life of the project (years)

t_{gen} is electricity generation cost (Rs/kWh)

$\delta_{t\&d}$ are transmission and distribution losses (%)

P is present worth factor

C_{grid} is grid line cost (Rs.)

$C_t$is distribution transformer cost (Rs.)

$\beta$is fraction of capital cost for operation and maintenance of the grid (%)

Table 5.3: Input parameters for grid extension

Transmission line cost	Rs./km
Distribution transformer cost	Rs.
Life of the project	Years
T & D losses	%
Electricity generation cost	Rs./kWh
Operation and maintenance cost	% of capital cost

5.5 ECONOMIC DISTANCE LIMIT

(Mahapatra & Dasappa, 2012)The economic distance limit (EDL) is a metric whose calculation gives implications that are similar to break-even analysis. It is computed by taking into account the life cycle cost of solar photovoltaic system and the distance at which this cost and the life cycle cost of grid extension match. Therefore, EDL is the distance where the life cycle cost of solar PV, as well as that of grid extension, become~~s~~ equal or their difference becomes zero and a break-even point (in terms of distance) is achieved. EDL signifies that this distance is the maximum distance which is economically feasible for extension of the grid, and beyond this distance, the grid extension becomes capital intensive and thus economically infeasible. Therefore beyond this distance, deployment of decentralized solar PV systems is advised for attaining rural electrification in place of grid extension. The expression used for the calculation of EDL is written as:

$$\left(\frac{LCC_{grid} \times EDL + LCC_{gen}}{L \times h \times n}\right) - LCC_{PV} = 0 \tag{7}$$

5.6 CASE STUDY: I: MEGHWALON KI DHANI, BARMER DISTRICT OF RAJASTHAN

A solar photovoltaic based micro-grid project was installed in the village Meghwalon ki Dhani in Barmer district of Rajasthan by organization A, under corporate social responsibility in 2014. The studied village was not connected to the central grid due to its remoteness in the desert area and the scattered density of household population. The secondary data was collected from the installing organization and local power utilities in addition to that referred from CERC reports.

5.6.1 Secondary data: (from organization A)

The data collected for solar PV system analysis from organization A and from the CERC guidelines is depicted in table 5.4(a).The other values required for the LCC analysis of solar PV system were calculated on the basis of the data available and formulae mentioned earlier.

Table 5.4 (a): Actual input parameters for LCC solar PV (case I)

Daily average household load	121 W
Total number of households in the village	100
Cost of PV system excluding cost of battery (C-PV)	Rs. 4660150
Cost of battery (C-B)	Rs. 989850
Life of battery	6 years
Daily operational hours	6 hours

Life of PV system	25 years
Capacity of PV system	25 kW
Carbon emission benefit (C)	0.53 Rs./kWh
Discount rate	10.7%
O & M costs as fraction of capital	0.5%

5.6.2 Secondary data: (from State Power Utilities and CERC guidelines)

The data collected for grid extension analysis from state and local power utilities (RERC and Discoms) and from the CERC guidelines is depicted in table 5.4(b).

Table 5.4 (b): Actual input parameters of grid extension

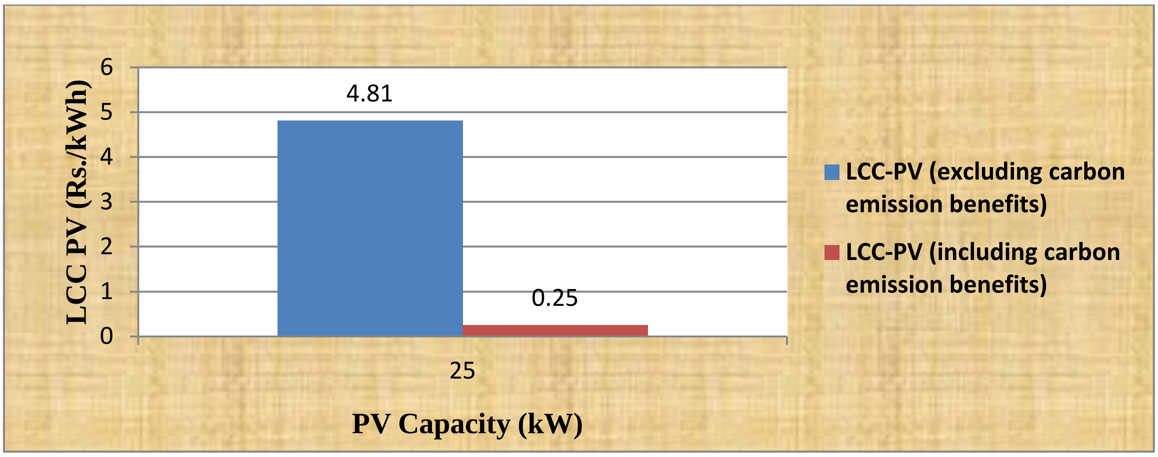
Electricity generation cost	Rs. 3.50/kWh
Grid line cost	Rs. 9.9 lakh/km
Transformer cost	Rs. 44150
O & M	1%
Distance from nearest substation	8 km
T & D losses	28.50%
Discount rate	10.7%
Load demand	12.1 kW
Daily operational hours	6 hours
Life of the project	25 years

The other values required for the LCC analysis of grid extension were calculated using Microsoft Excel on the basis of the data available and formulae mentioned earlier.

5.6.3 Life cycle cost of solar PV for case I

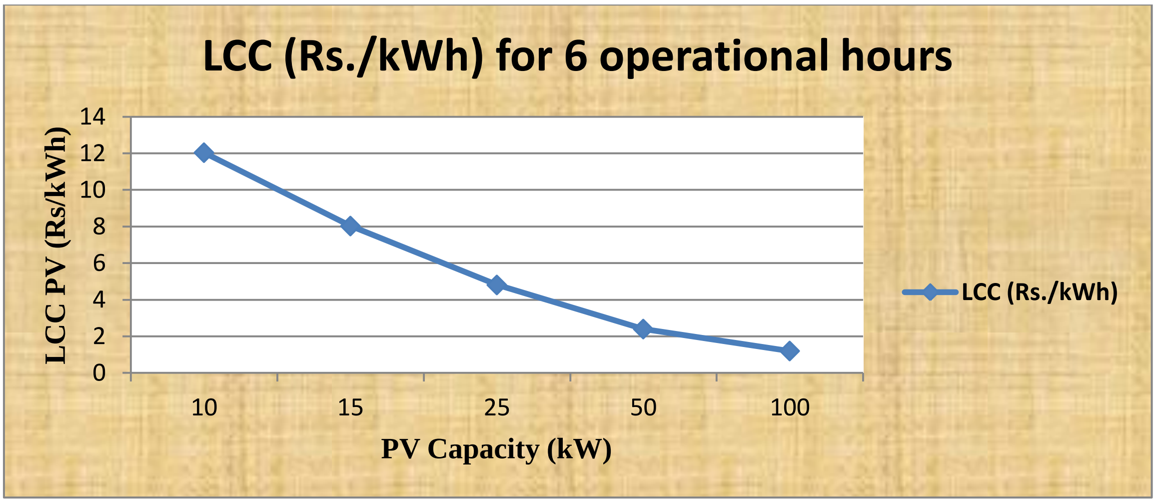
The life cycle cost of electricity generated by solar photovoltaic systems for case study I corresponding to Barmer district was calculated by using eq. (5) and is presented in figure 5.1. In the present analysis, the LCC_{PV} (excluding the environmental costs)for the 25 kW system capacity solar PV project in Barmer came out to be 4.81 Rs./kWh and when the environmental cost benefits were added to it, the cost was further reduced to 0.25 Rs./kWh.

Figure 5.1: LCC-PV (Rs/kWh) for case study I



In the present study, the operational hours are fixed at 6 based on the module and storage capacity of the solar PV based micro grid. The LCC values vary from Rs. 12.04/kWh to Rs. 1.20/kWh for system capacities of 10 kW to 100 kW respectively. The LCC for 15 kW and 50 kW are Rs. 8.03/kWh and Rs. 2.40/kWh respectively as shown in figure 5.2.

Figure 5.2: LCC (Rs. /kWh) of energy from PV systems (case I)

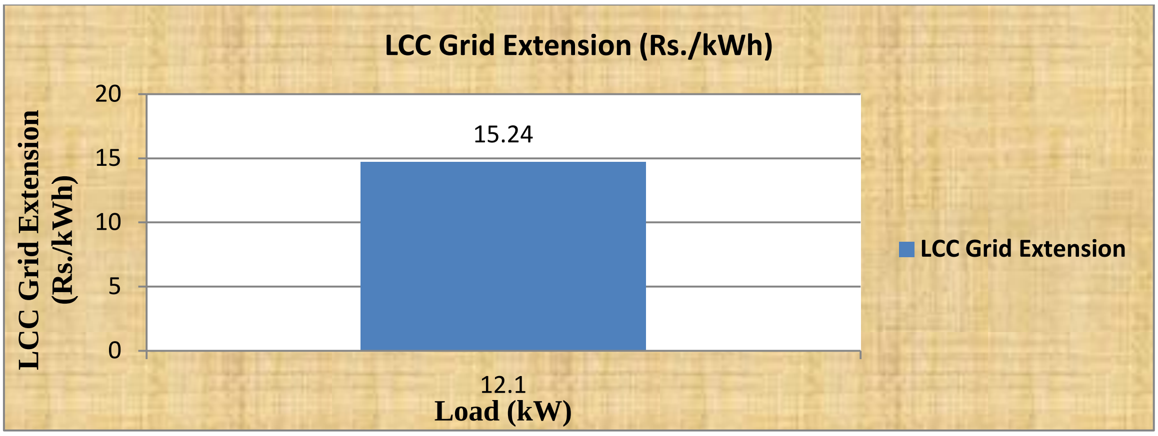


Further, it is assumed that the LCC of photovoltaic energy is not affected by the changes in operational hours because with an increase in operational hours, there is a need to increase the system capacity relatively, which in turn will lead to increase in the capital cost of the system, leading to a rise in the cost of energy generation. Therefore, for diverse operational hours, the LCC of energy from photovoltaic system persists to be virtually unchanged.

5.6.4 Life cycle cost of grid extension for case study I

The life cycle cost of grid extension for Case I in Barmer district of Rajasthan was calculated by using eq. (6) and is presented in figure 5.3. In the present analysis, the LCC_{GE} for the 25 kW system capacity project (for 6 h of grid-based power availability, similar to that of solar PV in Barmer) was calculated to be Rs. 15.24/kWh. The distance of the load centre from nearest existing grid pooling point is 8 km.

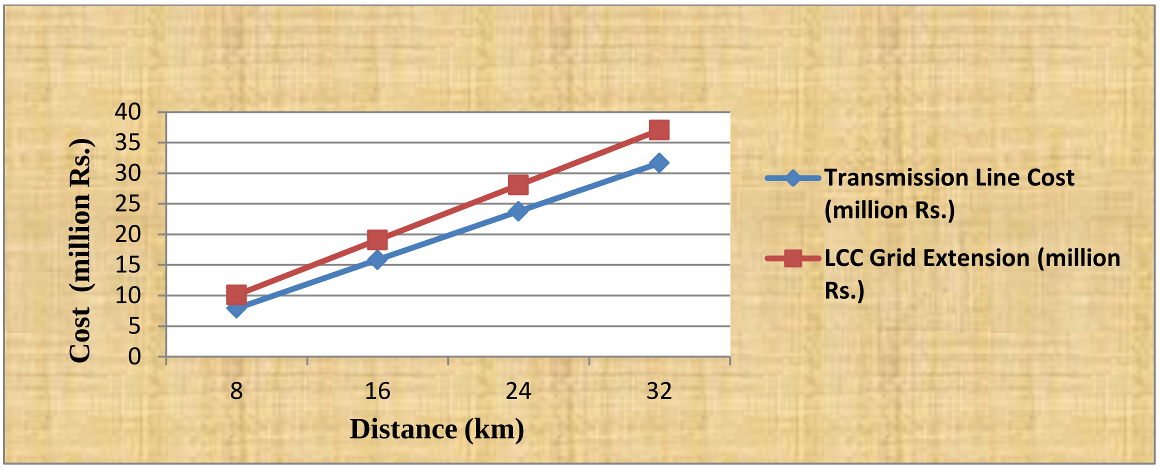
Figure 5.3: LCC-grid extension (Rs/kWh) for case I



For remote areas, the LCC of grid extension is largely influenced by the transmission line cost as compared to the generation cost of energy. As the cost of transmission increases, the LCC of grid extension also increases relatively which could be clearly seen in figure 5.4. For the capacity of 25 kW at different distances of the load centre from existing grid point, the transmission line cost increases with distance and thus, the LCC grid extension also raises.

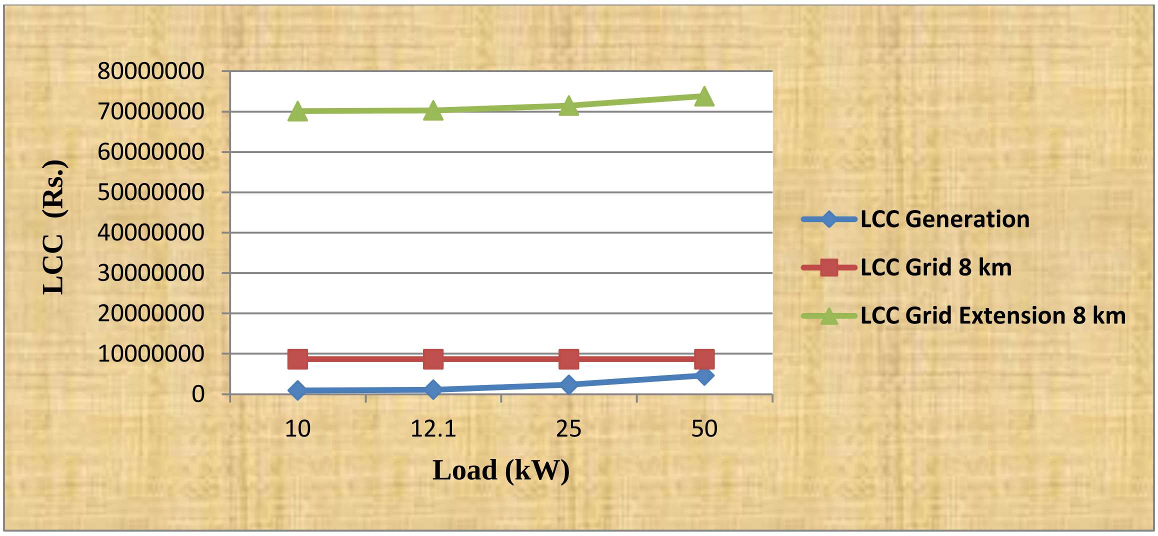
With increasing distance of village load centre from the nearest power substation, the extension of grid becomes highly capital intensive and thus, it is no more feasible to extend the conventional grid to such remote areas.

Figure 5.4: Transmission line cost and LCC grid extension with distance



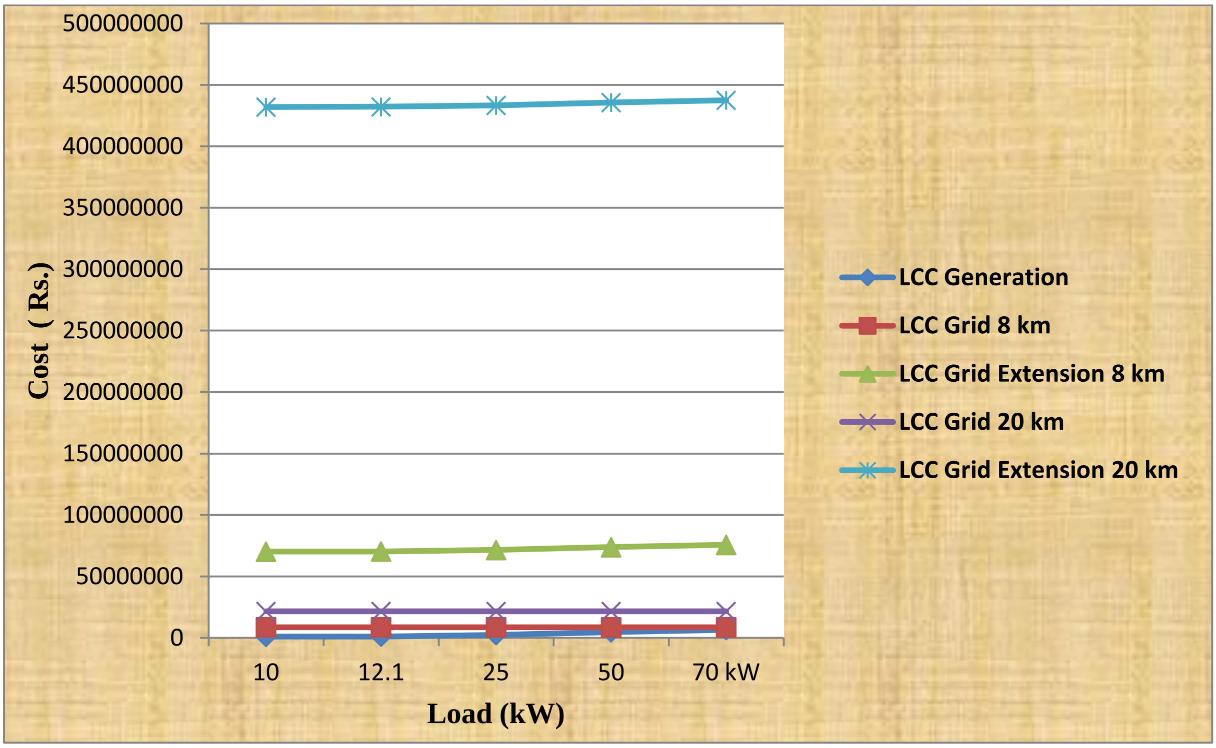
For a particular distance, the two main factors which influence the LCC for grid extension are the LCC for generation and LCC for grid lines (cable conductors/ transformer). For the present case, the distance of load centre from existing grid point is 8 km. The expenditure components of the LCC generation as well as LCC grid lines that influence the LCC for grid extension (for the present load demand of village i.e. 12.1 kW and the different values of loads) are calculated and shown in figure 5.5.It is clearly seen in the figure that the LCC generation is almost same for each capacity and the LCC grid is comparatively higher than LCC generation.

Figure 5.5: Cost components of different life cycle costs for 8 km distance (case I)



It is observed from figure 5.5 that the LCC of grid lines is higher than LCC of generation. The LCC of grid extension is governed by the two main components i.e. LCC of the grid line and the distance of the village load centre from the nearest power substation. Further, in comparison to the LCC of energy generation, the LCC of the grid line is the influential factor for grid extension.

Figure 5.6: LCC (Rs.) of energy for grid extension (case I)

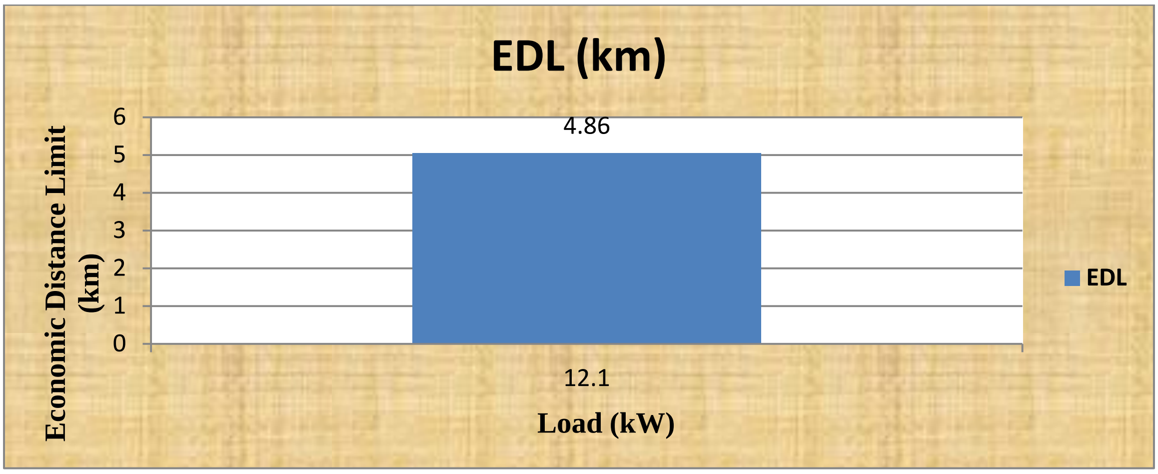


This figure clearly suggests that with the increase in the distance of the village load centre from the existing grid point, there is an increase in LCC of grid extension and vice-versa.

5.6.5 Economic distance limit for case I

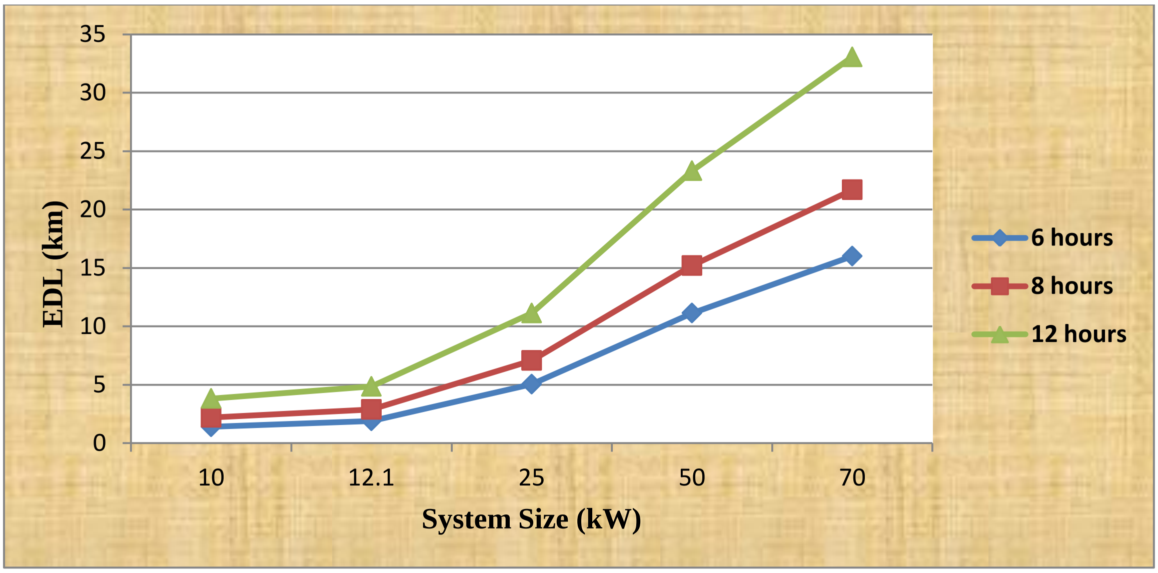
It is evident from previous discussion and analysis that EDL values are dependent on LCC of energy. The EDL is calculated by using the expression given in eq. (7). In the present case, the EDL for the 25 kW photovoltaic ~~systems~~ in a village at a distance of 8 km from the nearest grid point was calculated to be 4.86 km as shown in figure 5.7. This result implies that beyond a distance of 4.86 km, the extension of the conventional grid is not economically feasible in this particular case. The grid extension will be capital intensive in this case as the distance of the load centre from the grid feeding point is almost double the EDL.

Figure 5.7: EDL for case I



For photovoltaic systems, the life cycle cost of energy is mainly dependent on the capital cost of the system having a minimal operation cost associated since the fuel cost is zero. It is observed from figure 5.8 that with an increase in the availability of grid-based power from 6 h to 12 h, the EDL value also increases. In the present case, the EDL values vary from 1.4km to 33.06 km for the system capacity of10 kW to 70 kW respectively for the daily operation of PV system with an availability of grid-based power for 6h. Further, for a system capacity of 25 kW, the EDL value differs from 5.05 km to 11.14 km as the availability of grid-based power differs from 6h to 12h.

Figure 5.8: Economic distance limit for photovoltaic systems (case I)



Therefore, for case study I, it is reported that the LCC PV is far less than the LCC grid extension and the value of EDL asserts that it is not feasible to extend grid in this case as the distance is almost double the economic distance limit calculated in this case. Hence, in the present case study, grid-extension will be capital intensive, proving electrification through PV systems to be a more viable option for the site analyzed.

5.7 CASE STUDY: II: KHANPURIYA, KOTA DISTRICT OF RAJASTHAN

A solar photovoltaic micro-grid project was installed in the village Khanpuriya in Kota district of Rajasthan by organization B, which is an NGO (internationally funded) in 2014. The studied village was not connected to the central grid due to its remoteness in the desert area and the scattered density of household population. The data was taken from the installing organization and local power utilities along with CERC reports.

5.7.1 Secondary data: (from organization B)

The data collected for solar PV system analysis from organization B and CERC guidelines is depicted in table 5.5(a).

Table 5.5(a): Actual input parameters of solar PV (case II)

Daily average household load	118 W
Total number of households in the village	80
Cost of PV system excluding cost of battery (C-PV)	Rs. 3829000
Cost of battery (C-B)	Rs. 929850
Life of battery	6 years
Daily operational hours	6 hours
Life of PV system	25 years
Capacity of PV system	25 kW
Carbon emission benefit (C)	0.53 Rs/kWh
Discount rate	10.7%
O & M costs as fraction of capital	0.5%

Note: The other values required for the LCC analysis of solar PV system were calculated using Microsoft Excel on the basis of the data available and formulae mentioned earlier.

5.7.2 Secondary data: (from State Power Utilities and CERC guidelines)

The data collected for grid extension analysis from state and local power utilities (RERC and Discoms) and CERC guidelines is depicted in table 5.5(b).

Table 5.5 (b): Actual input parameters of grid extension (case II)

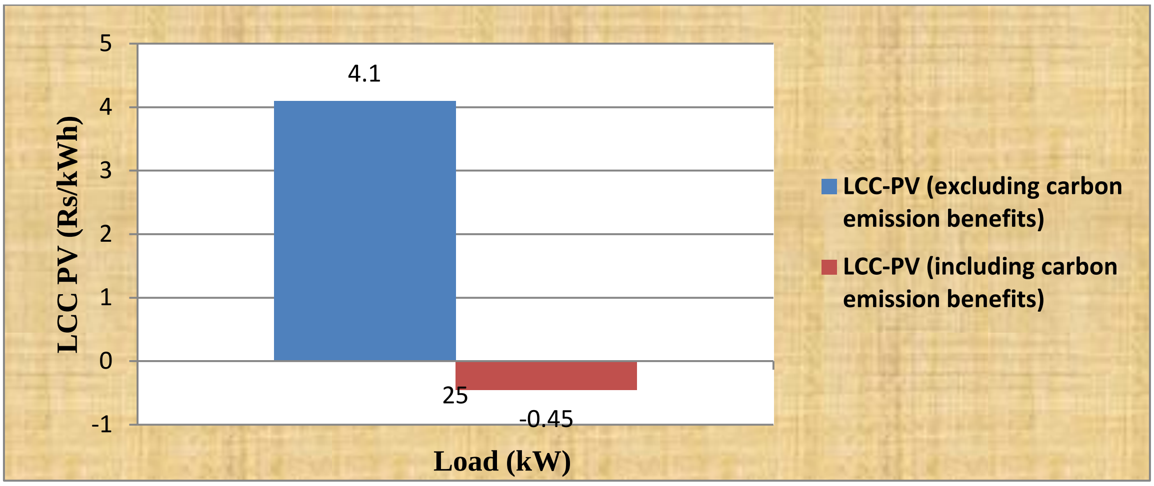
Electricity generation cost	Rs. 3.50/kWh
Grid line cost	Rs. 9.9 lakh/km
Transformer cost	Rs. 44150
O & M	1%
Distance from nearest substation	14 km
T & D losses	32.05%
Discount rate	10.7%
Load demand	14.2 kW
Daily operational hours	6 hours
Life of the project	25 years

The other values required for the LCC analysis of grid extension were calculated using Microsoft Excel on the basis of the data available and formulae mentioned earlier.

5.7.3 Life cycle cost of solar PV for case II

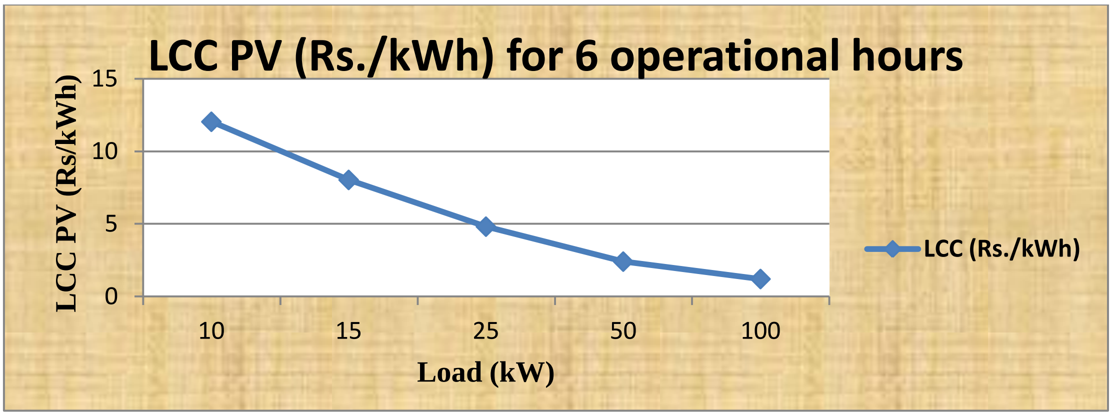
The life cycle cost for solar photovoltaic systems for case II in Kota district was calculated by using eq. (5) and is presented in figure 5.9. In the present analysis the LCC_{PV} (excluding the environmental costs, for 25 kW system capacity solar PV project in Kota district is 4.10 Rs./kWh and when the environmental cost benefits are added to it the costs is further reduced to -0.45Rs./kWh.

Figure 5.9: LCC-PV (Rs/kWh) for case II



As in case study I, the operational hours in present case II are fixed at 6 h based on the module and storage capacity for solar PV. The LCC values vary from Rs. 10.27/kWh to Rs. 1.02/kWh for system capacities of 10 kW to 100 kW respectively. The LCC for 15 kW and 50 kW are Rs. 6.8/kWh and Rs. 2.05/kWh respectively as shown in figure 5.10.

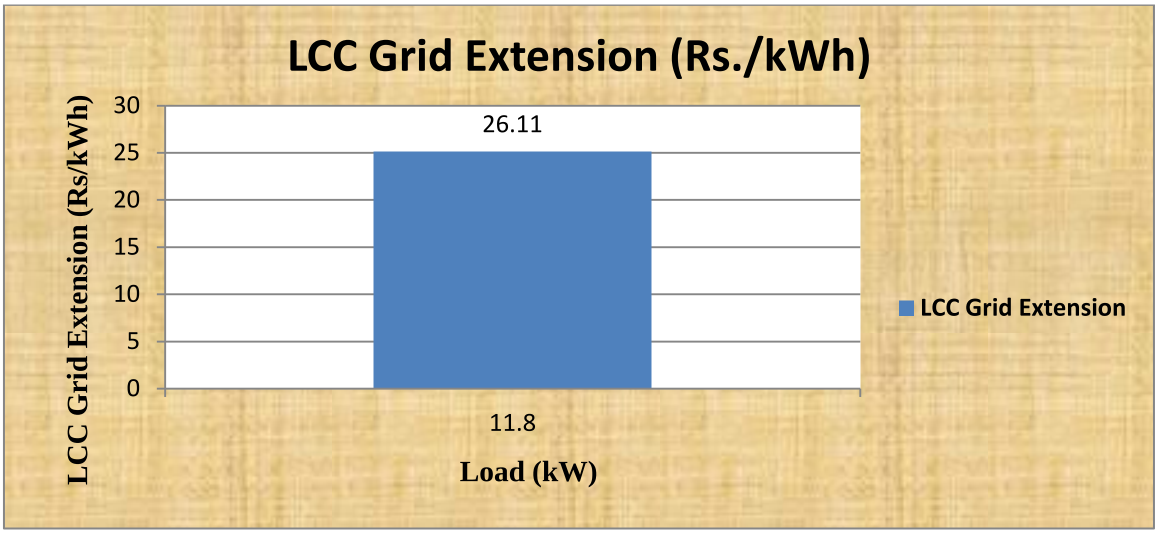
Figure 5.10: LCC (Rs. /kWh) of energy from PV systems (case II)



5.7.4 Life cycle cost of grid extension for case II

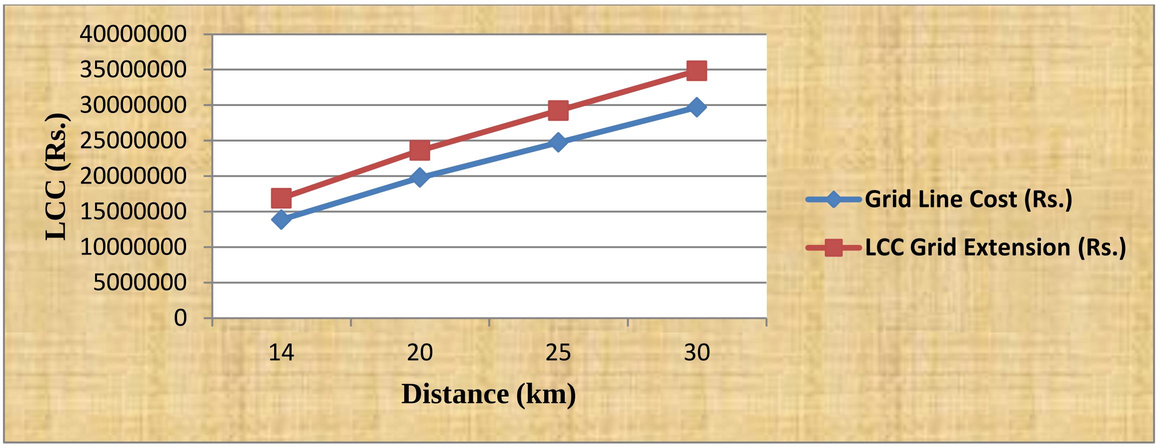
The life cycle cost of grid extension for case II in Kota was calculated by using eq. (6) and is presented in figure 5.11. In the present analysis, the LCC_{GE} for 25 kW system capacity project and 6 h of grid-based power availability, similar to that of solar PV in Kota is Rs. 26.11/kWh. The distance of the load centre from nearest existing grid is 14 km.

Figure 5.11: LCC-grid extension (Rs/kWh) for case II



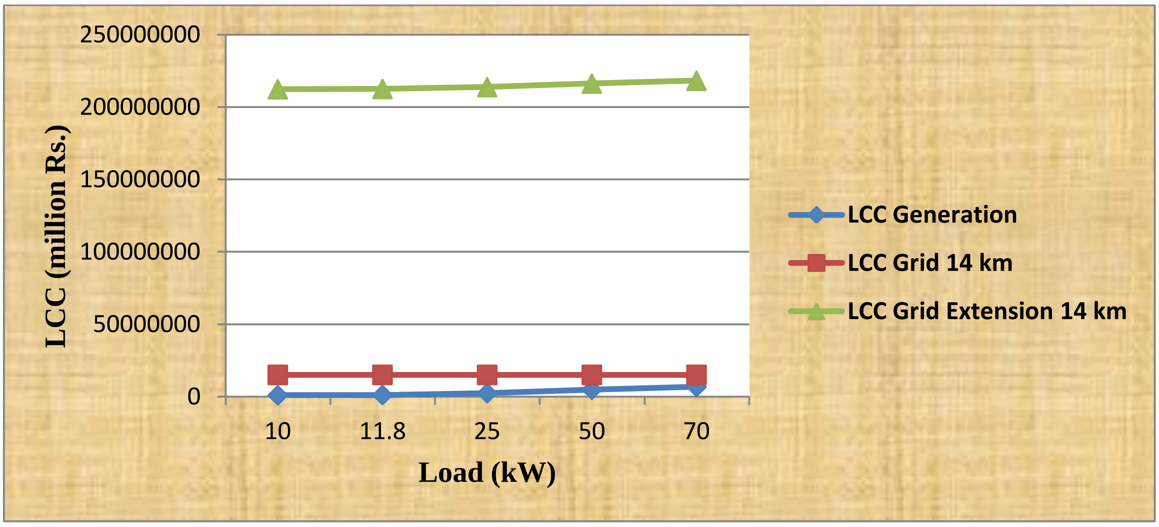
As mentioned earlier, for remote areas, the LCC grid extension is largely influenced by the transmission line cost as compared to the generation cost of energy. As the cost of transmission increases, the LCC of grid extension also increases relatively which could be clearly seen for case II also in figure 5.12. For capacity of 25 kW at different distances of the load centre from existing grid point the transmission line cost increases with increase in the distance and thus, the LCC grid extension is also increased.

Figure 5.12: Transmission line cost and LCC grid extension with distance (case II)



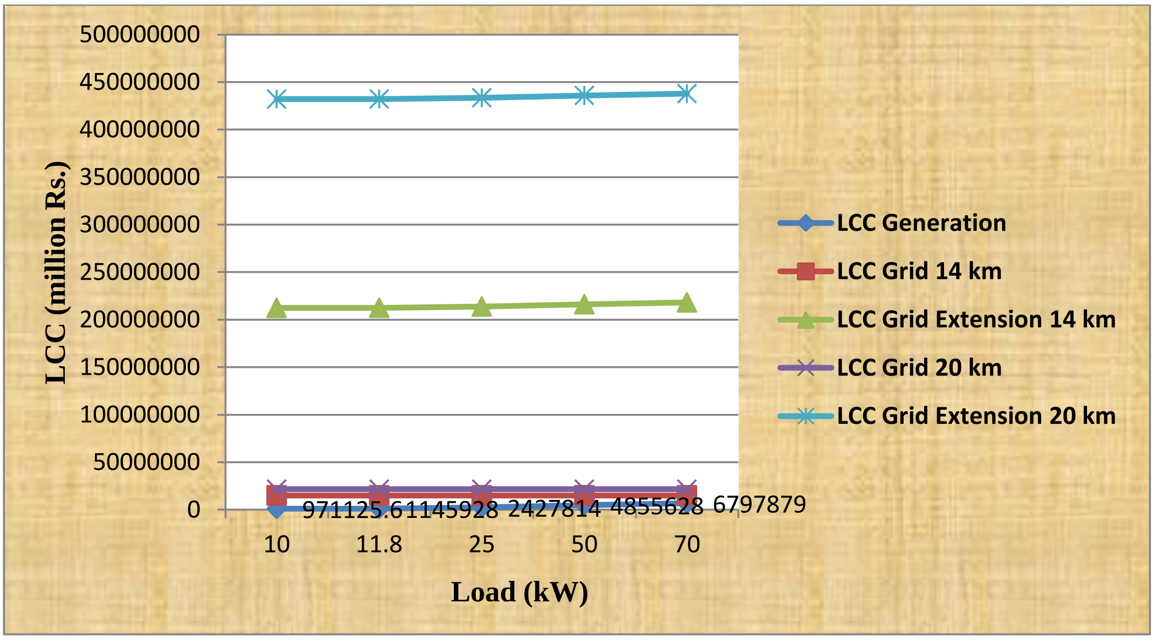
Thus, for a particular distance, the two main factors which influence the LCC for grid extension are the LCC for generation and LCC for grid lines (cable conductors/ transformer), the same persists for case II on the lines similar to that of case I. For the present case, the distance of load centre from existing grid point is 14 km and the LCC generation as well as LCC grid lines that influence the LCC for grid extension (for load demand of the present village in study i.e. 11.8 kW and the different values of loads) are calculated and shown in figure 5.13. It is clearly seen in the figure that the LCC generation is almost same for each capacity and the LCC grid is comparatively higher than LCC generation.

Figure 5.13: Cost components of different life cycle costs for 14 km distance (case II)



It is observed from figure 5.14 that the LCC of grid lines is higher than LCC of generation. Hence, the LCC of grid extension is governed by the two main components i.e. LCC of the grid line and the distance of the village load centre from the nearest power substation. Further, in comparison to the LCC of energy generation, the LCC of the grid line is the influential factor for grid extension.

Figure 5.14: LCC (Rs.) of energy for grid extension (case II)

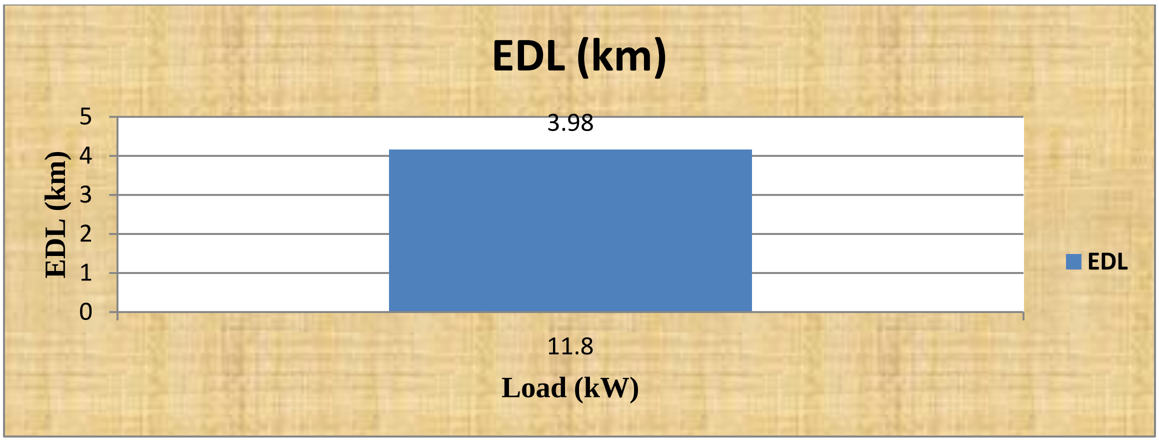


The above figure clearly suggests that with the increase in the distance of the village load centre from the existing grid point, there is an increase in LCC of grid extension and vice-versa.

5.7.5 Economic distance limit for case II

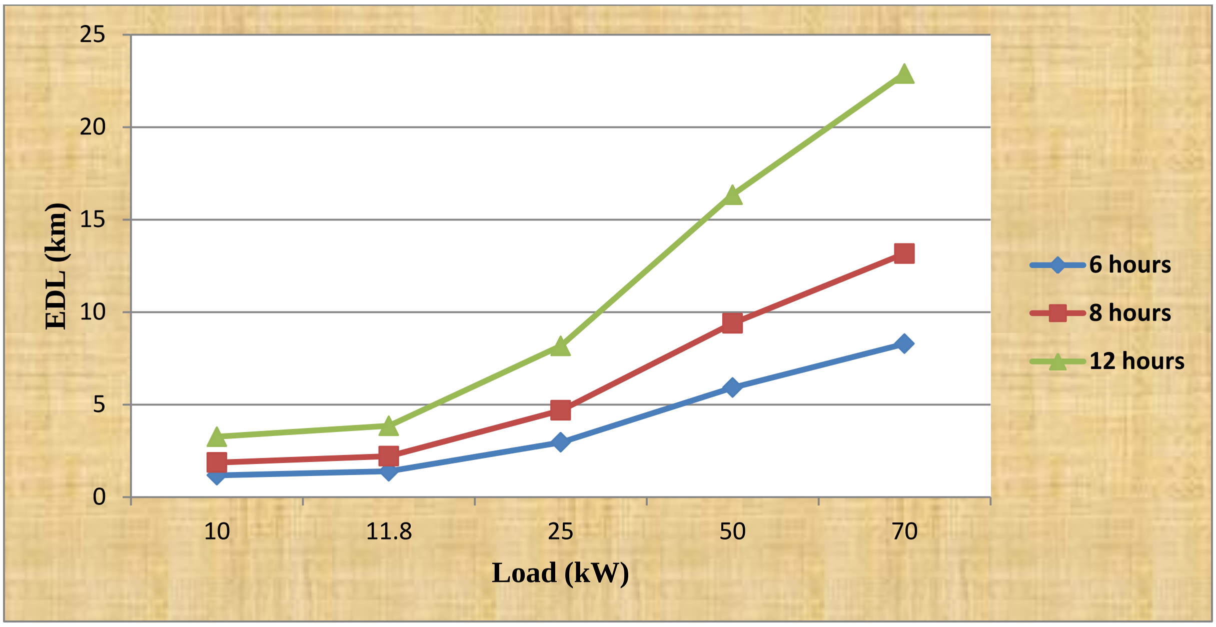
As discussed in the case study I, it is evident from the analysis that EDL values are dependent on LCC of energy. The EDL is calculated by using eq. (7). In the present case, the EDL for 25 kW photovoltaic systems in a village with a distance of 14 km from the nearest grid point is calculated to be 3.98 km as shown in figure 5.15. This EDL means that beyond the distance of 3.98 km, the extension of the conventional grid is not economically feasible as the grid extension is highly capital intensive and in this case as the distance of the load centre is nearly more than thrice the EDL.

Figure 5.15: EDL for solar PV, case II



Similarly; as discussed earlier that, for photovoltaic systems, the life cycle cost of energy is majorly dependent on the capital cost of the system with minimal operation cost attached as the fuel cost is negligible. It is observed from figure 5.16 that with an increase in the availability of grid-based power from 6 h to 12 h, the EDL value also increases. In the present case, the EDL values vary from 1.18 km to 8.29 km for the system capacity of 10 kW to 70 kW respectively for the daily operation of PV system with an availability of grid-based power for 6 h. Further, for a system capacity of 25kW, the EDL value differs from 2.96 km to 8.17 km as the availability of grid-based power differs from 6 h to 12 h.

Figure 5.16: Economic distance limit for photovoltaic systems (case II)



Therefore, it can be said on observing case study II also that the LCC PV is far lesser than the LCC grid extension and the EDL asserts that it is not feasible to extend grid in this case as the distance is almost double the economic distance limit and thus highly capital intensive, proving the electrification through PV systems more viable option in the present case study.

5.8 DISCUSSION AND INTERPRETATION

In the present study, it has been examined that the LCC of energy for grid extension is chiefly influenced by the distance of village load centre from the nearest power substation or the transmission cost/LCC of grid lines rather than the LCC of energy generation. It has also been observed that for any particular distance, as compared to higher load values, the LCC of energy for grid extension is lower at low loads which signify that with an increase in load the LCC of energy for a particular distance decreases.

Further, it is found that with an increase in the cost of photovoltaic energy system, the EDL also increases. On the other hand, with an increase in the transmission line cost, the EDL decreases. It is anticipated according to the prevailing trends that with an increase in transmission cost, the cost of grid extension also increases, and consequently a relative increase is observed in the associated LCC for grid extension. Thus, in the villages where the load demand is relatively low and which are located at a large distant from the nearest grid point, there is a huge scope for decentralized solar PV technology. Subsequently, for premeditated load demand and intended operational hours, photovoltaic systems are most appropriate. Another credit associated with the photovoltaic systems is that the fuel cost is zero and the operation and maintenance are also comparatively undemanding .At the same time, the reliability index of photovoltaic systems in comparison to that of conventional grid extension is relatively higher for remote villages.

Further, highlighting the darker side of PV systems, it is important to mention that in addition to the geological aspect (solar radiation at the site); the operation of photovoltaic systems is also heavily reliant on the day-to-day climate conditions of the site. The pattern of electricity consumption from a photovoltaic system and that from a grid system differs largely from each other as photovoltaic systems are restricted to supply a fixed amount of electricity per day while there is no such restriction with the grid-connected systems. It is further important to understand that the consistency and accessibility of electricity via grid-connected systems is very poor for rural communities and for remote locations it is further much poorer. Hence, the importance of usage of PV systems for remote areas has increased and proven to be viable. It is evident from both the studied villages that for similar dimensions the cost of photovoltaic systems for remote locations is far lower than that of extension of the grid for supply of electricity. Furthermore, the concept of economic distance limit has proven the viability of PV systems over grid extension for both the case studies. Hence, adoption of decentralized solar PV systems to electrify these villages is a comparatively suitable and feasible option.

For the villages where the possibility of grid extension is a far reality, decentralized generation presents numerous benefits to the people due to the following reasons:

a) Low load makes PV systems more economical

Most of the remotely located villages have a lower number of households (around 40-50 in number). In addition, their requirements for electricity are low as the demand is generally only for lighting purposes, charging phones, television, and at times transistors (radio sets).Therefore, the extension of the grid for such low load is highly capital intensive and thus economically unfeasible. On the other hand for such low loads solar PV systems are economically more viable.

b) High cost of grid extension due to large distance and unfavorable topography:

As demonstrated in the present study, the grid extension cost for remote rural villages shoots up accounting to the large distance from the nearest grid point. It thus becomes economically unviable to extend the grid to such villages. In addition, this cost is customarily much higher than the cost of decentralized PV systems in such remote villages.

c) High reliability of decentralized power:

The supply of power from the grid is often not consistent due to load shedding. Therefore, electricity from the grid is usually not considered of superior quality for such rural areas. Due to unreliable access to power supply, the villagers have to spend on alternative sources of energy like kerosene which adds to their expenses to a great extent. On the other hand, power supply from PV systems though limited, is highly reliable and consistent and environment friendly, thus favorable over the grid-based power supply.

5.9 CONCLUSION

Providing access to consistent and reliable modern energy to all is a critical challenge in India. Regardless of numerous efforts made by the government in form of policies and programs for rural electrification, the number of rural households without electricity access is large.

In the present study with the help of two case-based investigations, it was observed that decentralized power generation by photovoltaic systems could be relativelycost competitive for remote villages. Although the cost of electricity generation based on grid-connected systems is lower than that of renewable energy systems, still high transmission and distribution losses and higher cost of grid extension contributes to increased per unit cost of electricity as compared to that of solar energy based systems for large distance of village load centre from the nearest existing grid point. Therefore, based on the life cycle cost analysis performed to compare the cost of solar PV systems and grid-connected systems for distant locations of villages, it is concluded that as compared to the grid extension, the solar PV base systems are economically viable for remote villages. Contrary to the common conviction about the cost of energy that the leading capital investment for renewable energy systems is exceptionally high, using life cycle cost analysis it has been revealed in this study that for remote villages with low load demand, the decentralized power generation by photovoltaic systems can be more competitive in terms of cost.

A mathematical relationship has been drawn in this study between solar photovoltaic system capacity and the economic distance from the nearest existing grid point. In order to forecast the capacity of renewable energy systems and the optimum economical distance limit matching to that capacity, the mathematical relation drawn could be of utmost relevance. Thus, as examined according to the study it could be mentioned that for the remote villages that are distantly located from the nearest grid point, decentralized solar photovoltaic energy systems could be the most suitable sources of energy for providing economically feasible and reliable electricity supply. The LCC analysis and economic distance limit concept along with analyzing the cost-effectiveness of a decentralized PV system when compared with the most commonly adopted energy supply option i.e. a conventional grid-powered system anticipates to furnish a first-order intimation of when a decentralized PV system should be considered for electricity supply and when the extension of grid is considered to be a feasible option for power supply to the rural areas. Hence, it is illustrated that the break-even point occurs at high energy demand when the PV system cost decreases and the conventional grid system cost increases.

To conclude, it is imperative to introduce to the fact that the most relevant social benefit of providing decentralized energy sources in villages is access to reliable and good quality power supply to the rural population for their social upliftment and further use of power in productive activities. The significant positive impacts of reliable power supply could be seen through enhanced education level, business opportunities, energy security, empowerment of women, health improvements, etc, contributing to an overall economic and social development of the village. Furthermore, most importantly the photovoltaic energy base systems are environment-friendly with zero carbon emissions potential as compared to conventional coal-based power generation systems which are least compatible with the environment.

Chapter 6A

SOCIO-ECONOMIC IMPACT OF EXISTING DECENTRALIZED SOLAR BASED PROJECTS IN RAJASTHAN: SAMPLE SURVEY-I

CHAPTER 6A

SOCIO-ECONOMIC IMPACT OF EXISTING DECENTRALIZED SOLAR BASED PROJECTS IN RAJASTHAN: SAMPLE SURVEY-I

6.1 INTRODUCTION

In the present chapter the data collected from rural households of four districts of Rajasthan has been analyzed to examine the impact resulting from solar electrification. The main objective of this study is to analyze the socio-economic impact of existing solar based decentralized projects in rural Rajasthan by comparing it with pre solar electrification situation. This study attempts to examine how the presence of electricity changes overall cost of energy and its consumption pattern in rural households, and if there is any substantial impact on livelihood, education, women upliftment and health of households after electrification.

This chapter of the study has been divided into four sections, based on household survey. In the first section, we have discussed the ‘Household Profile’ of the respondents selected for the study. The first section comprises of general information about the households and information on household electricity and fuel consumption pattern. Second section deals with the ‘Household Attitude,' which reflects the views of households on various energy options before and after solar electrification. This section consists of views on energy options, benefits of solar electricity, and uses of solar light. The third section compares four important factors of this study before and after solar electrification, focusing on ‘Socio-economic Assessment’ of the households. These four factors comprise impact on livelihood and income, impact on upliftment of women, health and education. The fourth section deals with the opinion of these households on skill development, affordability and willingness to pay for solar energy systems.

The analysis of this research is studied through graphs, tabulation, and statistical tests. The statistical tests used in analyzing the data are Wilcoxon signed-rank test, paired-samples t-test, and two-way ANOVA. The Statistical Package for Social Sciences (SPSS Ver. 18) is used for the statistical analysis. The overall hypothesis that is tested on the collected data are summarized below, and discussed further in relevant sections of the chapter.

Table 6.1: Summary of the hypothesis and the testing method

S.No.	***Section***	***Hypothesis***	***Null hypothesis***	***Statistical test***
1.	Section II	There is a significant difference between household views on energy generated from kerosene/firewood before solar electrification and on solar generated electricity after solar electrification.	$\mu_b = \mu_a$	Wilcoxon signed-rank test
2.		There is a significant difference between household views on benefits of solar electricity before and after solar electrification.	$\mu_b = \mu_a$	Wilcoxon signed-rank test
3.		There is a significant difference in the number of hours devoted to various activities before and after solar electrification.	$\mu_b = \mu_a$	Wilcoxon signed-rank test
4.	Section III	There is a significant difference between the overall scores of impact on livelihood and income before and after solar electrification.	$\mu_b = \mu_a$	Paired-samples t-test and ANOVA
5.		There is a significant difference between the overall scores of impact on upliftment of women before and after solar electrification.	$\mu_b = \mu_a$	Paired-samples t-test and ANOVA
6.		There is a significant difference between the overall scores of impact on health before and after solar electrification.	$\mu_b = \mu_a$	Paired-samples t-test and ANOVA
7.		There is a significant difference between the overall scores of impact on education before and after solar electrification.	$\mu_b = \mu_a$	Paired-samples t-test and ANOVA

6.2 SECTION I: HOUSEHOLD PROFILE

Villages covered in this study were un-electrified since independence, and there is a bleak chance of connecting them to the conventional grid in future due to some limitations. With introduction of solar electrification in these selected villages, it is imperative to note changes brought about by this vital change in the lives of these households.

A total of 570 respondents were surveyed in this study, comprising 130, 100, 105, and 235 respondents from Pratapgarh, Barmer, Baran and Kota district respectively. Household profile consists of socio-economic characteristics of these households, and information on household electricity and fuel consumption pattern. This section explains the underlying characteristics of the respondents and gives an insight into overall profile of respondents which is helpful in analyzing other sections and also explaining the impact of solar electrification on these households.

6.2.1 Socio-economic characteristics of respondents

This study was carried out in four districts of Rajasthan, namely, Barmer, Pratapgarh, Kota, and Baran. A total of 14 villages were covered in these four districts, which were completely un-electrified before solar electrification. For these surveyed households 90 percent and 10 percent households were headed by male and female family members respectively (Table 6.2). The study result indicates that 71 percent heads of these households fall under the age bracket of 31 to 50 years. Regardingeducational attainments of these household heads, 54 percent, 32 percent, 9 percent,4 percent and 1 percent fall under the category of never attended school, primary level, junior middle level, senior middle level and college level and above respectively. As per their occupations, 40 percent, 25 percent, 1 percent, 17 percent, and 17 percent were casual labor, farmer, teacher, business person and others, respectively. The monthly income of these households was distributed as 11 percent, 12 percent, 15 percent, 27 percent and 34 percent for less than Rs. 4000, Rs. 4001-6000, Rs. 6001-8000, Rs. 8001-10000 and more than Rs. 10001, respectively. The table below summarizes the socio-economic characteristics of these households.

Table 6.2: Summary of Socio-economic characteristics of the household

N=570	Variables	Percentage (%)
Gender	Male	90.2
	Female	9.8
Age	<20 years	0
	20-30 years	20.4
	30-40 years	47.0
	40-50 years	23.9

	>50 years	8.0
Education Level	Never attended school	54.4
	Attended primary school	31.8
	Attended junior middle school	9.3
	Attended senior middle school	3.5
	College level or above	0.5
Occupation	Casual Labour	39.6
	Farmer	25.1
	Teacher	0.7
	Business person	17.5
	Other	17.0
Monthly income	<4000 Rs	11.1
	4001-6000 Rs	11.9
	6001-8000 Rs	15.1
	8001-10,000 Rs	27.2
	>10,000 Rs	34.1

Source: *Field data, 2016*

6.2.1.1 Gender-wise distribution of respondents

The overall gender-wise distribution is shown for the total number of respondents selected for this study along with district-wise bifurcation in the table 6.3.

Table 6.3: Gender-wise distribution of respondents

	Overall		**Pratapgarh**		**Barmer**		**Baran**		**Kota**	
	Number	***Percent***	***Number***	***Percent***	***Number***	***Percent***	***Number***	***Percent***	***Number***	***Percent***
Male	514	90.2	125	96.2	93	93.0	86	81.9	210	89.4
Female	56	9.8	5	3.8	7	7.0	19	18.1	25	10.6
Total	570	100.0	130	100.0	100	100.0	105	100.0	235	100.0

The table above explains the gender-wise distribution of respondents who participated in this study. Out of these respondents, (514) 90.20 percent belong to male group and (56) 9.8 percent respondents belong to female group.

In ***Pratapgarh*** district respondents, (125) 96.2 percent respondents belong to male group and (5) 3.8 percent belongs to female group. Out of the ***Barmer*** district, respondents, (93) 93 percent respondents belong to male group and (7) 7 percent belongs to female group. In ***Baran*** district, (86) 81.9 percent respondents belong to male group and (19) 18.1 percent belongs to female group. In ***Kota*** district, (210) 89.4 percent respondents belong to male group and (25) 10.6 percent belongs to female group. Hence, in relative terms maximum female respondents were in Baran district and male respondents in Pratapgarh district.

6.2.1.2 Age-wise distribution of respondents

The overall age-wise distribution for total number of respondents interviewed in this study along with the district-wise bifurcation is shown in table 6.4.

Table 6.4: Age-wise distribution of respondents

Age (Years)	**Overall**		**Pratapgarh**		**Barmer**		**Baran**		**Kota**	
	Number	***Percent***	***Number***	***Percent***	***Number***	***Percent***	***Number***	***Percent***	***Number***	***Percent***
<20 yrs	na	na	Na	na	na	na	na	na	na	na
21-30 yrs	116	20.4	32	24.6	18	18.0	22	21.0	44	18.7
31-40 yrs	268	47.0	60	46.2	50	50.0	68	64.8	90	38.3
41-50 yrs	136	23.8	23	17.7	27	27.0	12	11.4	74	31.5
>50 yrs	50	8.8	15	11.5	5	5.0	3	2.8	27	11.5
Total	570	100.0	130	100.0	100	100.0	105	100.0	235	100.0

The table above explains overall age-wise distribution of respondents interviewed in the study. There was no respondent belonging to the <20 years. Of the remaining respondents, (116) 20.4 percent belong to 21-30 years, (268) 47.70 percent belong to 31-40 years, (136) 23.80 percent belong to 41-50 years, and (50) 8.80 percent belong to > 50 years. Majority of the respondents (71 percent) fall within the agelimit of 31 to 50 years.

In ***Pratapgarh*** district, there were no respondents under the <20 years. From the remaining respondents, (32) 24.6 percentbelong to the 21-30 years, (60) 46.2 percent belong to the 31-40 years, (23) 17.7 percent belong to the 41-50 years, and (15) 11.5 percent belong to the > 50 years. In ***Barmer*** district, there were no respondents under <20 years. Of the remaining, (18) 18 percent belong to 21-30 years, (50) 50 percent belong to 31-40 years, (27) 27 percent belongs to 41-50 years, and (5) 5 percent belonged to > 50 years. In ***Baran*** district, there was no respondent under <20 years. Of the remaining respondents, (22) 21 percent belong to 21-30 years, (64) 64.8 percent belong to 31-40 years, (12) 11.4 percent belong to 41-50 years, and (3) 2.8 percent belonged to > 50 years. In ***Kota*** district, there was no respondent under <20 years. From the remaining respondents, (44) 18.7 percent belong to 21-30 years, (90) 38.3 percent belong to 31-40 years, (74) 31.5 percent belong to 41-50 years, and (27) 11.5 percent belongs to > 50 years.

6.2.1.3 Education levels of respondents

The overall distribution of education levels of the total number of respondents studied in the research with district-wise bifurcation is shown in the table 6.5.

Table 6.5: Education level wise distribution of respondents

Education	**Overall**		**Pratapgarh**		**Barmer**		**Baran**		**Kota**	
	Number	***%***	***Number***	***%***	***Number***	***%***	***Number***	***%***	***Number***	***%***
Never attended school	313	54.4	87	66.9	62	62.0	54	51.4	110	46.8
Attended primary school	181	31.8	23	17.7	28	28.0	33	31.4	97	41.3
Attended junior middle school	53	9.3	12	9.2	4	4.0	12	11.4	25	10.6
Attended senior middle school	20	3.5	8	6.2	5	5.0	4	3.8	3	1.3
College level or above	3	0.5	NA	NA	1	1.0	2	1.9	NA	NA
Total	570	100.0	130	100.0	100	100.0	105	100.0	235	100.0

The above table explains education level-wise distribution of respondents. Of the 570 respondents, (313) 54.40 percent never attended school, (181) 31.8 percent attended primary school, (53) 9.3 percent attended junior middle school, (20) 3.5 percent attended senior middle school and (3) 0.5 percent respondents were from college level or above. Hence, the majority of the respondents (85 percent) were educationally very backward; almost half of them having never gone to school. This distribution is also evident in the district-wise analysis.

In ***Pratapgarh*** district, (87) 66.90 percent respondents never attended school, (23) 17.7 percent attended primary school, (12) 9.2 percent attended junior middle school, (8) 6 percent attended senior middle school, while there were no respondents belonging to college level or above. In ***Barmer*** district, (62) 62 percent respondents never attended school, (28) 28 percent attended primary school, (4) 4.02 percent attended junior middle school, (5) 5 percent attended senior middle school while only (1) 1 percent belong to college level or above. In ***Baran*** district, (54) 51.4 percent respondents never attended school, (33) 31.4 percent attended primary school, (12) 11.4 percent attended junior middle school, (4) 3.8 percent attended senior middle school with (2) 1.9 percent respondents belonging to the college level or above. In ***Kota*** district, (110) 46.8 percent respondents never attended school, (97) 41.3 percent attended primary school, (25) 10.6 percent attended junior middle school, (3) 1.3 percent attended senior middle school, and there was no respondent from college level or above.

6.2.1.4 Occupation of respondents

Overall occupation-wise distribution is shown for the total number of respondents surveyed in this research with district-wise bifurcation being shown in Table 6.6.

Table 6.6: Occupation-wise distribution of respondents

Occupation	Overall		Pratapgarh		Barmer		Baran		Kota	
	Number	***%***	***Number***	***%***	***Number***	***%***	***Number***	***%***	***Number***	***%***
Casual Labour	226	39.6	43	33.1	37	37.0	51	48.6	95	40.4
Farmer	143	25.1	62	47.7	15	15.0	20	19.0	46	19.6
Teacher	4	0.7	NA	NA	NA	NA	3	2.9	1	0.4

Business person	100	17.5	14	10.8	10	10.0	9	8.6	67	28.5
Other	97	17.1	11	8.5	38	38.0	22	21.0	26	11.1
Total	570	100.0	130	100.0	100	100.0	105	100.0	235	100.0

The table explains occupation-wise distribution of respondents interviewed in the study. Of the 570 respondents, in all (226) 39.6 percent respondents were casual labour, (143) 25.1 percent were farmer, (4) 0.7 percent were teachers, (100) 17.5 percent were business persons while the remaining (97) 17.1 percent respondents do someother activity for a livelihood. The majority (39.6 percent) of the total respondents were engaged in casual labour due to unavailability of farming land and local employment opportunities. Around 25 percent respondents are engaged in farming; almost half of them belong to Pratapgarh district, due to non-availability of agricultural land, being forest area or uneven topography.

In ***Pratapgarh*** district, (43) 33.10 percent respondents are casual labor, (62) 47.7 percent are farmer, there being no teacher in this district, (14) 10.8 percent respondents do business while (11) 8.5 percent respondents are engaged in some other activity. In ***Barmer*** district, (37) 37.00 percent respondents are casual labor, (15) 15.00 percent respondents area farmer, there was no teacher in the district, (10) 10 percent were business persons while (38) 38 percent being engaged in some other activity. In ***Baran*** district, (51) 48.6 percent respondents are casual labor, (20) 19 percent respondents are farmers, (3) 2.9 percent respondents were teachers, (9) 8.6 percent were business persons and (22) 21 percent were engaged in some other activity. In ***Kota*** district, (95) 40.4 percent respondents were casual labor, (46) 19.6 percent were farmers, (1) 0.4 percent were teachers, (67) 28.5 percent were business person while (26) 11.1 percent were engaged in some other activity.

6.2.1.5 Monthly income of household

The overall monthly income-wise distribution for the total number of respondents interviewed in the study along with the district-wise bifurcation is shown in table 6.7.

Table 6.7: Monthly income-wise distribution of respondents

Monthly Income	Overall		Pratapgarh		Barmer		Baran		Kota	
	Number	*%*	*Number*	*%*	*Number*	*%*	*Number*	*%*	*Number*	*%*
<4000 Rs	63	11.10	15	11.5	2	2.0	2	1.9	44	18.7
4001-6000 Rs	68	11.90	19	14.6	3	3.0	3	2.9	43	18.3
6001-8000 Rs	86	15.10	25	19.2	2	2.0	11	10.5	48	20.4
8001-10,000 Rs	155	27.20	32	24.6	33	33.0	38	36.2	52	22.2
>10,000 Rs	198	34.70	39	30.0	60	60.0	51	48.6	48	20.4
Total	570	100.0	130	100.0	100	100.0	105	100.0	235	100.0

The table explains monthly income-wise distribution of respondents interviewed in this study. Of 570 respondents, (63) 11.1 percent respondents have monthly income less than Rs. 4000, (68) 11.9 percent have income between Rs. 4001-6000, (86) 15.12 percent have income between Rs. 6001-8000, (155) 27.2 percent have income between Rs. 8001-10,000 and (198) 34.70 percent have income above Rs. 10,000. More than 60 per cent respondents have monthly income above Rs. 8000, due to their engagement in either casual labor or business activity.

In ***Pratapgarh*** district, (15) 11.5 percent respondents have monthly income less than Rs. 4000, (19) 14.6 percent have income between Rs. 4001-6000, (25) 19.20 percent have income between Rs. 6001-8000, (32) 24.6 percent have income between Rs. 8001-10,000 and (39) 30 percent have income above Rs. 10,000. In ***Barmer*** district, (2) 2 percent respondents have monthly income less than Rs. 4000, (3) 3 percent have income between Rs. 4001-6000, (2) 2 percent have income between Rs. 6001-8000, (33) 33 percent have income between Rs. 8001-10,000 and (60) 60 percent have income above Rs. 10,000. In ***Baran*** district, (2) 1.9 percent respondents have monthly income less than Rs. 4000, (3) 2.9 percent have income between Rs. 4001-6000, (11) 10.5 percent have income between Rs. 6001-8000, (38) 36.2 percent have income between Rs. 8001-10,000 and (51) 48.6 percent have income above Rs. 10,000. In ***Kota*** district, (44) 18.7 percent respondents have monthly income less than Rs. 4000, (43) 18.3 percent have income between Rs. 4001-6000, (48) 20.4 percent have income between Rs. 8001-10,000, (52) 22.2 percent have income between Rs. 8001-10,000 and (48) 20.4 percent have income more than Rs. 10,000.

6.2.1.6 Household size

The overall household size-wise distribution for the total number of respondents surveyed in the research with category-wise bifurcation is shown in Table 6.8.

Table 6.8: Household size-wise distribution of respondents

Frequency	**Household Size**		**Male**		**Female**		**Children**	
	Number	***%***	***Number***	***%***	***Number***	***%***	***Number***	***%***
0	NA	NA	29	5.1	6	1.1	85	14.9
1	15	2.7	273	47.9	296	51.9	115	20.2
2	44	7.7	207	36.3	209	36.7	158	27.7
3	62	10.9	52	9.1	54	9.5	102	17.9
4	97	17.0	5	0.9	4	0.7	53	9.3
5	108	18.9	3	0.5	1	0.2	36	6.3
6	91	16.0	1	0.2	NA	NA	18	3.2
7	64	11.2	NA	NA	NA	NA	2	0.4
8	29	5.1	NA	NA	NA	NA	1	0.2
9	32	5.6	NA	NA	NA	NA	NA	NA
10	11	1.9	NA	NA	NA	NA	NA	NA
11	4	0.7	NA	NA	NA	NA	NA	NA
12	13	2.3	NA	NA	NA	NA	NA	NA
Total	570	100.0	570	100.0	570	100.0	570	100.0

The table explains the household size-wise distribution of respondents interviewed in the study**.** It is evident that, out of the total respondents, almost 52 per cent of the households have 4 to 6 family members including children. Thisexplains that majority of the households are relatively smaller in size. Out of the total households, 93 percent and 98 percent households have not more than three male and female members respectively. The distribution shows that the male member is the sole bread earner and with the availability of electricity females can also contribute in income generation. There are not more than 15 per cent of the households having more than eight members in a family. 21 per cent households have less than four family members.

6.2.2 Information on household electricity

The respondents were asked about the source of electricity including possibility of being connected to the conventional grid if they are getting electricity through Solar PV system.

Table 6.9: Source of electricity

S. No.	Source	Number	Percent
1	Conventional Grid	4	0.7
2	Solar PV	566	99.3
	Total	570	100.0

Table 6.9 depicts the responses of respondents surveyed for the source of electricity. Although all 570 houses are connected through solar PV system, some houses (4) have got conventional grid connection in the Meghwalon ki Dhani village of Barmer. Government has extended conventional grid electricity in the village recently, but solar being cheaper, they prefer solar electricity. Thus, in Meghwalon ki Dhani village despite availability of central grid power, they are using only solar PV system.

Asked about possibility of being connected to the conventional grid shortly, most villagers (563) responded negatively. Those who have conventional grid connection also feel that solar PV electricity is cheaper than a utility grid. Hence, they prefer using the solar electricity rather than grid-based electricity. The respondents who have shown interest in conventional source of electricity are those who could afford grid-based electricity and require a heavy load to run certain machines, but they are a minuscule proportion in the study.

6.2.3 Consumption pattern of energy

The respondents were interviewed regarding their monthly electricity and fuel consumption pattern. They revealed that before solar electrification there was no source of electricity in any of the villages and they were dependent on kerosene and firewood for illumination. Post solar electrification, households opting for solar electricity were charged on a monthly basis ranging from Rs. 100 to Rs.150 in different villages for the maintenance of the solar plant. The minimum monthly contribution was fixed at Rs. 100 and depending upon their requirement, they were directed to recharge the meter. Hence, solar electricity distribution was on pre-paid basis with minimum recharge of Rs. 100 per household. Based on the survey it was found that out of 570 households, 342 paid a minimum of Rs. 100 per month for electricity and 228 households paid Rs. 150 per month based on their consumption requirements and paying capacity.

Further, a comparison was drawn between monthly consumption expenditure of the households on other sources of energy like kerosene, firewood, and LPG, before and after solar electrification.

Table 6.10: Monthly fuel consumption expenditure of households

Category	**Before electrification**		**After electrification**	
	Frequency	***Percentage***	***Frequency***	***Percentage***
Low consumption expenditure (Less than Rs. 100)	30	5.3	235	41.2
Average consumption expenditure (Rs. 100 to Rs. 300)	314	55.1	165	29
High consumption expenditure (More than Rs. 300)	226	39.6	170	29.8
Total	570	100.0	570	100.0

The table 6.10 compares monthly fuel consumption expenditure of households after availability of solar electricity. Here, monthly fuel consumption expenditure comprises expenditure on kerosene, firewood, and LPG. For analysis, the responses of respondents about monthly fuel consumption have been put into three categories, with low, average and high consumption. Expenditure less than Rs. 100, between Rs. 100 and Rs. 300, and more than Rs. 300 is categorized as low, average and high monthly consumption respectively.

Prior to solar electrification, (30) 5.3 percent of respondents revealed that their monthly fuel expenditure was less than Rs. 100, (314) 55.1 percent were spending between Rs. 100 to Rs. 300 monthly on fuel consumption, with remaining (226) 39.6 percent spending more than Rs. 300 on monthly fuel consumption. After solar electrification, (235) 41.2 percent of the total respondents revealed that their monthly fuel expenditure is less than Rs. 100, (165) 29 percent respondents were spending between Rs. 100 to Rs. 300 monthly on fuel consumption, while remaining (170) 29.8 percent respondents were spending more than Rs. 300 on monthly fuel consumption.

The change in the monthly fuel consumption expenditure of households after solar electrification reveals that there has been a drastic decline in average spending on fuel consumption, as evident from increasing number of respondents falling into low consumption expenditure category with consequent decline in high and average consumption category. The most important reason behind this shift is a decline in consumption of kerosene and firewood for lighting purpose. Also, with the introduction of Pradhan Mantri Ujjwala Yojana, there has been an increase in LPG connections among households, due to which there is no drastic decline in high consumption category. Overall monthly expenditure on fuel has reduced post solar electrification, and this will contribute towards increase in savings for households.

6.3 SECTION II: HOUSEHOLD ATTITUDE

The second section deals with the 'Household Attitude,' which reflects the views of households on various energy options before and after solar electrification. This section consists of views on energy options, benefits of solar electricity, and uses of solar light. In this section, the questions are either frequency based or on the five-point Likert scale. For the statistical analysis, we have used Wilcoxon signed-rank test, which is used to determine whether the median difference between the two related groups (i.e., the two conditions – pre and post solar electrification) is statistically significant. It is a nonparametric test equivalent to the paired-samples t-test. In our study, the respondents are the same individuals tested under two different conditions on the same dependent variable.

6.3.1 Views of respondents on energy options

The respondents were asked about their views on usage of kerosene and firewood for lighting purpose before the introduction of solar electricity and similar questions on usage of electricity derived from solar energy post electrification. They were asked to give their views on availability, reliability, lower cost, easier maintenance, good for health and good for the safety of traditional fuels before electrification as well as on solar electricity post electrification. The responses to all the factors have been shown below in the table 6.11.

Table 6.11: Views on energy for lighting from kerosene and firewood

	Good Availability		**Good Reliability**		**Lower Cost**		**Easier Maintenance**		**Good for Health**		**Good for Safety**	
	Resp.	***%***	***Resp.***	***%***	***Resp.***	***%***	***Resp.***	***%***	***Resp.***	***%***	***Resp.***	***%***
Strongly Disagree	40	7.0	35	6.1	144	25.3	72	12.6	310	54.4	366	64.2
Disagree	156	27.4	129	22.6	264	46.3	154	27.0	186	32.6	119	20.9

Undecided	108	18.9	73	12.8	53	9.3	91	16.0	21	3.7	37	6.5
Agree	250	43.9	282	49.6	60	10.5	176	30.9	27	4.7	28	4.9
Strongly Agree	16	2.8	51	8.9	49	8.6	77	13.5	26	4.6	20	3.5
Total	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0

The table explains the views of respondents on energy from kerosene and firewood for lighting purpose. The survey indicates that majority respondents (43.9 percent) feel that kerosene and firewood have good availability, and regarding reliability, 49.6 percent respondents found it to be a reliable source of energy. Almost 71 percent respondents feel that the cost of kerosene especially is high. The main reason is black marketing of kerosene which raises the price per litre. The monthly quota does not meet the requirement of kerosene decided for the below poverty line (BPL) households; hence, they need to purchase it at a higher price to meet their demand. Regarding maintenance, the response was mixed, with 27 percent disagreeing and 31percent accepting that its maintenance is easier. Majority respondents (87 percent) feel that kerosene and firewood are not good for health. The response was the same for safety with almost 85 percent respondents admitting that the use of kerosene and firewood is not safe.

Table 6.12: Views on electricity generated from solar energy

	Good Availability		**Good Reliability**		**Lower Cost**		**Easier Maintenance**		**Good for Health**		**Good for Safety**	
	Resp.	*%*	***Resp.***	*%*	***Resp.***	*%*	***Resp.***	*%*	***Resp.***	*%*	***Resp.***	*%*
Strongly Disagree	29	5.1	17	3.0	20	3.5	24	4.2	12	2.1	19	3.3
Disagree	20	3.5	25	4.4	20	3.5	36	6.3	13	2.3	20	3.5
Undecided	25	4.4	37	6.5	33	5.8	125	21.9	22	3.9	37	6.5
Agree	415	72.8	390	68.4	271	47.5	239	41.9	140	24.5	92	16.1
Strongly Agree	81	14.2	101	17.7	226	39.6	146	25.6	383	67.2	402	70.5
Total	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0

The table depicts the views of respondents on electricity generated from solar energy and indicates that majority respondents (87 percent) find that electricity from solar energy has good availability and reliability too with 86 percent finding it to be a very reliable source of energy. Out of the total respondents, 87 percent feel that cost of electricity generated from solar energy for households is low. As for maintenance, the majority respondents (67 percent) accepted that its maintenance is easier. Most of respondents (91 percent) feel solar based electricity is good for health and regarding safety; the response was the same with almost 86 percent respondents admitting that the use of solar electricity is safe.

For statistical analysis, views of respondents were summed up to get an overall score views on energy options before and after electrification. The hypothesis that there is a significant difference between household views on energy generated from kerosene/firewood before solar electrification and on solar generated electricity after solar electrification is tested using Wilcoxon signed-rank test. The summary of the test as calculated by SPSS is produced in the tables below.

H_0: The median difference between the overall scores of views on energy before electrification and after electrification is equal to zero.

H_A: The median difference between the overall scores of views on energy before electrification and after electrification is not equal to zero.

Table 6.13:Ranks of respondents about views on energy options

		N	*Mean Rank*	*Sum of Ranks*
Overall scores for views on energy options after electrification - overall scores for views on energy options before electrification	Negative Ranks	3[a]	20.33	61.00
	Positive Ranks	565[b]	285.90	161535.00
	Ties	2[c]		
	Total	570		

a. Overall Scores for Views on Energy Options after Electrification < Overall Scores for Views on Energy Options before Electrification

b. Overall Scores for Views on Energy Options after Electrification > Overall Scores for Views on Energy Options before Electrification

c. Overall Scores for Views on Energy Options after Electrification = Overall Scores for Views on Energy Options before Electrification

Table 6.14: Test statistics[a] of views on energy options

	Overall scores for views on energy options after electrification - overall scores for views on energy options before electrification
Z	-20.645[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Table 6.15: Report on median of views on energy options

Overall scores for views on energy options before electrification	Overall scores for views on energy options after electrification	Difference in overall scores for views on energy options before and after electrification
15.00	26.00	10.00

The table 6.13 shows the ranks of 570 respondents about their views on energy options from fuels like kerosene and firewood before solar electrification and from solar energy after solar electrification. Of 570 respondents, 565 respondents elicited an improvement in their views on electricity generated from solar energy after solar electrification, whereas two respondents saw no improvement and three respondents felt otherwise. The difference scores were symmetrically distributed, as assessed by a histogram. A Wilcoxon signed-rank test determined that there was a statistically significant median increase in views on energy options (Mdn = 10 points) derived from solar energy when subjects imbibed the solar electricity (Mdn = 26 points) compared to energy options derived from traditional fuels like kerosene/firewood before electrification (Mdn = 15 points), z = -20.645, p <0.0005. Hence, we accept the alternate hypothesis. Therefore, it can be concluded that overall the respondents strongly support view that electricity generated from solar energy is better compared to traditional fuels on parameters like availability, reliability, cost, maintenance, health, and safety.

6.3.2 Benefits of solar electricity

The respondents were asked about the availability of facilities like entertainment (watching TV, social gatherings, etc.), information and education, and women upliftment prior to solar electrification and after solar electrification. For the statistical analysis, the views of respondents were summed up to get overall view on the availability of facility before and after electrification. The hypothesis that there is a significant difference between household views on facilities available before and after solar electrification in the form of benefits of solar electricity is tested using Wilcoxon signed-rank test. The summary of the test as calculated by SPSS is produced in the tables below.

H_0: The median difference between the overall scores of views on facilities available before electrification and after electrification is equal to zero.

H_A: The median difference between the overall scores of views on facilities available before electrification and after electrification is not equal to zero.

Table 6.16: Ranks of respondents about views on benefits of solar electricity

		N	*Mean Rank*	*Sum of Ranks*
Overall scores for views on facilities available after electrification - overall scores for views on facilities available before electrification	Negative Ranks	0[a]	.00	.00
	Positive Ranks	562[b]	281.50	158203.00
	Ties	8[c]		
	Total	570		

a. Overall Scores for Views on Facilities Available after Electrification < Overall Scores for Views on Facilities Available before Electrification

b. Overall Scores for Views on Facilities Available after Electrification > Overall Scores for Views on Facilities Available before Electrification

c. Overall Scores for Views on Facilities Available after Electrification = Overall Scores for Views on Facilities Available before Electrification

Table 6.17: Test statistics[a] of benefits of solar electricity

	Overall scores for views on facilities available after electrification - overall scores for views on facilities available before electrification
Z	-20.632[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Table 6.18: Report of median on benefits of solar electricity

Overall scores for views on facilities available before electrification	Overall scores for views on facilities available after electrification	Difference in overall scores for views on facilities available before and after electrification
4.00	12.00	8.00

The table 6.16 shows the ranks of 570 respondents about their views on facilities available before solar electrification and after solar electrification. Of the 570 respondents, 562 elicited an improvement in their views on facilities available after solar electrification, whereas eight respondents saw no improvement. The difference scores were symmetrically distributed, as assessed by a histogram. A Wilcoxon signed-rank test determined that there was a statistically significant median increase in views on facilities available (Mdn = 8 points) when subjects imbibed the solar electricity (Mdn = 12 points) compared to the facilities available from traditional fuels before electrification (Mdn = 4 points), $z = -20.632$, $p <0.0005$.Hence, we accept the alternate hypothesis. Therefore, it can be concluded that overall the respondents strongly support the view that facilities like entertainment, information and education and upliftment of women have improved after getting electricity generated from solar energy, thus explaining benefits of solar electricity.

6.3.3 Uses of solar light

6.3.3.1 Hours devoted to activities by households

The respondents were asked about the purpose for which solar electricity is used. The activities for which their responses were sought are household work, studies of children, agriculture, business, and other work. They were also asked about the number of hours devoted to these activities per day before solar electrification and after solar electrification. For better analysis, responses were categorized into five categories, i.e., no response or zero hours, 1-3 hours, 4-6 hours, 7-9 hours, and more than 9 hours for all activities. The tables below explain the number of hours devoted to these activities per day before and after solar electrification.

Table 6.19: Number of hours devoted to activities before solar electrification

Category (No. of Hours)	**Household Work**		**Studies**		**Agriculture**		**Business**		**Others**	
	Freq.	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***
N.R. (Zero)	-	-	91	16.0	379	66.5	468	82.1	387	67.9
1–3 hrs.	6	1.1	470	82.4	15	2.6	-	-	69	12.3
4-6 hrs.	100	17.6	9	1.6	156	27.4	74	13.0	97	17.1
7-9 hrs.	244	42.8	-	-	20	3.5	28	4.9	17	3
More than 9 hrs.	220	38.5	-	-	-	-	-	-	-	-
Total	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0

Table 6.20: Number of hours devoted to activities after solar electrification

Category (No. of Hours)	**Household Work**		**Studies**		**Agriculture**		**Business**		**Others**	
	Freq.	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***
N.R. (Zero)	-	-	87	15.3	375	65.8	456	80.0	252	44.2
1 – 3 hrs.	18	3.2	233	41.0	7	1.2	-	-	104	18.2
4-6 hrs.	510	89.4	250	43.7	45	7.9	32	5.7	119	20.9
7-9 hrs.	42	7.4	-	-	136	23.8	82	15.3	95	16.7
More than 9 hrs.	-	-	-	-	-	-	-	-	-	-
Total	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0

The table 6.20 explains responses on hours devoted to activities per day before and after solar electrification. The survey indicates that, before solar electrificationmajority respondents (81 percent) revealed females spent more than 7 hours on household work, while 82 percent said children devote 1 to 3 hours per day for studies which are only in day time, 66.5 percent respondents are not involved in agriculture and out of the remaining ones only 27.4 percentare spending 4 to 6 hours, majority respondents (82.1 percent) are not involved in any business and 18 percent of the total respondents involved in business, spend 4 to 9 hours, while only 30 percent of the total spend 1 to 6 hours in other activities. The common element in all the activities is that the respondents are only utilizing day time for the above activities mentioned and females can't contribute in any income generating activity being engaged in household work for the entire day. Children are also being affected due to lack of lighting in the night and can't study for long hours as their morning hours go in school.

After solar electrification, out of the total respondents 92.6 percent respondents revealed that females are now spending 7 hours per day on household activities, 41 percent and 43.7 percentrespondents said children spend 1 to 3 hours and 4 to 6 hours respectively on studies, 24 percent respondents said they are now spending 7 to 9 hours on agriculture, 21 percent respondents are spending 4 to 9 hours on business activities, and 37 percent of the total respondents said that they are now spending 4 to 9 hours on other activities. Post solar electrification there has been a visible reduction in household work for females in the daytime as in the night also they can do some of their work. Children are also able to study in the night for more hours. Due to the availability of light in the night, some farmers could extend their farming hours as they can do other work in the night also. Business as an activity has shown an increase in hours devoted to it due to availability of light and small shopkeepers can open their shops for some more hours in the late evenings. This has contributed to an increase in hours devoted to other activities, as there is availability of more time with no compulsion to finish all the work in day time.

For statistical analysis, numbers of hours spent by respondents were summed up to get an overall score of hours devoted to various activities before and after electrification. The hypothesis that there is a significant difference in the number of hours devoted to various activities before and after solar electrification is tested using Wilcoxon signed-rank test. Summary of the test as calculated by SPSS is produced in the tables below.

H_0: The median difference between the overall scores of a number of hours devoted to various activities before electrification and after electrification is equal to zero.

H_A: The median difference between the overall scores of a number of hours devoted to various activities before electrification and after electrification is not equal to zero.

Table 6.21: Ranks of respondents about hours devoted to activities

		N	*Mean Rank*	*Sum of Ranks*
Overall scores for number of hours devoted to activities after electrification - overall scores for number of hours devoted to activities before electrification	Negative Ranks	98[a]	181.36	17773.00
	Positive Ranks	382[b]	255.67	97667.00
	Ties	90[c]		
	Total	570		

a. Overall Scores for Number of Hours devoted to Activities after Electrification < Overall Scores for Number of Hours devoted to Activities before Electrification

b. Overall Scores for Number of Hours devoted to Activities after Electrification > Overall Scores for Number of Hours devoted to Activities before Electrification

c. Overall Scores for Number of Hours devoted to Activities after Electrification = Overall Scores for Number of Hours devoted to Activities before Electrification

Table 6.22: Test statistics[a] of hours devoted to activities

	Overall scores for number of hours devoted to activities after electrification - overall scores for number of hours devoted to activities before electrification
Z	-13.248[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Table 6.23: Report on median of hours devoted to activities

Overall scores for number of hours devoted to activities before electrification	Overall scores for number of hours devoted to activities after electrification	Difference in overall scores for number of hours devoted to activities before and after electrification
14.00	15.00	1.00

The table 6.21 shows ranks of 570 respondents about number of hours devoted to activities before solar electrification and after solar electrification. Of the 570 respondents, 382 respondents elicited an improvement in the number of hours devoted to various activities after solar electrification, whereas 90 respondents saw no improvement and 98 felt otherwise. Different scores were symmetrically distributed, as assessed by a histogram. A Wilcoxon signed-rank test determined that there was statistically significant median increase in the number of hours devoted to various activities (Mdn = 1 point) when subjects imbibed the solar electricity (Mdn = 15 points) compared to the number of hours devoted to various activities before electrification (Mdn = 14 points), z = -13.248, $p <0.0005$.Hence, we accept the alternate hypothesis. Therefore, it can be concluded that overall the respondents strongly support the view that they can devote more time to activities like studies, agriculture, business and other activities after getting electricity generated from solar energy. Consequential decline in time spent on household work by females, has helped them to devote their time to other activities.

6.3.3.2 Brightness of fuel

The respondents were asked about brightness of fuel used by them like kerosene or candle in the night before solar electrification and brightness of solar light after electrification. The hypothesis that there is a significant difference in the satisfaction of respondents on the brightness of fuel before and after solar electrification is tested using Sign test due to asymmetry in the difference score. The summary of the test calculated by SPSS is produced in the tables below.

H_0: The median difference between the satisfaction of respondents on the brightness of fuel before electrification and after electrification is equal to zero.

H_A: The median difference between the satisfaction of respondents on the brightness of fuel before electrification and after electrification is not equal to zero.

Table 6.24: Frequencies of respondents about satisfaction on brightness of fuel

		N
Satisfied with the brightness of solar after solar electrification - satisfied with the brightness of fuel other than solar before electrification	Negative Differences[a]	0
	Positive Differences[b]	528
	Ties[c]	42
	Total	570

a. Satisfied with the Brightness of Solar After Solar Electrification < Satisfied with the Brightness of Fuel Other than Solar Before Electrification

b. Satisfied with the Brightness of Solar After Solar Electrification > Satisfied with the Brightness of Fuel Other than Solar Before Electrification

c. Satisfied with the Brightness of Solar After Solar Electrification = Satisfied with the Brightness of Fuel Other than Solar Before Electrification

Table 6.25: Test statistics[a] of satisfaction on brightness of fuel

	Satisfied with the brightness of solar after solar electrification - satisfied with the brightness of fuel other than solar before electrification
Z	-22.935
Asymp. Sig. (2-tailed)	.000

a. Sign Test

Table 6.26: Median report of satisfaction on brightness of fuel

Satisfied with the brightness of fuel other than solar before electrification	Satisfied with the brightness of solar after solar electrification	Difference in satisfaction on brightness of fuel and solar electricity before and after electrification
1.00	5.00	4.00

The table 6.26 shows ranks of 570 respondents about their satisfaction on brightness of fuel before solar electrification and after solar electrification. Of 570 respondents, 528 respondents elicited an improvement in the satisfaction on the brightness of fuel after solar electrification, whereas 42 respondents saw no improvement. The difference scores were not symmetrically distributed, as assessed by a histogram. A Sign test determined that there was a statistically significant median increase in the satisfaction on brightness of fuel (Mdn = 4 points) when subjects imbibed the solar electricity (Mdn = 5 points) compared to the satisfaction on brightness of fuel before electrification (Mdn = 1 point), z = -22.935, p <0.0005.Hence, we accept the alternate hypothesis. It can be concluded therefore, that satisfaction of respondents on the brightness of fuel after getting electricity generated from solar energy is far better as compared to the brightness from traditional fuels like kerosene or candle.

Chapter 6B

SOCIO-ECONOMIC IMPACT OF EXISTING DECENTRALIZED SOLAR BASED PROJECTS IN RAJASTHAN: SAMPLE SURVEY-II

CHAPTER 6B

SOCIO-ECONOMIC IMPACT OF EXISTING DECENTRALIZED SOLAR BASED PROJECTS IN RAJASTHAN: SAMPLE SURVEY- II

6 .4 SECTION III: SOCIO-ECONOMIC ASSESSMENT OF HOUSEHOLDS

The third section compares four important factors of this study before and after solar electrification, and mainly focuses on ‘socio-economic assessment’ of the households. These four factors are the impact on livelihood and income, upliftment of women, health and education. In this section, the questions are either frequency based or on the five-pointLikert scale. For statistical analysis, two parametric tests, paired-samples t-test and two-way ANOVA is used. The paired-samples t-testis used to determine whether the mean difference between paired observations (i.e., the two conditions – pre and post solar electrification) is statistically significantly different from zero. Two-way ANOVA is used to establish if there is two-way interaction effect between two independent variables in the post-electrification data. In the study, respondents are the same individuals tested under two different conditions on the same dependent variable.

6.4.1 IMPACT ON LIVELIHOOD AND INCOME

Income generating opportunities for rural households are relatively bleak on account of various factors. For households which were un-electrified since independence, solar electrification is expected to carry some external benefits as it can help in creating new sources of income for the households. Electricity is an important infrastructure facilitating the adoption of broader range of income-generating activities as well as better operation of the old ones. In order to measure impact of solar powered electricity on livelihood and income through this survey, the researcher asked respondents of their views on hours devoted to livelihood activities, average monthly income earned from these activities, monthly expenditure on kerosene or candle for Lighting, and number of family members involved in income generating before and after solar electrification. For statistical analysis, paired-samples t-test and two-way ANOVA was applied apart from tabulation and graphical representation.

6.4.1.1 Hours devoted to livelihood activities in the evening

The researcher asked respondents about use of solar light for livelihood activities and number of hours devoted per day in the evening before and after solar electrification. Activities for which their responses were sought are agriculture, grocery shop, a vegetablevendor,weaving and tailoring, and other work. The objective was to assess whether solar electrification has an impact on increase in time devoted to such activities in late evening hours. Tables below explain the number of hours devoted to livelihood activities per day before and after solar electrification.

Table 6.27: Hours devoted to livelihood activities in the evening before solar electrification

Category (No. of Hours)	Agriculture		Grocery Shop		Vegetable Vendor		Weaving and Tailoring		Others	
	Freq.	*%*	*Freq.*	*%*	*Freq.*	*%*	*Freq.*	*%*	*Freq.*	*%*
Zero	166	29.1	432	75.8	531	93.2	519	91.1	390	68.4
0–2 hrs.	171	30.0	28	4.9	-	-	33	5.8	130	22.8
2-4 hrs.	233	40.9	110	19.3	39	6.8	10	1.8	29	5.1
4-5hrs.	-	-	-	-	-	-	8	1.4	21	3.7
5-6 hrs.	-	-	-	-	-	-	-	-	-	-
Total	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0

Table 6.28: Hours devoted to livelihood Activities in the evening after solar electrification

Category (No. of Hours)	Agriculture		Grocery Shop		Vegetable Vendor		Weaving and Tailoring		Others	
	Freq.	*%*	*Freq.*	*%*	*Freq.*	*%*	*Freq.*	*%*	*Freq.*	*%*
Zero.	164	28.8	420	73.7	518	90.9	487	85.4	278	48.8
0–2 hrs.	159	27.9	-	-	-	-	33	5.8	94	16.5
2-4 hrs.	247	43.3	29	5.1	5	0.9	19	3.3	119	20.9
4-5hrs.	-	-	103	18.1	19	3.3	22	3.9	53	9.3
5-6 hrs.	-	-	18	3.2	28	4.9	9	1.6	26	4.6
Total	570	100.0	570	100.0	570	100.0	570	100.0	570	100.0

The above tables 6.27 and 6.28, explains responses on hours devoted to livelihood activities per day in the evening before and after solar electrification. The survey indicates that prior to solar electrification most respondents (404) stated that members of the household were spending maximum time on agriculture for livelihood. Of the 570 respondents, 138, 39, 51, and 180 said that their household members devote time to grocery shop, vegetable vending, weaving, and tailoring, and other work like carpentry, handicrafts, and some masonry work respectively in the evening. In thecase of agriculture, out of 570 these respondents, there was no response from 29.1 per cent, while 30 per cent and 40.9 per cent said they spent 0-2 hours and 2-4 hours on agriculture in the evening respectively. In the case of grocery shop, of these 570 respondents, there was no response from 75.8 per cent while , 4.9 per cent and 19.3 per cent said they spent 0-2 hours and 2-4 hours on grocery shop in the evening respectively. In case of vegetable vendors, of these 570 respondents, there was no response from 93.2 per cent, while 6.8 per cent said they spent 2-4 hours on vegetable vending in the evening. In case of weaving & tailoring, of these 570 respondents, there was no response from 91.1 per cent respondents, 5.8 per cent and 3.2 per cent said they spent 0-2 hours and 2-5 hours on weaving & tailoring respectively in the evening. Concerning other work, out of 570 respondents, there was no response from 68.4 per cent while, 22.8 per cent and 8.8 per cent said they could spend 0-2 and 2-5 hours on other work in the evening respectively. Due to non-availability of electricity in the evening, the male and female household members could not devote much time to livelihood activities in the evening as they needed finishing their household and external work like collection of wood, kerosene, etc. for Lighting and cooking purpose daily in the day time.

After solar electrification, majority respondents (406) revealed that members of the household were spending maximum time on agriculture for livelihood. Of these 570 respondents, 150, 52, 83, and 292 respondents said that household members devote time to grocery shop, vegetable vending, weaving, tailoring, and other works like carpentry, handicrafts, and masonry during evening respectively. In the case of agriculture, there was no response from 28.8 per cent while, 27.9 per cent and 43.3 per cent said they spent 2-4 hours , 4-5 hours on agriculture in the evening respectively from the 570 respondents. In the case of agrocery shop, out of 570 respondents, there was no response from 73.7 per cent respondents, 5.1 per cent, 18.1 per cent and 3.2 per cent said they could spend 0-2 hours, 2-4 hours and 4-5 hours on grocery shop in the evening respectively. In thecase of avegetable vendor, out of 570 respondents, there was no response from 90.9 per cent respondents, 4.2 per cent and 4.9

per cent said they could spend 2-5 hours and 5-6 hours on vegetable vending in the evening respectively. In case of weaving & tailoring, out of 570 respondents, there was no response from 85.4 per cent respondents, 5.8 per cent, 7.2 per cent and 1.6 per cent said they could spend 0-2 hours, 2-5 hours and 5-6 hours on weaving & tailoring in the evening respectively. As for other work, out of 570 respondents, there was no response from 48.8 per cent respondents, 16.5 per cent, 21.2 per cent and 4.6 per cent said they could spend 0-2 hours, 2-5 hours and 5-6 hours on other work in the evening respectively. The better quality and consistent availability of light were found to enable households to extend their activities by a few hours after sunset. A natural change observed in their lifestyle was that many households chose to do indoor household work such as washing, cooking, and cleaning in the evenings and occupying themselves with productive work during the daytime.

6.4.1.2 Average monthly income earned

The respondents were asked about the average monthly income of households earned from the above-mentioned livelihood activities before and after solar electrification. The average monthly income was divided into five categories. The table below explains the changes in the average monthly income after the introduction of solar electrification in the villages under the study.

Table 6.29: Average monthly income earned from livelihood activities before and after solar electrification

Average monthly income (in Rs.)	**Before solar electrification**		**After solar electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
No Response	38	6.7	36	6.3
<1000	314	55.1	109	19.1
1001-3000	200	35.1	292	51.2
3001-5000	18	3.2	122	21.4
5001-7000	-	-	11	1.9
> 7000	-	-	-	-
Total	570	100.0	570	100.0

The table 6.29 above explains average monthly income earned, before and after solar electrification, of households participating in this study. Of 570 respondents, 6.7 per cent gave no response, and there were no respondents belonging to the Rs. 5001-7000 and > Rs.

7000 category before electrification. From the remaining respondents, (314) 55.1 per cent had average income less than Rs. 1000, (200) 35.1 per cent had average income between Rs. 1001-3000, and (18) 3.2per cent had an average income between Rs. 3001-5000 before electrification. After solar electrification, (109) 19.1 per cent had average income less than Rs. 1000, (292) 51.2 per cent had an average income between Rs. 1001-3000, (122) 21.4 per cent had an average income between Rs. 3001-5000, and (11) 1.9 per cent had an average income between Rs. 5001-7000. 6.3 per cent of the total respondents gave no response to the said question. With solar light intervention, 34 % of the houses report that there is an increase in monthly income in the range of INR 1001 -5000.

Due to increase in time spent on livelihood activities as well due to new opportunities for income generating activities after electrification, there has been an increase in average monthly income of households. Female contribution through in-house productive activities due to the availability of time is also an important factor in rising income level.

6.4.1.3 Amount spent on kerosene/candles for lighting

Respondents were asked about the amount of money spent on kerosene or candles to meet lighting needs every month before and after solar electrification. Their monthly expenditure on lighting needs is divided into five categories. The table below explains monthly expenditure on lighting needs.

Table 6.30: Monthly expenditure on lighting needs before and after solar electrification

Monthly expenditure on lighting needs (in Rs.)	**Before solar electrification**		**After solar electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
<60	22	3.9	304	53.3
61-100	93	16.3	251	44.1
101-200	145	25.4	15	2.6
201-300	218	38.2	-	-
> 301	92	16.1	-	-
Total	570	100.0	570	100.0

The above table 6.30 explains the monthly expenditure on lighting needs by kerosene/candles, before and after solar electrification, of households who participated in the study. Out of the 570 respondents, (22) 3.9per cent,(93) 16.3per cent, (145) 25.4 per cent,(218) 38.2 per cent and (92) 16.1 per cent had monthly expenditure on lighting needs less than Rs. 60, between Rs. 61-100, between Rs. 101-200, between Rs. 201-300, and more than Rs. 301 respectively, before electrification. After solar electrification, (304) 53.3per cent,(251) 44.1per cent, and (15) 2.6 per cent had monthly expenditure on lighting needs less than Rs. 60, between Rs. 61-100, and between Rs. 101-200 respectively.

Lighting is by far the most important use of electricity with all the electrified households. The survey results highlight that the monthly expenditure on lighting required to be fulfilled by kerosene or candles is reduced substantially after solar electrification. The beneficiary households have continued to use kerosene for purposes other than lighting the room after the installation of solar electricity but in smaller quantity.

6.4.1.4 Family members involved in income generating activities

The respondents were asked about the number of family members involved in the income generating activities before and after electrification. The table below shows the number of family members involved in income generating activities.

Table 6.31: Family members involved in income generating activities before and after solar electrification

Number of Persons	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
1	462	81.1	243	42.6
2	100	17.5	274	48.1
3	5	0.9	47	8.2
4	1	0.2	2	0.4
5 and more	2	0.4	4	0.8
Total	570	100.0	570	100.0

The above table 6.31 explains the number of family members involved in income generating activities, before and after solar electrification, of households who participated in the study. Out of the 570 respondents, (462) 81.1 per cent, (100) 17.5 per cent, (5) 0.9 per cent, (1) 0.2 per cent and (2) 0.4 per cent revealed that out of the total members of household only one, two, three, four, and more than four members were involved respectively, before electrification.After solar electrification, (243) 42.6 per cent, (274) 48.1 per cent, (47) 8.2 per cent, (2) 0.4 per cent, and (4) 0.8 per cent revealed that out of the total household members only one, two, three, four, and more than four members were involved respectively.

The survey results highlight that with availability of solar-powered electricity, there has been increase in the number of family members of a household in income generating activities. This has also contributed towards an increase in their average monthly income. Availability of light has been a game changer.

6.4.1.5 Statistical analysis

For statistical analysis, the impact on livelihood and income has been assessed through the overall score by adding up the responses of sub-factors like hours devoted to livelihood activities, average monthly income, and amount spent on kerosene/candles for lighting before and after solar electrification. All these factors jointly explain the impact of solar electrification on livelihood and income of households. The hypothesis that there is a significant change between overall scores of impact on livelihood and income before and after solar electrification is tested using paired-samples t-test and two-way ANOVA.

A paired-samples t-test was used to determine whether there was statistically significant mean difference between overall score of impact on livelihood and income (Income_Aft) after solar electrification as compared to an overall score of impact on livelihood and income (Income_Bfr) before solar electrification. Data are mean ± standard deviation unless otherwise stated. Eleven outliers were detected that were more than 1.5Box-lengths from the edge of the box in a box plot. Inspection of their values did not reveal them to be extreme, and they were kept in the analysis. The assumption of normality was not violated, as assessed by visual inspection of a Normal Q-Q Plot. The summary of the test as calculated by SPSS is produced in the tables below.

Table 6.32: Paired samples statistics for overall scores of impact on income and livelihood

		Mean	*N*	*Std. Deviation*	*Std. Error Mean*
Pair 1	***Income_Aft***	10.73	570	3.484	.146
	Income_Bfr	6.15	570	2.459	.103

Table 6.33: Paired samples test for overall scores of impact on income and livelihood

	Paired Differences			*t*	*df*	*Sig. (2-tailed)*
	Mean	*Std. Deviation*	*Std. Error Mean*			
Income_Aft - Income_Bfr	4.584	1.852	.078	59.084	569	.000

There is an improvement in the overall score of impact on livelihood and income after adopting the solar electrification (10.73 ± 3.484) as opposed to the pre-electrification (6.15 ± 2.459), a statistically significant mean increase of 4.584 ± 0.078 (mean diff ± SE), *t* (569) = 59.084, $p < .0005$, $d = 2.47$. Mean difference was statistically significantly different from zero at 0.01 levels. Therefore, we can reject the null hypothesis and accept the alternative hypothesis.

A two-way ANOVA was conducted to examine effect of education level and occupation of respondent on the overall score of impact on livelihood and income after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.34: Two-way factorial analysis of variance of overall scores of impact on livelihood and income after solar electrification

	Sum of Squares	*Df*	*Mean Square*	*F*	*Sig.*
Between Occupation	262.488	4	65.622	6.028	.000
Between Education	20.731	4	6.910	.635	.593
Interaction Occupation X Education	129.753	13	14.417	1.324	.221
Residual	5986.947	550	10.885		
Total	6399.919	569	11.307		

Table 6.34 about the overall score of impact on livelihood and income after solar electrification from the responses of households reveals that: -

1. There was a statistically significant interaction between the effects of occupation on the overall score of impact on livelihood and income, *F* (4, 569) = 6.028, *p* = .0005.

2. There was no statistically significant interaction between the effects of education level on the overall score of impact on livelihood and income, *F* (4, 569) = .635, *p* = .593.

3. There was no statistically significant interaction between the effects of education level and occupation on the overall score of impact on livelihood and income, *F* (13, 569) =1.324, *p* = .221.

The analysis reveals that there is no statistically significant effect of education level and occupation on the overall score of impact on livelihood and income after solar electrification. Thus, we accept the null hypothesis.

A two-way ANOVA was conducted to examine the effect occupation and monthly income of respondent on the overall score of impact on livelihood and income after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.35: Two-way factorial analysis of variance of overall scores of impact on livelihood and income after solar electrification

	Sum of Squares	***Df***	***Mean Square***	***F***	***Sig.***
Between Occupation	260.997	4	65.249	6.014	.000
Between Monthly Income	15.474	4	3.868	.357	.840
Interaction Occupation X Monthly Income	202.026	13	15.540	1.432	.140
Residual	5945.896	548	10.850		
Total	6424.393	569	11.291		

Table 6.35 about the overall score of impact on livelihood and income after solar electrification from the responses of households reveals that:-

1. There was a statistically significant interaction between the effects of occupation on the overall score of impact on livelihood and income, *F* (4, 569) = 6.014, *p* = .000.

2. There was no statistically significant interaction between the effects of monthly income on the overall score of impact on livelihood and income, *F* (4, 569) = .357, *p* = .840.

3. There was no statistically significant interaction between the effects of occupation and monthly income on the overall score of impact on livelihood and income, *F* (13, 569) =1.432, *p* = .140.

The analysis reveals that there is no statistically significant effect of occupation and monthly income on the overall score of impact on livelihood and income after solar electrification. Thus, we accept the null hypothesis. The occupation of households play an important role in impacting their livelihood and income level, but since their monthly income and education level was low before electrification; it doesn't have any significant impact on livelihood and income of households.

Electricity is expected to offer new incoming generating sources or improve existing ones. The extension of working hours into the late evenings as well as adjusting household chores at different times of the day resulting from the presence of electricity are found to aid in raising incomes. Time saved in collecting firewood, transporting kerosene, use of electrical devices for easier cooking added to these benefits and was found to help raise household income. Adding up to family members to their contribution in the income generating activity has also led to an increase in household income.

6.4.2 IMPACT ON UPLIFT-MENT OF WOMEN

The upliftment of women in rural areas is extremely low on account of various factors. Solar powered electrification has been an important intervention in rural areas which has contributed towards the upliftment of women. In order to measure the impact of solar powered electricity on women upliftment, respondents were asked solar light decreased the workload of women, availability of free time for other activities, involvement of women in activities, contribution to family income, safety for women in the night, and frequency of women visiting outside in the evening or night before and after solar electrification. For statistical analysis, the paired-samples t-test and two-way ANOVA was applied apart from tabulation and graphical representation.

6.4.2.1 Decrease in workload of women in the family

The respondents were asked whether household workload of women in the family was less before or after solar electrification. The objective was to assess whether the solar electrification has an impact on reduction in time devoted to such activities. They were asked to give their response on a five-pointlikert scale. The table below explains the views of respondents on workload comparison of women before and after solar electrification.

Table 6.36: Views of respondents on workload comparison of women before and after solar electrification

Response	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	366	64.2	3	0.5
Disagree	160	28.1	4	0.7
Undecided	39	6.8	30	5.3
Agree	4	0.7	228	40.0
Strongly Agree	1	0.2	305	53.5
Total	570	100.0	570	100.0

The above table 6.36 explains the views of respondents, on workload comparison of women before and after solar electrification, participating in the study. The survey indicates that of 570 respondents, (526) 92.3 per cent opined that women did not get less workload, (39) 6.8 per cent were undecided and (5) 0.9 per cent felt otherwise, before electrification. After solar electrification, (533) 93.5 per cent respondents agreed that women have less workload, (30) 5.3 per cent were undecided, and (7) 1.2 per cent felt otherwise.

The survey result shows that majority respondents are of the opinion that there is a decline in the workload of women during day time after solar electrification. Due to the availability of light in the night, women could evenly distribute their workload throughout the day. Also, with introduction of electric and gas based cooking, their time in the collection of wood for cooking and time is reduced.

6.4.2.2 Free time for women for other activities

The respondents were asked whether women had more free time for other activities before electrification or after electrification. The objective was to assess whether the solar electrification has given them more time to spend with family and in leisure. They were asked to give their response on a five-point likert scale. The table below explains the views of respondents on the availability of free time for women for other activities before and after solar electrification.

Table 6.37: Views of respondents on availability of free time for women before and after solar electrification

Response	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	351	61.6	8	1.4
Disagree	198	34.7	7	1.2
Undecided	10	1.8	9	1.6
Agree	11	1.9	193	33.9
Strongly Agree	-	-	353	61.9
Total	570	100.0	570	100.0

The above table 6.37 explains the views of respondents, on the availability of free time for women for other activities before and after solar electrification, who participated in the study. The survey indicates that out of 570 respondents, (549) 96.3 per cent said that women did not have free time for other activities, (10) 1.8 per cent were undecided and (11) 1.9 per cent felt otherwise, before electrification. After solar electrification, (546) 95.8 per cent respondents agreed that women have free time for other activities, (9) 1.6 per cent were undecided, and (15) 2.6 per cent felt otherwise.

The survey result shows that solar electrification has reduced time spent by women on such activities as gathering firewood and kerosene because their requirement is less after electrification and cooking is also easier and faster with use of electrical appliances. Apart this from reducing drudgery of rural women, it also allows them spending time with family members, doing other income generating activities and attending non-formal education classes.

6.4.2.3 Women getting involved in various activities

The respondents were asked what activities women get involved into before and after solar electrification. They were asked to give their preferences for activities like income generating, household work, creative stuff, leisure time with family and other activity. The table below explains views of respondents about women activities in before and after solar electrification.

Table 6.38: Views of respondents on involvement of women in various activities before and after solar electrification

Activities	Before Solar Electrification		After Solar Electrification	
	Frequency	*Per Cent*	*Frequency*	*Per Cent*
Income Generating	11	1.9	112	19.6
Household Work	288	50.5	26	4.6
Creative Stuff	23	4.0	55	9.6
Leisure Time with Family	40	7.0	176	30.9
Others	125	21.9	90	15.8
No Response	83	14.6	111	19.5
Total	570	100.0	570	100.0

The above table 6.38 explains the views of respondents, about activities women, are involved in before and after solar electrification, participating in the study. The survey indicates that out of 570 respondents, (11) 1.9 per cent, (288) 50.5 per cent, (23) 4 per cent, (40) 7 per cent and (125) 21.9 per cent revealed that women are involved in income generating activities, household work, creative stuff, leisure time with family, and other work respectively, before electrification.After solar electrification, (112) 19.6 per cent, (26) 4.6 per cent, (55) 9.6 per cent, (176) 30.9 per cent, and (90) 15.8 per cent revealed that women were involved in income generating activities, household work, creative stuff, leisure time with family, and other work respectively.

The survey shows women shifted their involvement to other activities due to the availability of light, substantially reducing their household workload. Enhanced leisure time for women is an important change due to electrification, giving them time to focus on their family, children and on themselves especially.

6.4.2.4 Contribution by women to family income

The respondents were asked whether women contribute to family income through above-mentioned activities before and after solar electrification. The objective was to assess whether the solar electrification has an impact on the contribution of women in the family income. They were asked to give their response on a five-pointlikert scale. The table below explains the views of respondents on the contribution of women to family income before and after solar electrification.

Table 6.39: Views of respondents on contribution by women to family income before and after solar electrification

Response	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	249	43.7	243	42.6
Disagree	269	47.2	169	29.6
Undecided	46	8.1	50	8.8
Agree	3	0.5	62	10.9
Strongly Agree	3	0.5	46	8.1
Total	570	100.0	570	100.0

The above table 6.39 explains the views of respondents, on the contributionof women to family income before and after solar electrification, who participated in the study. The survey indicates that out of 570 respondents, (518) 90.9 per cent said that women did not contribute to family income, (46) 8.1 per cent were undecided and (6) 1 per cent felt otherwise, before electrification. After solar electrification, (108) 19per cent respondents agreed that women are contributing to family income, (50) 8.8per cent were undecided, and (412) 72.2 per cent revealed that they are not contributing.

The survey shows women have thus started contributing to family income, though marginally. This has improved the overall monthly income of households, and at the same time, such women have become relatively independent to some extent. Slow shift of women towards income generating activities is mainly due to lack of opportunities for them.

6.4.2.5 Safety of women in the evening/night

The respondents were asked whether women feel safe in the late evening and night outside their house before and after solar electrification. They were asked to give their response on a five-pointlikert scale. The table below explains the views of respondents on the safety of women atnight and late evening before and after solar electrification.

Table 6.40: Views of respondents on safety of women in the evening/night before and after solar electrification

Response	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	351	61.6	22	3.9
Disagree	154	27.0	17	3.0
Undecided	23	4.0	16	2.8
Agree	19	3.3	269	47.2
Strongly Agree	23	4.0	246	43.2
Total	570	100.0	570	100.0

The above table 6.40 explains the views of respondents, on the safety of women atnight and late evening before and after solar electrification. The survey indicates that out of 570 respondents, (505) 88.6 per cent said that before electrification women did not feel safe in the late evening and night, (23) 3.3 per cent were undecided and (42) 7.3 per cent felt otherwise. After solar electrification, (515) 90.4 per cent respondents agreed women feel safe in the late evening and night, (16) 2.8per cent were undecided, and (39) 6.9per cent felt otherwise.

The survey result shows that women feel safer in the late evening and night relatively after electrification. Availability of light has made them feel safer even if male members are not at home. A lady in Upla Kota used to open her grocery shop only until 5 pm earlier, but after electrification, she kept open her shop until 8 pm. This is an example of upliftment and enhanced the sense of security for women.

6.4.2.6 Women going out in the evening/night

The respondents were asked if women go out more often during late evenings or night before or after solar electrification. The objective was to assess whether solar electrification has an impact on visit of women outside during night or evening. They were asked to give their response on a five-pointlikert scale. The table below explains the views of respondents on how often women would go out in the evening/night before and after solar electrification.

Table 6.41: Views of respondents on women going out in the evening/night before and after solar electrification

Response	Before Solar Electrification		After Solar Electrification	
	Frequency	*Per Cent*	*Frequency*	*Per Cent*
Strongly Disagree	246	43.2	48	8.4
Disagree	277	48.6	21	3.7
Undecided	10	1.8	32	5.6
Agree	37	6.5	203	35.6
Strongly Agree	-	-	266	46.7
Total	570	100.0	570	100.0

The above table 6.41 explains the views on women participation as on how often women would go out in the evening/night before and after solar electrification. The survey indicates that of 570 respondents, (523) 91.8 per cent said that before electrification women did not go out more often in the late evening and night, (10) 1.8 per cent were undecided and (37) 6.5 per cent felt otherwise. After solar electrification, (469) 82.3 per cent respondents agreed that now women go out more often in the late evening and night, (32) 5.6 per cent were undecided, and (69) 12.1 per cent felt otherwise.

The survey result shows that women have started going out more often due to the availability of light in the village as well as due to the availability of solar lamps in few households at some places. Earlier, the only option they had was a kerosene lamp which was not very safe in the absence of street lights.

6.4.2.7 Statistical analysis

For the statistical analysis, the impact on upliftment of women has been assessed through the overall score by adding up the responses of sub-factors like change in workload of women, time for other activities, involvement in other activities, contribution to family income, safety in the evening and frequency of visits in the evening/night before and after solar electrification. All these factors jointly explain the impact of solar electrification on upliftment of women. The hypothesis that there is a significant difference between the overall scores of impact on upliftment of women before and after solar electrification is tested using paired-samples t-test and two-way ANOVA.

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the overall score of impact on upliftment of women (Upliftment_Aft) after solar electrification as compared to an overall score of impact on upliftment of women (Upliftment_Bfr) before solar electrification. Data are mean ± standard deviation unless otherwise stated. Three outliers were detected that were below from the bottom edge of the box in a box plot. Inspection of their values did not reveal them to be extreme, and they were kept in the analysis. The assumption of normality was not violated, as assessed by visual inspection of a Normal Q-Q Plot. The summary of the test as calculated by SPSS is produced in the tables below.

Table 6.42: Paired samples statistics for overall scores of impact on upliftment of women

		Mean	*N*	*Std. Deviation*	*Std. Error Mean*
Pair 1	***Upliftment_Aft***	22.02	570	2.749	.115
	Upliftment_Bfr	10.41	570	3.040	.127

Table 6.43: Paired samples test for overall scores of impact on upliftment of women

	Paired Differences			*t*	*df*	*Sig. (2-tailed)*
	Mean	*Std. Deviation*	*Std. Error Mean*			
Upliftment_Aft - Upliftment_Bfr	11.612	4.660	.195	59.496	569	.000

There is an improvement in the overall score of impact on upliftment of women after adopting the solar electrification (22.02 ± 2.749) as opposed to the pre-electrification (10.41 ± 3.040), a statistically significant mean increase of 11.612 ± 0.195 (mean diff ± SE), t (569) = 59.496, $p < .0005$, $d = 2.49$. The mean difference was statistically significantly different from zero at 0.01 levels. Therefore, we can reject the null hypothesis and accept the alternative hypothesis.

A two-way ANOVA was conducted to examine the effect of education level and occupation of respondent on the overall score of impact on upliftment of women after solar electrification**.** The summary of the test as calculated by SPSS is shown in the table below.

Table 6.44: Two-way factorial analysis of variance of overall scores of impact on upliftment of women after solar electrification

	Sum of Squares	*Df*	*Mean Square*	*F*	*Sig.*
Between Occupation	59.088	4	14.772	1.965	.098
Between Education	27.262	3	9.087	1.209	.306
Interaction Occupation X Education	49.196	9	5.466	.727	.684
Residual	4135.057	550	7.518		
Total	4270.603	566	7.545		

Table 6.44 about the overall score of impact on upliftment of women after solar electrification from the responses of households reveals that: -

1. There was no statistically significant interaction between the effects of occupation on the overall score of impact on upliftment of women, F (4, 569) = 1.965, p = .098.

2. There was no statistically significant interaction between the effects of education level on the overall score of impact on upliftment of women, F (4, 569) = 1.209, p = .306.

3. There was no statistically significant interaction between the effects of education level and occupation on the overall score of impact on upliftment of women, *F* (13, 569) = .727, *p* = .684.

The analysis reveals that there is no statistically significant effect of education level and occupation on the overall score of impact on upliftment of women after solar electrification. Thus, we accept the null hypothesis.

A two-way ANOVA was conducted to examine the effect of occupation and monthly income of respondent on the overall score of impact on upliftment of women after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.45: Two-way factorial analysis of variance of overall scores of impact on upliftment of women after solar electrification

	Sum of Squares	***Df***	***Mean Square***	***F***	***Sig.***
Between Occupation	66.545	4	16.636	2.230	.065
Between Monthly Income	14.922	4	3.730	.500	.736
Interaction Occupation X Monthly Income	130.081	13	10.006	1.341	.184
Residual	4088.109	548	7.460		
Total	4299.656	569	7.557		

Table 6.45 about the overall score of impact on upliftment of women after solar electrification from the responses of households reveals that: -

1. There was no statistically significant interaction between the effects of occupation on the overall score of impact on upliftment of women, F (4, 569) = 2.230, p = .065.

2. There was no statistically significant interaction between the effects of monthly income on the overall score of impact on upliftment of women, F (4, 569) =.500, p = .736.

3. There was no statistically significant interaction between the effects of occupation and monthly income on the overall score of impact on upliftment of women, F (13, 569) = 1.341, p = .184.

The analysis reveals that there is no statistically significant effect of occupation and monthly income on the overall score of impact on upliftment of women after solar electrification. Thus, we accept the null hypothesis. Since the education level and month income were low before electrification; it doesn't have any significant impact on upliftment of women of households.

The majority of the women reported a reduction in the workload during day time. Thisis attributed to the fact that with the help of solar light they can now work at night as a result of which they don't have to complete all the work by day time. Due to a reduction in workload, women have now more free time for them and are using such time for income generation activities like leaf plate making, mat making, etc., creative activities like weaving, and stitching, etc., extra household work and leisure time with family. With solar light intervention, houses have reported that there is an increase in the monetary contribution by females. With the help of solar light, women also feel safe to travel at night since earlier it was not possible due to darkness and consequently they can spend more time outside in the late evenings.

6.4.3 IMPACT ON HEALTH

The health condition in rural areas is extremely poor on account of various factors. The role of electricity is expected to help improve health in many ways. In order to measure the impact of solar powered electricity on health through the survey, respondents were asked about their views on health issues while using kerosene lamp for cooking and after using solar light, frequency of visit to doctor for health problems, has solar light helped in saving money spent on doctor visit, and views on safety before and after solar electrification. For statistical analysis, the paired-samples t-test and two-way ANOVA was applied apart from tabulation and graphical representation.

6.4.3.1 Health problems faced by women while cooking

The respondents were asked if while cooking with kerosene lamp did females in particular faced any health problems like headache, breathing problems, watery eyes, red eyes, etc. before electrification and do they come across such problems with the use of solar light post electrification. The objective was to assess whether the solar electrification has an impact on improvement in health conditions of females mainly due to the smoke issuing from the firewood stoves. They were asked to give their response on a five-pointlikert scale. The table below explains the views of respondents on health problems faced by females before and after solar electrification.

Table 6.46: Views of respondents on health problems faced by women before and after solar electrification

Response	Before Solar Electrification		After Solar Electrification	
	Frequency	*Per Cent*	*Frequency*	*Per Cent*
Strongly Disagree	44	7.7	227	39.8
Disagree	41	7.2	123	21.6
Undecided	19	3.3	8	1.4
Agree	146	25.6	60	10.5
Strongly Agree	320	56.1	152	26.7
Total	570	100.0	570	100.0

The above table 6.46 explains the views of women participants on health problems faced by them before and after solar electrification, who participated in the study. Survey indicates that prior to electrification of 570 respondents, (466) 81.7 per cent said that women did face health issues while cooking with a kerosene lamp and firewood, (19) 3.3 per cent were undecided and (85) 14.9 per cent felt otherwise. After solar electrification, (350) 61.4 per cent respondents revealed that women did not face health problems now, (8) 1.4 per cent were undecided, and (212) 37.2 per cent said that women still face such health issues.

The survey result shows that majority respondents are of the opinion that there is a reduction in the health issues accruing from the usage of firewood stoves for cooking after solar electrification. Due to good availability of light in the night, many householdshave shifted their kitchen outside the house, in which the traditional firewood cooking stove was built. The advantage of this external kitchen was that it reduced indoor air pollution in homes and also made these homes cleaner. Also, with the introduction of electric and gas based cooking, the smoke is reduced.

6.4.3.2 Visit to doctor for health problems

Respondents were asked regarding frequency of visits to the doctor for health problems mentioned in the previous question per month before and after electrification. They were asked to give their response on a five-point likert scale. The table below explains the views of respondents on a visit to a doctor for health problems before and after solar electrification.

Table 6.47: Views of respondents on visit to a doctor for health problems before and after solar electrification

Response	Before Solar Electrification		After Solar Electrification	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
>10 times	239	41.9	21	3.7
6-8 times	76	13.3	12	2.1
4-6 times	56	9.8	63	11.1
2-4 times	172	30.2	200	35.1
<2 times	27	4.7	274	48.1
Total	570	100.0	570	100.0

The above table 6.47 explains the views of respondents, on a visit to a doctor for health problems, before and after solar electrification, of households who participated in the study. Out of the 570 respondents, (239) 41.9 per cent, (76) 13.3 per cent, (56) 9.8 per cent, (172) 30.2 per cent and (27) 4.7 per cent paid a visit to doctor for the above-mentioned health issuesmore than 10 times, 6-8 times, 4-6 times, 2-4 times, and less than 2 times per month respectively, before electrification. After solar electrification, (21) 3.7 per cent, (12) 2.1 per cent, (63) 11.1 per cent, (200) 35.1 per cent and (274) 48.1 per cent paid a visit to doctor for the above-mentioned health issues more than 10 times, between 6-8 times, between 4-6 times, between 2-4 times, and less than 2 times per month respectively.

The survey result shows that majority respondents are of the opinion that there is a reduction in the frequency of visit to a doctor for health problems mentioned after solar electrification. The external kitchen and usage of other appliances for cooking have helped in the improvement of the health of households and especially women.

6.4.3.3 Savings on Doctor Visits

The respondents were asked whether solar lighting has helped to save money spent on doctor visits or they used to save more before electrification. They were asked to give their response on a five-point likert scale. The table below explains the views of respondents about savings on doctor visits before and after solar electrification.

Table 6.48: Views of respondents about savings on doctor visits before and after solar electrification

Response	Before Solar Electrification		After Solar Electrification	
	Frequency	*Per Cent*	*Frequency*	*Per Cent*
Strongly Disagree	443	77.7	115	20.2
Disagree	52	9.1	55	9.6
Undecided	14	2.5	54	9.5
Agree	26	4.6	253	44.4
Strongly Agree	35	6.1	93	16.3
Total	570	100.0	570	100.0

The above table 6.48 explains the views of respondents, about savings on doctor visits before and after solar electrification, who participated in the study. The survey indicates that out of 570 respondents, (495) 86.8per cent said that households are not able to save money due to frequent visits to the doctor, (14) 2.5per cent were undecided and (61) 10.7 per cent felt otherwise, prior to electrification. After solar electrification, (246) 60.7 per cent respondents revealed that households could save some money due to are duction in health problems as compared to earlier, (54) 9.5per cent were undecided, and (170) 29.8per cent said that households are still not able to save money.

The survey result shows that majority respondents are of the opinion that they can save more money spent on a visit to a doctor for health problems after solar electrification. It is a logical corollary to a reduction in the visit to the doctor for health problems after solar electrification.

6.4.3.4 Views on safety

The respondents were asked about their views on safety before and after solar electrification. The question on safety was bifurcated further into sub-questions like a safety while commuting in the dark, safety from accidental burns, safety from wild creatures, and safety from theft before and after electrification. They were asked to give their response on a five-point likert scale. The table below explains the views of respondents regarding safety before and after solar electrification.

Table 6.49: Views of respondents about safety before solar electrification

Response	Safety while Commuting in Dark		Safety from Accidental Burns		Safety from Wild Creatures		Safety from Theft	
	Frequency	*%*	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*
Strongly Disagree	349	61.2	38	6.7	564	98.9	458	80.4
Disagree	151	26.5	399	70.0	1	0.2	63	11.1
Undecided	23	4.0	59	10.4	3	0.5	44	7.7
Agree	30	5.3	48	8.4	2	0.4	3	0.5
Strongly Agree	17	3.0	26	4.6	-	-	2	0.4
Total	570	100.0	570	100.0	570	100.0	570	100.0

Table 6.50: Views of respondents about safety after solar electrification

Response	Safety while Commuting in Dark		Safety from Accidental Burns		Safety from Wild Creatures		Safety from Theft	
	Frequency	*%*	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*
Strongly Disagree	99	17.4	3	0.5	96	16.8	20	3.5
Disagree	32	5.6	1	0.2	29	5.1	11	1.9
Undecided	44	7.7	5	0.9	26	4.6	35	6.1
Agree	112	19.6	13	2.3	367	64.4	71	12.5
Strongly Agree	283	49.6	548	96.1	52	9.1	433	76.0
Total	570	100.0	570	100.0	570	100.0	570	100.0

The above tables 6.49 and 6.50, explains views of respondents, regarding safety before and after solar electrification. The survey indicates that out of 570 respondents, (500) 87.7 per cent, (437) 76.7 per cent, (565) 99.1 per cent, and (521) 91.5 per cent said that they did not feel safe while commuting in dark within village, from accidental burns from kerosene lamps and firewood, from wild creatures like snakes and scorpions, etc., and there is no safety from theft respectively, before electrification. On the contrary, (47) 8.3 per cent, (74) 13 per cent, (2) 0.4 per cent, and (5) 0.9 per cent felt otherwise respectively. After solar electrification, (395) 69.2 per cent, (561) 98.4 per cent, (419) 73.5 per cent, and (504) 88.5 per cent said that they feel safe while commuting in dark within village, from accidental burns, snakes and scorpions, etc., and there is safety from theft respectively. On the contrary,

(131) 23 per cent, (4) 0.7 per cent, (125) 21.9 per cent, and (31) 5.4 per cent felt otherwise respectively.

The survey shows majority respondents are of the opinion that safety on various sub-factors has improved after solar electrification. The availability of light outside the house and on village streets in the night and reduction of kerosene and firewood usage for cooking has been a major factor behind this change.

6.4.3.5 Statistical analysis

For the statistical analysis, the impact on health has been assessed through the overall score by adding up the responses of sub-factors like their views on health issues while using kerosene lamp for cooking and after using solar light, frequency of visit to doctor for health problems, has solar light helped in saving money spent on doctor visit, and views on safety before and after solar electrification. All these factors jointly explain the impact of solar electrification on the health of households. The hypothesis that there is a significant difference between the overall scores of impact on health before and after solar electrification is tested using paired-samples t-test and two-way ANOVA.

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the overall score of impact on health (Health_Aft) after solar electrification as compared to an overall score of impact on health (Health_Bfr) before solar electrification. Data are mean ± standard deviation unless otherwise stated. Four outliers were detected that were below from the bottom edge of the box in a box plot. Inspection of their values did not reveal them to be extreme, and they were kept in the analysis. The assumption of normality was not violated, as assessed by visual inspection of a Normal Q-Q Plot. The summary of the test as calculated by SPSS is produced in the tables below.

Table 6.51: Paired samples statistics for overall scores of impact on health

		Mean	*N*	*Std. Deviation*	*Std. Error Mean*
Pair 1	***Health_Aft***	27..57	570	4.859	.204
	Health_Bfr	12.08	570	2.589	.108

Table 6.52: Paired samples test for overall scores of impact on health

	Paired Differences			*t*	*df*	*Sig. (2-tailed)*
	Mean	*Std. Deviation*	*Std. Error Mean*			
Health _Aft - Health _Bfr	15.493	4.965	.208	74.505	569	.000

There is an improvement in the overall score of impact on upliftment of women after adopting the solar electrification (27.57 ± 4.859) as opposed to the pre-electrification (12.08 ± 2.589), a statistically significant mean increase of 15.493 ± 0.208 (mean diff ± SE), *t* (569) = 74.505, $p < .0005$, $d = 3.12$. The mean difference was statistically significantly different from zero at 0.01 levels. Therefore, we can reject the null hypothesis and accept the alternative hypothesis.

A two-way ANOVA was conducted to examine the effect of education level and occupation of respondent on the overall score of impact on health after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.53: Two-way factorial analysis of variance of overall scores of impact on health after solar electrification

	Sum of Squares	*Df*	*Mean Square*	*F*	*Sig.*
Between Occupation	92.122	4	23.030	3.279	.011
Between Education	60.655	3	20.218	2.879	.035
Interaction Occupation X Education	177.172	9	19.686	2.803	.003
Residual	3862.458	550	7.023		
Total	4192.406	566	7.407		

Table 6.53 about the overall score of impact on health after solar electrification from households' responses reveals that: -

1. There was a statistically significant interaction between the effects of occupation on the overall score of impact on health, *F* (4, 566) = 3.279, *p* = .011.

2. There was a statistically significant interaction between the effects of education level on the overall score of impact on health, *F* (4, 566) =2.879, *p* = .035.

3. There was a statistically significant interaction between the effects of education level and occupation on the overall score of impact on health, *F* (13, 569) = 2.803, *p* = .003.

The analysis reveals that there is a statistically significant effect of education level and occupation on the overall score of impact on health after solar electrification. Thus, we accept the alternate hypothesis.

Occupation and monthly income

A two-way ANOVA was conducted to examine the effect occupation and monthly income of respondent on the overall score of impact on health after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.54: Two-way factorial analysis of variance of overall scores of impact on health after solar electrification

	Sum of Squares	***Df***	***Mean Square***	***F***	***Sig.***
Between Occupation	102.389	4	25.597	3.823	.004
Between Monthly Income	129.467	4	32.367	4.834	.001
Interaction Occupation X Monthly Income	314.246	13	24.173	3.610	.000
Residual	3669.002	548	6.695		
Total	4215.104	569	7.408		

Table 6.54 about the overall score of impact on health after solar electrification from the responses of households reveals that: -

1. There was astatistically significant interaction between the effects of occupation on the overall score of impact on health, *F* (4, 566) = 3.823, *p* = .004.

2. There was a statistically significant interaction between the effects of monthly income on the overall score of impact on health, *F* (4, 566) =4.834, *p* = .001.

3. There was a statistically significant interaction between the effects of occupation and monthly income on the overall score of impact on health, *F* (13, 569) = 3.610, *p* = .000.

The analysis reveals that there is a statistically significant effect of occupation and monthly income on the overall score of impact on health after solar electrification. Thus, we accept the alternate hypothesis. The education level, occupation and monthly income of households has a significant impact on the health of households.

The majority of the respondents have reported an improvement in the health conditions of members of households. Thisis attributed to the fact that with the help of solar light females has an option of shifting their kitchen outside the house as well as usage of other appliances for cooking thus reducing the consumption of kerosene and firewood. This has tremendously reduced pollution in the house, and consequently, health issues have reduced. Consequently, the households can save some money out of their reduced visits to the doctor. With solar light intervention, there has been a sense of safety for households. They feel safer now while commuting in the night, less accidental burns from kerosene and firewood, safety from animals in the dark and safety from theft as well. Hence, solar electrification has impacted the health conditions in villages positively.

6.4.4 IMPACT ON EDUCATION

Education level in rural areas is vulnerable due to various factors. The role of electricity is expected to help improve education level in many ways. To measure the impact of solar powered electricity on education through the survey, respondents were asked about the number of hours children study in the evening and night, concentration and interest of children in studies, performance in exams, and female education status before and after solar electrification. For statistical analysis, the paired-samples t-test and two-way ANOVA was applied apart from tabulation and graphical representation.

6.4.4.1 Number of hours children study in the evening and night

The respondents were asked about the number of hour's children study in the evening and night before electrification and post electrification. The objective was to assess whether the solar electrification has an impact on the duration of study in the evening and night. The number of hours was categorized into five categories, and the respondents were asked to select any one. The table below shows the number of hour's children study in the evening and night before and after solar electrification.

Table 6.55: Number of hours children study in the evening and night before and after solar electrification

Hours	**Before Solar Electrification (With Kerosene Lamp &Candle)**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
0-1	103	18.1	44	7.7
1-2	56	9.8	59	10.4
2-3	155	27.2	182	31.9
3-4	164	28.8	176	30.9
>4	47	8.2	64	11.2
No Response	45	7.9	45	7.9
Total	570	100.0	570	100.0

The above table 6.55 explains the views of respondents of households who participated in the study, on the number of hour's children study in the evening and night, before and after solar electrification. Out of the 570 respondents, (103) 18.1 per cent, (56) 9.8 per cent, (155) 27.2 per cent, (164) 28.8 per cent and (47) 8.2 per said that children study for0-1 hours, 1-2 hours, 2-3 hours, 3-4 hours, and more than 4 hours per day in the evening and night respectively, before electrification.After solar electrification, (44) 7.7 per cent, (59) 10.4 per cent, (182) 31.9 per cent, (176) 30.9 per cent and (64) 11.2 per cent said that children study for 0-1 hours, 1-2 hours, 2-3 hours, 3-4 hours, and more than 4 hours per day in the evening and night respectively. There was no response from (45) 7.9 per cent respondents.

The survey result shows that majority respondents (63 per cent) are of the opinion that there is an improvement in the duration of study in the evening and night after solar electrification. Due to better illumination after dusk, the children are willing to study more in the late evening and night. Also, the brightness of light from kerosene and candle before electrification was insufficient for children to study in the night.

6.4.4.2 Interest of children in studies

The respondents were asked about the interest and concentration of children in studies before electrification and post electrification. They were asked to give their response on a five-point likert scale. The table below explains the development of interest and concentration of children in studies before and after solar electrification.

Table 6.56: Interest of children in studies before and after solar electrification

Response	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	14	2.4	2	0.4
Disagree	500	87.7	146	25.6
Undecided	19	3.3	4	0.7
Agree	24	4.2	84	14.7
Strongly Agree	13	2.3	334	58.6
Total	570	100.0	570	100.0

The above table 6.56 explains the views of respondents who participated in the study, on development of interest and concentration of children in studies before and after solar electrification. The survey indicates that out of 570 respondents, (514) 90.1 per cent said that children did not have an interest in studies nor their concentration was good, (19) 3.3 per cent were undecided and (37) 6.5 per cent felt otherwise, before electrification. After solar electrification, (418) 73.3 per cent respondents revealed that children have started developing an interest in studies and their concentration has improved, (4) 0.7per cent were undecided, and (148) 26per cent revealed that there is no change.

The survey shows that majority respondents are of the opinion that children have developed an interest in studies and can concentrate more after solar electrification. Due to good availability of light after dawn, the children are willing to study. The insufficient brightness of light through kerosene and candles before electrification was a hindrance for developing interest towards studies.

6.4.4.3 Performance of children in exams

The respondents were asked about the marks scored by children before electrification and post electrification. Objective was to assess if the solar electrification has improved their performance in studies. They were asked to give their response on a five-pointlikert scale. The table below explains the marks scored by children before and after solar electrification.

Table 6.57: Performance of children in exams before and after solar electrification

Response	**Before Solar Electrification**		**After Solar Electrification**	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	219	38.4	25	4.4
Disagree	282	49.5	17	3.0
Undecided	9	1.6	64	11.2
Agree	27	4.7	204	35.8
Strongly Agree	33	5.8	260	45.6
Total	570	100.0	570	100.0

The above table 6.57 explains the views of respondents, about the marks scored by children before and after solar electrification, who participated in the study. It indicates that out of 570 respondents, (501) 87.9per cent said that children did not score good marks in their examination, (9) 1.6 per cent were undecided and (60) 10.5 per cent felt otherwise, before electrification. After solar electrification, (464) 81.4 per cent respondents revealed that children had improved their performance in exams as compared to earlier, (64) 11.2per cent were undecided, and (42) 7.4 per cent revealed that there is no change in their performance.

Since children used to help in other work during daytime, and after dawn, they were not able to study much due to which, their performance in exams was not satisfactory in many cases. The survey result shows that majority respondents are of the opinion that the performance of children in exams has improved after solar electrification. This can be attributed to better availability of light and improved concentration and interest in studies.

6.4.4.4 Condition of female education

The respondents were asked about the condition of female education before electrification and post electrification. The objective was to assess whether the solar electrification has improved the female education. They were asked to give their response on a five-point likert scale. The table below explains the condition of female education before and after solar electrification.

Table 6.58: Condition of female education before and after solar electrification

Response	Before Solar Electrification		After Solar Electrification	
	Frequency	***Per Cent***	***Frequency***	***Per Cent***
Strongly Disagree	357	62.6	26	4.6
Disagree	51	8.9	5	0.9
Undecided	25	4.4	6	1.1
Agree	133	23.3	344	60.4
Strongly Agree	4	0.7	189	33.2
Total	570	100.0	570	100.0

The above table 6.58 explains the views of respondents, on the condition of female education before and after solar electrification, who participated in the study. The survey indicates that out of 570 respondents, (408) 71.5 per cent said that female education was not promoted in their villages, (25) 4.4 per cent were undecided and (137) 24 per cent felt otherwise, before electrification. After solar electrification, (533) 93.6 per cent respondents revealed that households have started promoting female education as compared to earlier, (6) 1.1per cent were undecided, and (31) 5.3 per cent revealed that there is no change.

Since thefemale child was engaged in household work as the work had to be finished during the day time, they did not get much opportunity to study. The survey result shows that majority respondents are of the opinion that female education has improved after solar electrification. This can be attributed to the better availability of light and improved concentration and interest in studies. Also, awareness about female child education has played an important role.

6.4.4.5 Statistical analysis

For the statistical analysis, the impact on education has been assessed through the overall score by adding up the responses of sub-factors like the number of hour’s children study in the evening and night, concentration and interest of children in studies, performance in exams, and condition of female education before and after solar electrification. All these factors together explain the impact of solar electrification on the education level of households. The hypothesis that there is a significant difference between the overall scores of impact on education before and after solar electrification before and after solar electrification is tested using paired-samples t-test and two-way ANOVA.

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the overall score of impact on education (Education_Aft) after solar electrification as compared to an overall score of impact on education (Education_Bfr) before solar electrification. Data are mean ± standard deviation unless otherwise stated. No outliers were detected in a box plot. The assumption of normality was not violated, as assessed by visual inspection of a Normal Q-Q Plot. The summary of the test as calculated by SPSS is produced in the tables below.

Table 6.59: Paired samples statistics for overall scores of impact on education

		Mean	*N*	*Std. Deviation*	*Std. Error Mean*
Pair 1	***Education_Aft***	15.36	570	2.276	.095
	Education _Bfr	8.70	570	2.692	.113

Table 6.60: Paired samples test for overall scores of impact on education

	Paired Differences			*t*	*df*	*Sig. (2-tailed)*
	Mean	*Std. Deviation*	*Std. Error Mean*			
Education _Aft - Education _Bfr	6.653	3.855	.161	41.203	569	.000

There is an improvement in the overall score of impact on upliftment of women after adopting the solar electrification (15.36 ± 2.276) in contrast to pre-electrification (8.70 ± 2.692), a statistically significant mean increase of 6.653 ± 0.161 (mean diff ± SE), t (569) = 41.203, $p < .0005$, $d = 1.73$. The mean difference was statistically significantly different from zero at 0.01 levels. Therefore, we can reject the null hypothesis and accept the alternative hypothesis.

A two-way ANOVA was conducted to examine the effect of education level and occupation of respondent on the overall score of impact on education after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.61: Two-way factorial analysis of variance of overall scores of impact education after solar electrification

	Sum of Squares	*Df*	*Mean Square*	*F*	*Sig.*
Between Occupation	24.935	4	6.234	2.493	.042
Between Education	19.496	3	6.499	2.599	.052
Interaction Occupation X Education	29.435	9	3.271	1.308	.230
Residual	1375.403	550	2.501		
Total	1449.270	566	2.561		

Table 6.61 about the overall score of impact on education after solar electrification from the responses of households reveals that: -

1. There was a statistically significant interaction between the effects of education level on the overall score of impact on education, *F* (4, 566) =2.493, *p* = .042.

2. There was a statistically significant interaction between the effects of occupation on the overall score of impact on education *F* (3, 566) = 2.599, *p* = .052.

3. There was no statistically significant interaction between the effects of education level and occupation on the overall score of impact on education, *F* (9, 566) = 1.308, *p* = .230.

The analysis reveals that there is no statistically significant effect of education level and occupation on the overall score of impact on the overall score of impact on education after solar electrification. Thus, we accept the null hypothesis.

A two-way ANOVA was conducted to examine the effect occupation and monthly income of respondent on the overall score of impact on education after solar electrification**.** The summary of the test as calculated by SPSS is produced in the table below.

Table 6.62: Two-way factorial analysis of variance of overall scores of impact education after solar electrification

	Sum of Squares	***Df***	***Mean Square***	***F***	***Sig.***
Between Occupation	32.668	4	8.167	3.319	.011
Between Monthly Income	43.164	4	10.791	4.385	.002
Interaction Occupation X Monthly Income	45.334	13	3.487	1.417	.146
Residual	1348.632	548	2.461		
Total	1469.798	569	2.583		

Table 6.62 about the overall score of impact on education after solar electrification from the responses of households reveals that: -

1. There was a statistically significant interaction between the effects of occupation on the overall score of impact on education**,** *F* (4, 566) =3.319, *p* = .011.

2. There was astatistically significant interaction between the effects of monthly income on the overall score of impact on education, *F* (13, 569) = 4.385, *p* = .002.

3. There was no statistically significant interaction between the effects of occupation and monthly income on the overall score of impact on education, *F* (13, 569) = 1.417, *p* = .146.

The analysis reveals that there is no statistically significant effect of occupation and monthly income on the overall score of impact on educationafter solar electrification. Thus, we accept the null hypothesis. The occupation and monthly income of households don't have a significant impact on the education of households.

The majority of the respondents have reported an improvement in the education level of children. Thisis attributed to the fact that with the help of solar light children could now concentrate more on their studies and this has extended their duration of the study as well. Consequently, it has improved their performance in exams. The indirect influence of electricity is with the shifting of some household chores into the evenings thereby enabling the children, especially females, to attend school during the day time. The extended evenings, the presence of TV, the ability to attend non-formal education, facilitate higher literacy and school enrollment rates. Hence, solar electrification has impacted the education level in villages positively.

6.5 SECTION IV: SKILL DEVELOPMENT – AFFORDABILITY AND WILLINGNESS TO PAY

The fourth and last section deals with opinion of households on skill development and affordability and willingness to pay for solar energy systems. The response of households is represented through tabulation, graphs and piecharts.

6.5.1 SKILL DEVELOPMENT PROGRAM

The respondents were asked about skill development programs, and whether household members are interested in pursuing such programs at the village level, benefits of such programs for youth, and villagers wish to have such programs.

6.5.1.1 Skill development programs at village level

The respondents were asked if a skill development program is being implemented by a government agency in the village. The table below explains the responses of households.

Table 6.63 Skill development program implemented in village

Response	*Frequency*	*Pratapgarh*
Yes	110	19.3
No	460	80.7
Total	570	100.0

The above table 6.63 explains the responses of households, on whether a skill development program is being implemented by a government agency in the village. Out of 570 respondents, (110) 19.3 per cent revealed that few skill development programs were implemented in their village, but (460) 80.70 per cent respondents said that no skill development programs were implemented in their village either during pre-electrification or post-electrification.

6.5.1.2 Willingness of villagers for such programs

The respondents were asked whether they wish to have such programs in their villages. The table below explains the responses of households.

Table 6.64: Willingness of villagers for such programs

Response	***Frequency***	***Percentage***
Strongly Disagree	18	3.2
Disagree	18	3.2
Undecided	123	21.6
Agree	376	66.0
Strongly Agree	35	6.1
Total	570	100.0

The above table 6.64 explains responses of households participating in the study on whether they wish to have such programs in their villages. Out of 570 respondents, (411) 72.1 per cent revealed that they want such programs to be implemented in their village for skill development, (123) 21.6 per cent respondents were undecided, and (36) 6.4 per cent were not interested in such programs. The study reveals that majority households are interested in such programs and they will actively participate in them for their skill development. This will be an add-on for their employability because agriculture is not a predominant activity in the villages covered under the study.

6.5.1.3 Training of youth for maintenance of solar lighting system

The respondents were asked whether it would be beneficial if, the youth of village is trained for general working and maintenance of solar lighting systems. The table below explains the responses of households.

Table 6.65: Training of youth for maintenance of solar lighting system

Response	***Frequency***	***Percentage***
Strongly Disagree	22	3.9
Disagree	59	10.4
Undecided	20	3.5

Agree	422	74.0
Strongly Agree	47	8.2
Total	570	100.0

The above table 6.65 explains the responses of households, on whether it would be beneficial if the youth of village is trained for general working and maintenance of solar lightening systems, who participated in the study. Out of 570 respondents, (469) 82.2 per cent revealed that it would be beneficial if the you this trained for general working and maintenance of solar lighting systems, (20) 3.5 per cent respondents were undecided, and (81) 14.3 per cent felt otherwise. Majority respondents revealed that training the youth for maintenance of solar lighting system will be a potential employment opportunity and their dependency on external service agents will be reduced. This will help in improvement in reliability of solar lighting system.

6.5.1.4 Availability of electric stoves for cooking

The respondents were asked whether they are willing to prefer electric stoves, if they are made available, over other traditional methods of cooking. The table below explains the responses of households.

Table 6.66: Availability of electric stoves for cooking

Response	***Frequency***	***Percentage***
Strongly Disagree	49	8.6
Disagree	35	6.1
Undecided	40	7.0
Agree	180	31.6
Strongly Agree	266	46.7
Total	570	100.0

The above table 6.66 explains the responses of households, on whether they are willing to prefer electric stoves, if they are made available, over other traditional methods of cooking, who participated in the study. Out of 570 respondents, (446) 78.3 per cent revealed that they would be willing to prefer electric stoves, if they are made available, over other traditional methods of cooking, (40) 7.0 per cent respondents were undecided, and (94) 14.7

per cent said that they would use traditional methods for cooking. The study reveals that majority households prefer electric stoves over the traditional cooking system, which is the main factor behind the deterioration of female health.

6.5.2 AFFORDABILITY AND WILLINGNESS TO PAY

The respondents were asked about affordability and willingness of households to pay for solar lighting systems and how much they can pay.

6.5.2.1 Willingness to pay more

The respondents were asked whether they are willing to pay more for electricity if more reliable service is provided to them. The table below explains the responses of households.

Table 6.67: Willingness to pay more

Response	***Frequency***	***Percentage***
Strongly Disagree	30	5.3
Disagree	31	5.4
Undecided	33	5.8
Agree	293	51.4
Strongly Agree	183	32.1
Total	570	100.0

The above table 6.67 explains the responses of households, on whether they are willing to pay more for electricity if more reliable service is provided to them, who participated in the study. Out of 570 respondents, (476) 83.5 per cent revealed that they are willing to pay more for electricity, (33) 5.8 per cent respondents were undecided, and (61) 10.7 per cent said that they are not willing to pay more. The study reveals that majority households are willing to pay more if the availability and reliability of solar lighting system is improved. This will be an important factor in determining the importance of electricity for rural households.

6.5.2.2 Ability to pay

The respondents were asked how much they can pay for solar energy system per month. The table below explains the responses of households.

Table 6.68: Ability to pay

Response	***Frequency***	***Percentage***
Less than Rs. 200	337	59.1
2001 – 500 Rs.	59	10.4
501 – 1000 Rs.	52	9.1
More than Rs. 1000	122	21.4
Total	570	100.0

The above table 6.68 explains the responses of households, on how much they can pay for solar energy system per month, who participated in the study. Out of 570 respondents, (337) 59.1per cent, (59) 10.4 per cent, (52) 9.1 per cent, and (122) 21.4 per cent revealed that they could pay less than Rs. 200, between Rs. 201-500, between Rs. 501-1000, and more than Rs. 1000 respectively. The study reveals that majority households can pay not more than Rs. 200 per month for the solar lighting system. This is due to lower income generation in households. There are few households who are willing to spend even more than Rs. 200.

6.5.2.3 Willingness to pay

The respondents were asked how much they are willing to pay for solar energy system per month. The table below explains the responses of households.

Table 6.69: Willingness to pay

Response	***Frequency***	***Percentage***
Less than Rs. 200	265	46.5
201 – 500 Rs.	239	41.9
501 – 1000 Rs.	36	6.3
More than Rs. 1000	30	5.3
Total	570	100.0

The above table 6.69 explains the responses of households, on how much they are willing to pay for solar energy system per month, who participated in the study. Out of 570 respondents, (265) 46.5 per cent, (239) 41.9 per cent, (36) 6.3, and (30) 5.3 per cent revealed that they could pay less than Rs. 200, between Rs. 201-500, between Rs. 501-1000, and more than Rs. 1000 respectively. The study reveals that majority households are willing to pay less than Rs. 200 per month, but there are an equally high number of households who can pay between Rs. 201 – 500 per month. This shows that households are ready to pay more if the electricity is available consistently and it has contributed towards an increase in average monthly income.

6.5.2.4 Cycle of payment

The respondents were asked how they would like to pay for the solar energy system for the whole year. The table below explains the responses of households.

Table 6.70: Cycle of payment

Response	***Frequency***	***Percentage***
Lump sum	66	11.6
Two Installments	111	19.5
Three Installments	40	7.0
Monthly Payment	353	61.9
Total	570	100.0

The above table 6.70 explains the responses of households, about their cycle of payment for solar energy system per year, who participated in the study. Out of 570 respondents, (66) 11.6 per cent, (111) 19.5 per cent, (40) 7.0, and (353) 61.9 per cent revealed that they would like to pay a lump sum amount, intwo installments, inthree installments, and as monthly paymentrespectively in a year. The survey reveals that majority households are interested in monthly payment for electricity charges due to inconsistency in the flow of income.

6.6 Conclusion

It has been observed in the course of this research that there has been a significant difference in the pre and post conditions of electrification in all the studied villages. Increase in household income, high enrollments in school, increased hours of study during evening, increased participation in non-formal education, increased consumption of energy and more free time owing to lower firewood collection; less indoor air pollution, less carbon dioxide emissions was reported and evaluated in the villages electrified with decentralized solar energy. Thus, on the whole, decentralized solar PV systems have provided a better quality and affordable electric power which has proven to be advantageous as it bring light of hope to the families.

Chapter 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter aims at summarizing the findings of the research study and portraying conclusions drawn from them. In conjunction with the conclusions, the recommendations for future policy implications and scope of further research are also presented in this chapter. The summary of the inferences built is in succession with the pre-designed objectives of the present study.

Energy is an indispensable parameter for the growth and development of any nation. Therefore, it is also considered that energy is in alliance with the sustainable development of the communities. Electricity, as a chief form of energy is learned to be an essential component for economic and productive activities, as well as for the comprehensive social welfare of the population. It has been observed that access to electricity has strong positive linkages with human development index and thus is largely responsible for the socio-economic growth and development of the communities and the nation on the whole. Though based on the review of literature and secondary data available it is also important to mention that the access to reliable and good quality electricity remains a dream in pipe line for most of the rural households in India. At the same time, it is observed that with special reference to Rajasthan, the challenges of offering electricity supply to rural households are manifold. To mention, the ever rising demand-supply gap, large distance of villages from nearest grid points, crumbling electricity transmission and distribution infrastructure and capital intensive delivery of electricity are few of the challenges contributing to the poor electricity access to rural areas. Lack of access to modern energy has also been responsible for hindering the socio-economic upliftment of the rural population. While on the other hand, it has been observed over the decades, that those villages which are provided with electricity access have shown positive growth trends for all the major indicators of human development index, i.e. health, literacy and standard of living.

This study attempted to fill the gap in the research on the socio-economic impacts of the decentralized rural electrification based on solar PV systems, particularly focusing the impact on local economies. The purpose of this study was to discover whether any significant characteristics in the impact of the decentralized electrification based on solar energy on local economies were observed post electrification comparing with the socio-economic status in pre-electrification conditions. For this purpose, the study examined the impacts both quantitatively and qualitatively for two types of conditions, i.e. pre and post electrification on local economies such as new businesses and job creation, agricultural and other productive activities, upliftment of women, education level, improvement in health, and household income by conducting the questionnaire based survey and focus group discussions in the remote villages of Rajasthan that are electrified by decentralized solar systems and the availability of conventional grid is yet not reported there. Further, the study also examined the feasibility of decentralized solar PV systems over conventional grid extension for the remote villages.

The community or village based decentralized electrification with solar photovoltaic energy systems which is self-reliant in nature is one of the best option and a promising alternative to provide electricity to the rural villages, particularly in remote areas, where extension of grid based on conventional energy is not possible as well as in those villages where grid extension is possible due to few of the following reasons:

- The extension of grid is highly capital intensive in remote areas due to the geographical features,
- Low population densities which results in increased cost of electricity generation, and
- Poor distribution and transmission infrastructure leading to unreliable supply of electricity especially during the evening hours.

The rural electrification position in Rajasthan particularly in remote areas is relatively poor and needs to be addressed on priority. Further, for Rajasthan, the intervention and promotion of rural electrification is a vital element in order to uplift the well-being of the rural communities, as with access to electrification a broad platform of opportunities could be made available to the people contributing to improve their social-economic profile and standard of living for a better future. At the same time, positive environmental impacts would also contribute to a collective social welfare.

The rural electrification scenario of Rajasthan and the possible alternative decentralized energy systems have been thoroughly studied and researched, particularly in context of remote rural areas. The insights from the existing literature highlights the prevailing issues of power sector in the state for rural electrification. The secondary data demonstrated that there exist two types of villages which do not have access to electricity; one which are un-electrified and the other which are de-electrified. Further, it was observed that government has introduced various policies and programmes for electrification of rural areas, despite that the electrification level is poor derived from the local politics, lack of strong financial infrastructure, poor transmission and distribution infrastructure and many more. Adoption of decentralized renewable based energy options for electrifying the remote villages is lacking in Rajasthan as compared to other states in India like West Bengal, Orissa, Uttar Pradesh, etc.

During the extensive review of literature, around one hundred and fifty articles were thoroughly reviewed by the researcher out of which 76 papers were found appropriate for the present research. Based on the existing literature, the studies conducted by the researchers found that there is a great potential of solar PV systems to enhance the power supply especially to the rural communities in any state which is cost effective and environment friendly.

As mentioned earlier, the study was conducted in two parts; the first part intended to analyze the socio-economic impacts of decentralized rural electrification based on solar PV systems on the rural population and the second part aimed to evaluate the cost-effectiveness of these decentralized energy generation systems based on solar power over the conventional grid extension method. The investigation of socio-economic impact assessment was based on primary data collected via questionnaire survey method and focused group discussions of 570 households in rural Rajasthan and was analyzed implying various statistical tools using SPSS software. The estimation of cost-comparison was based on secondary data collected from the project implementing organizations and various published and un-published data from local and state utilities. The costs were compared adapting Life Cycle Cost Analysis.

The information compiled and the survey and research analysis performed along with the results obtained during the course of the present research study has been assembled in seven chapters of the thesis;

The first chapter gives the brief introduction of the thesis furnishing the overview of all the relevant areas and topics related to the present study. It includes the statement of the problem, objectives of the research, importance of the study, the research gap and the complete plan of thesis is portrayed in this chapter.

The second chapter displays an abridgment of the existing literature obtainable on the subject matter. Under the literature survey, assorted studies performed at national and international juncture are endured which provided the thorough understanding of the research area for finding out the research gap.

The third chapter demonstrates the research methodology adopted in the study. It gives an overview and framework of the design accepted for the primary survey and data collection, scope of the study and the statistical technique used for analyzing the data.

The fourth chapter described the detailed scholastic review of the renewable energy resources and their uses along with the assessment of the rural electrification situation in Rajasthan. The theoretical understanding of the research gap and statement of the problem including the comprehension of justification of objectives of the study is also justified in this chapter.

The fifth chapter sketches the empirical evaluation of the sample survey along with the brief profile of the sample households which includes their monthly household income, monthly expenditure on fuel and electricity, household characteristics etc. The analysis of the survey is included in this chapter comprising of the results that support the hypothesis formulated for this chapter. The discussion based on the findings of the research is also placed in this chapter.

The sixth chapter comprised of the comparative cost analysis of the extension of grid connected thermal electricity and off-grid Solar PV technology based electricity. Both the case studies adopted for the research in rural Rajasthan were evaluated to support the argument made for this chapter and to provide suggestions for further research.

Finally seventh chapter, i.e. this chapter is entirely focused to present the summary of findings and suggestions or policy implications keeping in view the future prospects. It ascertains that life cycle cost of decentralized solar systems is cost-effective for remote areas. It analyzes that the rural electrification adopting solar technologies have created significant positive impacts on the socio-economic aspects of the rural population of the surveyed villages. Further, it discusses the importance of the adoption of decentralized solar technologies for energy generation and delivery relating it to the environmental benefits associated with it. The problems and loopholes concerning the implication of off-grid technologies are highlighted along with the proposed models for the improved operations of such projects for potential welfare and growth of the society. The suggestions for proper implementation of such off-grid renewable energy projects for rural electrification are made which could improve and uplift the standard of living of the rural population and help government achieving the desired growth and development of the country as a whole.

7.1 SUMMARY OF KEY FINDINGS

Solar micro-grid systems based on decentralized technology can play a vital role in promoting rural electrification in the remote areas. These systems can lay a positive impact on the socio-economic growth of the local economies if employed efficiently. In the present study it was observed that the electrification based on solar micro-grids have shown positive impact on the socio-economic profile of the households. It helped creating employment opportunities, promoting small business, enhancing agricultural productivity and improving other productive activities. In addition to the increasing household income, the education level and health facilities have also improved.

In the present research a survey of 570 households was carried out in rural Rajasthan. The socio-economic features of the households considered for the study that influence the adoption of electricity were; age, gender, education, family size, occupation and monthly income. It was indicated by the study that the major predictor variables of electricity adoption were size of household, occupation, education and monthly income.

The results of adoption of electricity among the households revealed that almost all the households possess electric appliances like fan, radio, lights, television, sewing machines and mobile phones. The electrical appliances which were least acquired and were found in few of the households were computer, flour mill, refrigerator and chaff cutter.

Pertaining to the benefits from electricity that directly relate to the socio-economic profile of the villagers, it was revealed during the study that the major benefits were enjoyed at household level. Though the benefits were reported in the productive sector as well like agriculture and small industries, but an improvement in the quality of life of the households was observed at a large scale. As the priority of the households was to get relieved of the prolonging darkness and most use of the electricity was done for lightning purposes. With the access to electric connection, electricity was used not only for indoor lightening but also for street lights enhancing the security of the community.

It was found that for information and entertainment purpose radios were used in most of the households. To improve and enhance communication facilities ownership of mobile phone was also established. As reported by households, television was another common electric appliance among households whose major use was entertainment and access to information.

In the households involved in agricultural activities it was reported that after electrification around 27.9 percent households were able to work for around 2-4 hours in the evening time and 43.3 percent households were able to work for around 4-5 hours in the evening time as well whereas before electrification they were not able to work in evening due to dark.

The major source of income in majority of household was agriculture and daily wage labour. Households were also involved in small businesses like grocery shop or general stores, pottery, handicrafts, tailoring and weaving, flour-mill and vegetable vendors etc. All these activities require electricity for increasing production and income. With the solar light intervention, 34 percent of the houses have reported that there is an increase in monthly income in the range of INR 1001 -5000.

After solar electrification, 53.3 per cent households spend less than Rs. 60 for monthly expenditure on lighting needs, 44.1per cent spend between Rs. 61-100, and 2.6 per cent spend between Rs. 101-200. This has been reduced to a great extent as before electrification maximum households used to spend between Rs.300-500.

The number of family members involved in income generating activities have also increased after electrification. It was found that before electrification only one member was earning in around 81.1 per cent households, and likewise there were two earning members in 17.5 per cent households, three earning members in 0.9 per cent households, four earning members were only in 0.2 per cent households and just 0.4 per cent households comprised of more than four earning members. After solar electrification, one member was earning in around 42.6 per cent households, and likewise there were two earning members in 48.1 per cent (increased by 30.6 percent) households, three earning members in 8.2 per cent (increased by 7.3 percent) households, four earning members were only in 0.4 per cent households and 0.8 per cent households comprised of more than four earning members.

After solar electrification, 93.5 per cent respondents reported that the household workload of women has reduced drastically and they have more leisure now. After solar electrification, 95.8 per cent respondents reported that women have free time for other activities which involve income generating activities too. After solar electrification, 19.6 per cent, 4.6 per cent, 9.6 per cent, 30.9 per cent, and 15.8 per cent revealed that women are involved in income generating activities, household work, creative stuff, leisure time with family, and other work respectively. The survey indicates that 90.9 per cent said that women did not contribute to family income, before electrification. After solar electrification, 19 per cent respondents agreed that women have started contributing to family income.

After solar electrification, 90.4 per cent respondents reported that women feel safe in the late evening and night, 2.8 per cent were undecided, and 6.9 per cent felt otherwise. The survey indicates that before electrification, 81.7 per cent women faced health issues while cooking with a kerosene lamp and firewood. Whereas, after solar electrification, it reduced by 20.3 percent as 61.4 per cent respondents revealed that women did not face health problems as compared to earlier, and only 37.2 per cent respondents reported that women still face such health issues.

After solar electrification, 60.7 per cent respondents revealed that households could save some money due to a reduction in health problems as compared to earlier; on the other hand 29.8 per cent reported that households are still not able to save money.

After solar electrification, 69.2 per cent respondents reported that they feel safe while commuting in dark within the village, 98.4 per cent reported that they feel safe from accidental burns from kerosene lamps and firewood, 73.5 per cent reported that they feel safefrom wild creatures like snakes, scorpions, etc., and 88.5 per cent reported that there is safety from theft. After solar electrification, 7.7 per cent, 10.4 per cent, 31.9 per cent, 30.9 per cent and 11.2 per cent said that children study for 0-1 hours, 1-2 hours, 2-3 hours, 3-4 hours, and more than 4 hours per day in the evening and night respectively. After solar electrification, 73.3 per cent respondents revealed that children have started developing an interest in studies and their concentration has improved as compared to earlier, whereas 26 per cent revealed that there is no change. 81.4 per cent respondents revealed that children had improved their performance in exams as compared to earlier, and only 7.4 per cent revealed that there is no change in their performance.

After solar electrification, 93.6 per cent respondents revealed that households have started promoting female education as compared to earlier.

72.1 per cent respondents revealed that they want skill development programs to be implemented in their village, and just 6.4 per cent were not interested in such programs. 82.2 per cent revealed that it would be beneficial if the youth is trained for general working and maintenance of solar lighting systems.

78.3 per cent households reported that they are willing to prefer electric stoves, if they are made available, over other traditional methods of cooking,which means they wish to adopt green and clean cooking. 83.5 per cent respondents revealed that they are willing to pay more for electricity, and 10.7 per cent revealed that they are not willing to pay more.

It was revealed during the study that the major challenge in getting access to electricity connection from the utility grid was the distance of the households from nearest grid substation. This fact was known by the respondents which made them to adopt alternatives for electrification, as reliable electricity from grid was a far reality for them.

As per the second primary objective of the present study the life cycle cost of off-grid solar electricity for a remote village in Barmer district (case study I) for the 25 kW system capacity, excluding the environmental costs was calculated to be 4.81 Rs. /kWh and when the environmental cost benefits were added to it, the cost was further reduced to 0.25 Rs. /kWh. The LCC$_{GE}$ for the 25 kW system capacity project (for 6 h of grid-based power availability, similar to that of solar PV in Barmer) was calculated to be Rs. 15.24/kWh. The distance of the load centre from nearest existing grid pooling point is 8 km. The economic distance limit (EDL) (case I) for the 25 kW photovoltaic system~~s~~ in village Meghwalon ki Dhani, Barmer district at a distance of 8 km from the nearest grid point was calculated to be 4.86 km. This result implies that beyond a distance of 4.86 km, the extension of the conventional grid is not economically feasible in this particular case.

The life cycle cost of off-grid solar electricity for remote village in Kota district (case study II) for the 25 kW system capacity, excluding the environmental costs was calculated to be 4.10 Rs./kWh and when the environmental cost benefits are added to it the cost is further reduced to -0.45Rs./kWh. The LCC$_{GE}$ for 25 kW system capacity project and 6 h of grid-based power availability, similar to that of solar PV in Kota is Rs. 26.11/kWh. The distance of the load centre from nearest existing grid is 14 km. EDL for 25 kW photovoltaic systems in village Khanpuriya; Kota district (case II) with a distance of 14 km from the nearest grid point is calculated to be 3.98 km. This EDL means that beyond the distance of 3.98 km, the extension of the conventional grid is not economically feasible as the grid extension is highly capital intensive in this case as the distance of the load centre is nearly more than three times the EDL.

In establishing the difference in socio-economic conditions as well as reliability of power pre and post solar electrification, the data was exposed to further analysis by applying independent sample t test at 95% confidence level. These results further indicated that majority of the respondent using solar electricity were benefitted on a large scale economically as well as socially. There was a significant difference between conditions after solar electrification and before electrification situations in households, education facilities, health facilities and business.

7.2 CONCLUSIONS AND POLICY RECOMMENDATIONS

The remotely located and scantily populated villages in Rajasthan that were taken as case studies for solar energy based rural electrification in this research work have peculiar characteristics that favored decentralized energy systems for meeting their energy needs. Being located in hilly regions and desert-covered areas the extreme remoteness and very low and scattered population density of these villages lead to power demand values too low to justify huge investments in augmentation of the infrastructure of an existing centralized energy delivery system. This ultimately results in an increase in the cost of electrification of such villages, particularly by power transmission grid extension. Apart from economic viability and feasibility over extending the existing power network, it has also been observed from the present study that lives of the people in these remote villages has been positively influenced by decentralized solar PV systems based electrification.

The results of the analysis performed using paired-t-test have shown that there is a positive relationship between electrification and socio-economic determinants such as education, health, income and women-upliftment. Therefore, based on these results, the null hypothesis taken up for the present study that the household’s socio-economic determinants and the electricity adoption do not share a significant relationship was rejected. It was interpreted from the results that the rural households have been enjoying significant benefits after adoption of decentralized solar electrification. The quality of life of a large number of respondents has improved due to intervention of solar micro-grids in these villages. It was also recognized, that utilization of electricity has substantially benefitted the families of the households which owned small businesses like grocery shops and handicrafts etc.

Other than, health, education, income and women-empowerment; rural electrification was found to have a positive association with few other multifaceted social impacts such as raising standard of living, employment provision, the environmental safeguarding and many more. Consequently, when looked upon in a holistic perspective and as studied by the data collected; rural electrification has resulted in an improvement in the lives of people. It was also found that most of the parameters included in the study share a significant positive correlation with the electricity supply position of the village.

A significant difference is observed both pre and post solar electrification in all the studied villages. Villages electrified with solar micro-grids were found to have increased household income, enrollments in school, hours of study during evening, participation in non-formal education, consumption of energy and more free time owing to lower firewood collection; less indoor air pollution, and carbon dioxide emissions. All these impacts ultimately lead to a higher Human Development Index (HDI) and to some extent also contributed to attainment of a few of the Millennium Development Goals (MDGs).

Decentralized solar PV systems have provided a better quality and affordable source of electric power which has proven to be advantageous as it brings a light of hope to hundreds of such families and also cater to providing opportunities and a pleasant environment for social gatherings. The hope aroused and a feeling derived with the access of electricity itself is a positive impact on the lives of the people who have been living in dark for most of their life time. It is observed that as an infrastructure, availability of electricity has a potential to enhance the quality of the lives of rural masses in the future. It is indicated that with electricity access a significant positive change is brought as a result of ownership and use of electric appliances like televisions, refrigerators and other electrical devices in homes, shops, schools, hospitals and rural offices.

- **Remote rural electrification by off-grid solar PV systems**

This research as such carried out a study of the socio-economic impacts of solar PV based decentralized electricity systems for remote villages in Rajasthan. It has done so by establishing the need for such systems over extension of the power grid using detailed cost-benefit analysis based on life cycle costing approach. Apart from finding that solar PV based decentralized system has a lower life cycle cost than that for grid extension, this study also demonstrates that solar micro-grid system in the studied remote villages has contributed to improved quality of life for the people and thus is a good solution for electrification of the remote rural communities in India paving way for their economic growth and development. A very vital impact of such a technology based rural electrification has been observed to be the reduction of consumption and expenditure on kerosene for lighting purposes which was found to be substantial in households of all income groups due to the intervention of solar electricity. Women and children have been immensely benefitted as is proved in this study. Women found it easy to perform household activities and children were able to devote more time to studies during the evening hours which has enhanced their academic performance in schools. Availability of light in the village has also contributed to the decline in crimes and anti-social activities. Solar intervention has improved rural incomes both at micro and macro level. Reduced consumption of kerosene and traditional bio-fuels by the households has contributed to better health conditions and a comfortable environment both inside and outside the house.

Though the cost of electricity generation from renewable energy sources is much higher than that from the conventional energy sources, the decentralized RE options are substantially less capital intensive for the remote areas. For such areas the cost of RE is relatively affordable considering the high cost of laying down the transmission infrastructure of the centralized grid.

Keeping in view the positive impacts of electrification by solar PV, their decreasing costs and proven feasibility have given impetus to decentralized energy systems. Thus solar PV systems should be considered to electrify the remote rural areas as well as those areas where grid connection exists. This will help in reducing blackouts and provide solution to voltage problems and power quality problems and will provide reliable electric supply to the households. At the same time the climate change impacts will be addressed.

The present research study has pointed to a noticeable positive impact on the socio-economic condition and general quality of life for the people who inhabit the villages studied and who had never seen light before solar electrification. Their socio-economic profile was remarkably poor prior to solar intervention. Thus, it is recommended to implement such off-grid solar energy projects in other remote villages that are devoid of electricity since decades. Based on the findings of the study it is suggested that the process and planning of rural electrification should focus on the assessment of social impacts by utilization of electricity for households as well as for productive uses. Intervention and promotion of electricity could help in supporting the rural business, increase the agricultural productivity and enhancing the overall economy of the rural villages. Thus, it is suggested that policy planning should target decentralized micro-grid based on solar energy for rural electrification.

- **Green and Clean Cooking Mission and Skill Development Programme**

It is recommended that government should promote the use of electric stoves for cooking in rural households as a Green and Clean Cooking Mission and for that the appliances should be made easily available at a low cost. It is also recommended that the government should extend its skill development programs in these remote communities post electrification via such off-grid solar projects to make such solutions more economically feasible and beneficial to rural communities. This could result in income generating options for the villagers through carpentry, handicrafts, pottery, weaving and tailoring etc to improve the local economies and generate employment.

- **Enhancing Regulatory Framework**

Despite having an exclusive ministry for renewable energy sources and a huge potential of solar energy, the growth of solar and other renewable energy sources in India is insignificant in terms of production of electricity. Therefore, the policy and regulatory framework is required to be reformed in order to utilize maximum from the enormous potential of these resources in India. There is a need to enhance and promote the adoption of solar energy and not just the addition of generation capacity to improve the economies. Further, it is observed that the main focus of the government policies is to provide the capital subsidies on solar energy to the poor. On the contrary, there is a need to focus on the maintenance of the installed solar systems and training of the rural youth to get involved in the correct operation and maintenance of the projects.

- **Public-Private-Partnership**

Another important aspect in which India lags behind is the inadequate focus on promotion of Public-Private-Partnership. Promotion of Public-Private-Partnership could result in better functioning of the solar PV programs as this will improve the financial as well as the institutional structure of the programs. At the same time, it is suggested to encourage the private sector and NGOs to penetrate in the rural electrification sector, using this tested off-grid solar technology for the remote areas. This could be a very good initiative under the CSR projects. To a large extent it is likely to reduce migration of rural labour to urban centres. Hence, it can be said that decentralized electricity will pave way to a healthy decentralized economy.

- **Strengthen the Institutional Framework**

It is recommended to strengthen the institutional framework of such projects as it was analyzed during this study that solar projects with strong management and monitoring mechanisms could be helpful for smooth operation of the systems. It is found in the study that, sustainability features of solar PV programs could be enhanced and maintained by different institutional innovations. Introducing innovative practices in delivery model will help in making the projects sustainable and will also enhance the satisfaction of the consumers. It has been revealed by the findings of the study that with better understanding and sensitivity towards the PV systems people have developed a positive attitude for the service provided to them. Though the electricity from solar PV systems almost becomes free of cost in long term and is highly subsidized for the poor, it is suggested that a minimum charges should be applied on the consumers for the use of electricity and should not be provided to them free of cost. This will instigate a sense of responsibility towards the system which will help in better utilization and operation of the system and energy. As the people show little sincerity towards the systems provided to them for free than for the services for which they pay, therefore to make them understand the worth of the system, involvement of user’s money in it is important.

Consequently, it is important to understand that other than the technical aspects the institutional as well as financial aspects are of equal importance for the sustainability and viability of any such rural electrification program. Therefore, to achieve the effectiveness of the economic incentives provided the strong institutional framework is needed as this would also improvise on the quality of operation and management of the PV systems. Policies should also focus on the training of the local people for sustainable operation and maintenance of the systems.

- **Adopting EDL**

Further, it is important to understand the economics of electrification, the cost involved in the supply of power including cost of generation, transmission and distribution for the possible alternatives of energy generation sources. EDL is an important concept which is suggested to be calculated before deciding the mode of electrification for remote and hilly regions for a comprehensive assessment of various electrification options for a region.

It is inevitable to note that as India striving to achieve the growth rate of 8 percent and above, rural electrification based of decentralized solar energy systems would help in achieving the goal. The increase in cost of conventional energy could be mitigated by adopting solar energy; this will also provide the opportunities to meet the requirements of Kyoto Protocol and is beneficial for long term energy security. Most important of all, rural electrification brings with it rural employment opportunities and other social development benefits which in turn raise the Human Development Index of the country.

To conclude this study could help in achieving energy planning and energy security of rural and remote population. At the same time, promotes solar energy deployment and adoption in India and the state.

7.3 RESEARCH CONTRIBUTIONS OF THE PRESENT STUDY

The present study is an attempt to analyze the socio-economic impacts of the rural electrification based on decentralized solar energy in Rajasthan. In this study the researcher has analyzed the social-economic impact on the lives of the rural population as well as has carried the cost comparison of solar PV systems with that of utility grid extension.

Based on the present research, the researcher has tried to throw light on the benefits of adoption of solar energy systems for rural electrification. The study aims at encouraging and promoting solar power generation for remote areas. This study can prove to be helpful in achieving energy planning and energy security of the rural and remote population.

Furthermore, it will be helpful in assessing the employment generation opportunities with solar implantations. In the study of the social profile (health and education) of rural areas for further implementations and improvement which can be promising in increasing growth trends.

This research could be beneficial for the think tanks and policy makers as it highlights several policy initiatives which could be adopted for improving the rural electrification scenario and promoting solar energy along with achieving energy security in India.

The research study can provide a base for further research in national and state level rural electrification strategies.

7.4 LIMITATIONS OF THE PRESENT STUDY

The macro level study of the economic, agricultural and animal husbandry profile of the villages could not be carried due to unavailability of the data and diversity of the villages. In addition to this due to unavailability of data the equity and returns could not be included in the cost comparison as in few cases it was not involved also. Further, during the analysis few of the variables did not show expected significant results.

It was observed that the relationship of women upliftment with electrification is a bit complicated and needs extensive data, so that could not be explained explicitly in the present research. The same limitation was faced with the willingness to pay for solar systems by the stakeholders.

Due to the fact that no villages with pre-installed decentralized solar projects were present in the east zone of the State, this zone was excluded from the study. Thus, this collectively renders a scope to carry the research further on this topic with the left out aspects.

7.5 AREA OF FURTHER RESEARCH

To carry the research further, the loan and equity aspects could be included to study the cost comparison of solar PV systems vis-à-vis utility grid extension. Macro level (taking into account the village profile as a whole instead of household demographic profile) socio-economic analysis could be done to understand the impacts of solar projects more exclusively for the expansion of rural electrification programs. An extensive study could be carried out exclusively on women-upliftment based on scenario of after installation solar PV systems in remote areas.

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ANNEXURES

ANNEXURE I

HOUSEHOLD SURVEY TEMPLATE FOR SOCIO-ECONOMIC IMPACT ASSESSMENT OF DECENTRALIZED RURAL ELECTRIFICATION BASED ON SOLAR ENERGY

Household Profile

PART 1: Address of Interviewee

Date of Interview:

Village:

District:

PART 2: General Information about the Household

1.1 Name of Respondent:

1.2 Gender of Respondent:

Male	
Female	

1.3 Age of Respondent: Tick the range

<20 years	
20-30 years	
30-40 years	
40-50 years	
>50 years	

1.4 Education Level of Respondent: (tick)

Never attended school	
Attended primary school	
Attended junior middle school	
Attended senior middle school	
College level or above	

1.5 Occupation of Respondent:(Tick)

Casual Labour	
Farmer	
Teacher	
Business person	
Other	

1.6 Monthly income of the household: (tick the range)

<4000 Rs	
4001-6000 Rs	
6001-8000 Rs	
8001-10,000 Rs	
>10,000 Rs	

1.7 Household size (No.):

Total	
Male	
Female	
Children	

Information on Household Electricity and Fuel Uses

PART 1: General Information

2.1 What is your source of electricity?

[1] Conventional Grid (Electricity supplied by government by transformers or poles/towers etc.) ( )

[2] Solar PV ( )

2.2 If you are using Solar PV, any possibilities of being connected to the conventional grid in the near future?

Yes ( ) No ( )

PART 2: Consumption Pattern

2.3 Monthly electricity and fuel consumption

TYPE	Price per unit (in Rs)	Before Solar Electrification		After Solar Electrification	
		Units consumed/month	Cost (Rs./month)	Units consumed/month	Cost (Rs./month)
Solar Electricity		**N.A.**	**N.A.**	KWh	
Firewood		Kg		Kg	
Kerosene		Ltr.		Ltr.	
LPG		Cylinder.		Cylinder.	

<u>Household Attitudes</u>

<u>PART 1: Your Views on Energy Options</u>

3.1 Views on energy from fuels like Kerosene/Firewood: (before electrification)

Category	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Good Availability					
Good Reliability					
Lower cost					
Easier Maintenance					
Good for Health					
Good for Safety					
Outstanding overall view					

3.2 Views on electricity generated from solar energy: (after electrification)

Category	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Good Availability					
Good Reliability					
Lower cost					
Easier Maintenance					
Good for Health					
Good for Safety					
Outstanding overall view					

3.3 Benefits of solar electricity:

Were the following facilities available before electrification?

Category	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Entertainment (watching TV, social gatherings etc.)					
Information and Education					
Women Upliftment					

Are these facilities available now (after solar electrification) and do you find them beneficial?

Category	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Entertainment (watching TV, social gatherings etc.)					
Information and Education					
Women Upliftment					

PART 2: IMPACTS

3.4 Uses of Solar Light (please tick)

a) For what purpose do you use solar electricity also mention the hours devoted to these activities per day? (Please tick)

Purpose	**Hours devoted before solar electrification per day**	**Hours devoted after solar electrification per day**
Household		
Studies		
Agriculture		
Business		
Others		

b) Do you agree that you were satisfied with the brightness of fuel you used **before solar electrification** (like kerosene or candle) or are you more satisfied now with the **brightness of solar light (after electrification)**? (Please tick)

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

3.5 Impact on Livelihood and Income

a) For what kind of livelihood activity do you use solar light? And for how many hours you work on these activities during the evening? (Please tick)

	Before Solar Electrification					**After Solar Electrification**				
Activity	0-2 hrs	2-4 hrs	4-5 hrs	5-6 hrs	>6 hrs	0-2 hrs	2-4 hrs	4-5 hrs	5-6 hrs	>6 hrs
Agriculture										
Grocery shop										
Vegetable vendor										
Weaving and tailoring										
others										

b) Average monthly income earned from the above activities:

Average monthly income (in Rs)	**Before solar electrification**	**After solar electrification**
< 1000		
1001-3000		
3001-5000		
5001-7000		
>7001		

c) How much you spend on kerosene/candles to meet your lightening needs every month?

Monthly expenditure (in Rs) on lightening needs by kerosene/candles	**Before solar electrification**	**After solar electrification**
< 60		
61-100		
101-200		
201-300		
> 301		

d) How many members of your family were/are involved in income generating activities?

	Before Solar Electrification	**After Solar Electrification**
Number of Persons		

3.6 Impact on Upliftment of women

a) Have the solar light decreased the workload of women in your family? (please tick)

Response	***Workload was less before electrification***	***Workload is less after solar electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

b) Women had more free time for other activities earlier or have now? (please tick)

Response	***Had more free time before electrification***	***Have more free time after solar electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

c) In what activities women get involved before and after? (please tick)

	Before Electrification	***After Electrification***
Income generating		
Household work		
Creative stuff		
Leisure time with family		
Others		

d) Do they contribute to family income by these activities?

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

e) Do women feel safer in the evening/night? (please tick)

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

f) Do women go out more often during evening/night now (with solar light) or they used to earlier?(Please tick)

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

3.7 *Impact on health*

a) While cooking with kerosene lamp did you face any health problems like a headache, breathing problem, watery eyes, red eyes etc. and do they come across such problems with the use of solar light? (please tick)

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

b) How frequently did you visit the doctor for these problems per month? (Please tick)

	Before Electrification	***After Electrification***
< 2 times		
2-4 times		
4-6 times		
6-8 times		
> 10 times		

c) Do you think solar lighting has helped you save the money spent on doctor visits or you saved more before?

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

d) Give your views on a safety before and after the solar light intervention. (please tick)

Before electrification

Safety	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Safety while commuting in dark within village					
Safety from accidental burns from kerosene lamps and firewood.					
Safety from wild creatures, like snakes and scorpions etc.					
Safety from theft					

After electrification

Safety	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Safety while commuting in dark within village					
Safety from accidental burns from kerosene lamps and firewood					
Safety from wild creatures, like snakes and scorpions etc.					
Safety from theft					

e) In the case of an emergency at night, what do you do to visit nearest health centre/doctor/nurse? (please tick)

Case	**Before solar electrification**	**After solar electrification**
Use Kerosene lamps		
Call for help		
Wait till morning		
Use solar light	N.A.	

3.8 Impact on Education

a) For how many hours children study in the evening and night? (please tick)

Hours	**Before solar electrification (with kerosene lamp and candles)**	**After solar electrification**
0-1		
1-2		
2-3		
3-4		
>4		

b) Children used to concentrate more and develop an interest in studies before or now? (Please tick)

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

c) Their grades/marks were better before or have improved now after the intervention? (Please tick)

	Better Before Electrification	***Better After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

d) Female education was more before or is there any increase in female education, after solar electrification? (Please tick)

	Before Electrification	***After Electrification***
Strongly Disagree		
Disagree		
Undecided		
Agree		
Strongly Agree		

PART 3: Training Programme

3.9 ***Skill Development Programme:***

Is there any skill development programme being implemented by government/agency in the village? (Please tick)

Yes ( ) No ( )

3.10 Do you wish to have such are a programme? (Please tick)

Strongly Disagree	
Disagree	
Undecided	
Agree	
Strongly Agree	

3.11 Do you think that it would be beneficial if, the youth of village is trained for general working and maintenance of solar lightening systems? (Please tick)

Strongly Disagree	
Disagree	
Undecided	
Agree	
Strongly Agree	

3.12 If electric stoves for cooking are made available, will you be willing to prefer them over other methods of cooking? (Please tick)

Strongly Disagree	
Disagree	
Undecided	
Agree	
Strongly Agree	

PART 4: Affordability and Willingness to Pay for Solar Energy Systems

3.13 Would you be willing to pay more for electricity if more reliable service will be provided? Please tick.

Strongly Disagree	
Disagree	
Undecided	
Agree	
Strongly Agree	

3.14 How much are you able to pay for a solar energy system (per month)? (Please tick)

Less than 200 Rs	
201 - 500 Rs	
501 - 1000 Rs	
More than 1000 Rs	

3.15 How much are you willing to pay for a solar energy system (per month)? (Please tick)

Less than 200 Rs	
201 - 500 Rs	
501 - 1000 Rs	
More than 1000 Rs	

3.16 How much are you willing to pay with a possible loan (per month)? (Please tick)

Less than 200 Rs	
201 - 500 Rs	
501 - 1000 Rs	
More than 1000 Rs	

3.17 How would you like to pay for the solar energy system? (Please tick)

Lump Sum	
Two Payments	
Three Payments	
Monthly Payments	

List of variables with acronyms

Variables	Variables defined	Acronyms
Expenditure on Kerosene and Fuel	1) a) Expenditure on Kerosene before electrification b) Expenditure on Kerosene after electrification 2) a) Expenditure on firewood before electrification b) Expenditure on firewood after electrification	1) a) EXPKER_bef b) EXPKER_aft 2) a) EXPFIR_bef b) EXPFIR_aft
Impact on Livelihood and Income	1) a) No. of hours devoted for income generating activities before electrification b) No. of hours devoted for income generating activities after electrification 2) a) Monthly Income from these activities before electrification b) Monthly Income from these activities after electrification 3) a) No. of Employed Members in the family before electrification b) No. of Employed Members in the family after electrification	1) a) AGRI_bef GROSH_bef VEGVEN_bef WEATAI_bef OTHER_bef b) AGRI_aft GROSH_aft VEGVEN_aft WEATAI_aft OTHER_aft 2) a) MONTINC_bef b) MONTINC_aft 3) a) EMPMEM_bef b) EMPMEM_aft

Impact on Women Empowerment	1) a) Household workload before electrification b) Household workload after electrification 2) a) Leisure time before electrification b) Leisure time after electrification 3) a) Other activities before electrification b) Other activities after electrification 4) a) Income contribution before electrification b) Income contribution after electrification 5) a) Safety during evening/night hours before electrification b) Safety during evening/night hours after electrification 6) a) Socializing during evening/night hours before electrification b) Socializing during evening /night hours after electrification	1) a) WRLD_bef b) WRLD_aft 2) a) LESTM_bfr b) LESTM_aft 3) a) INCGEN_bef HOSWRK_bef CRESTF_bef OTHER_bef b) INCGEN_aft HOSWRK_aft CRESTF_aft OTHER_aft 4) a) INCGEN_bef b) INCGEN_aft 5) a) SAFEVNT_bef b) SAFEVNT_aft 6) a) EVENGT_bef b) EVENGT_aft

Impact on Health	1) a) Health problems before electrification b) Health problems after electrification	1) a) HEAPRO_bef b) HEAPRO_aft
	2) a) Doctor visits before electrification b) Doctor visits after electrification	2) a) DOCVST_bef b) DOCVST_aft
	3) a) Expenditure on doctor before electrification b) Expenditure on doctor after electrification	3) a) EXPDOC_bef b) EXPDOC_aft
	4) a) Other benefits before electrification b) Other benefits after electrification	4) a) SAFCM_bef ACCBUR_bef WLDCR_bef THEFT_bef b) SAFCM_aft ACCBUR_aft WLDCR_aft THEFT_aft
	5) a) Medical emergency at night before electrification b) Medical emergency at night after electrification	5) a) KERLAM_bef CFH_bef WTM_bef USL_bef b) KERLAM_aft CFH_aft WTM_aft USL_aft

Impact on Education	1) a) No. of hours before electrification b) No. of hours after electrification 2) a) Concentration before electrification b) Concentration after electrification 3) a) Grades/marks before electrification b) Grades/marks after electrification 4) a) Female education before electrification b) Female education after electrification	1) a) NHOUR_bef b) NHOUR_aft 2) a) CONCTN_bef b) CONCTN_aft 3) a) GRDMRK_bef b) GRDMRK_aft 4) a) FMEDU_bef b) FMEDU_aft
Impact on Entertainment and Information	1) a) Entertainment and information facilities before electrification b) Entertainment and information facilities after electrification	1) a) ENTER_bef INFEDU_bef b) ENTER_aft INFEDU_aft

ANNEXURE II

STRUCTURE OF INDIAN POWER SECTOR

India's power sector prolongs to be a central pillar of its overall growth and development. Thus being a vital subject, the Indian Power Sector is regulated by the Central as well as the state government. The entire structure of Indian power sector is portrayed in table a below.

Table a: Structure of Indian power sector

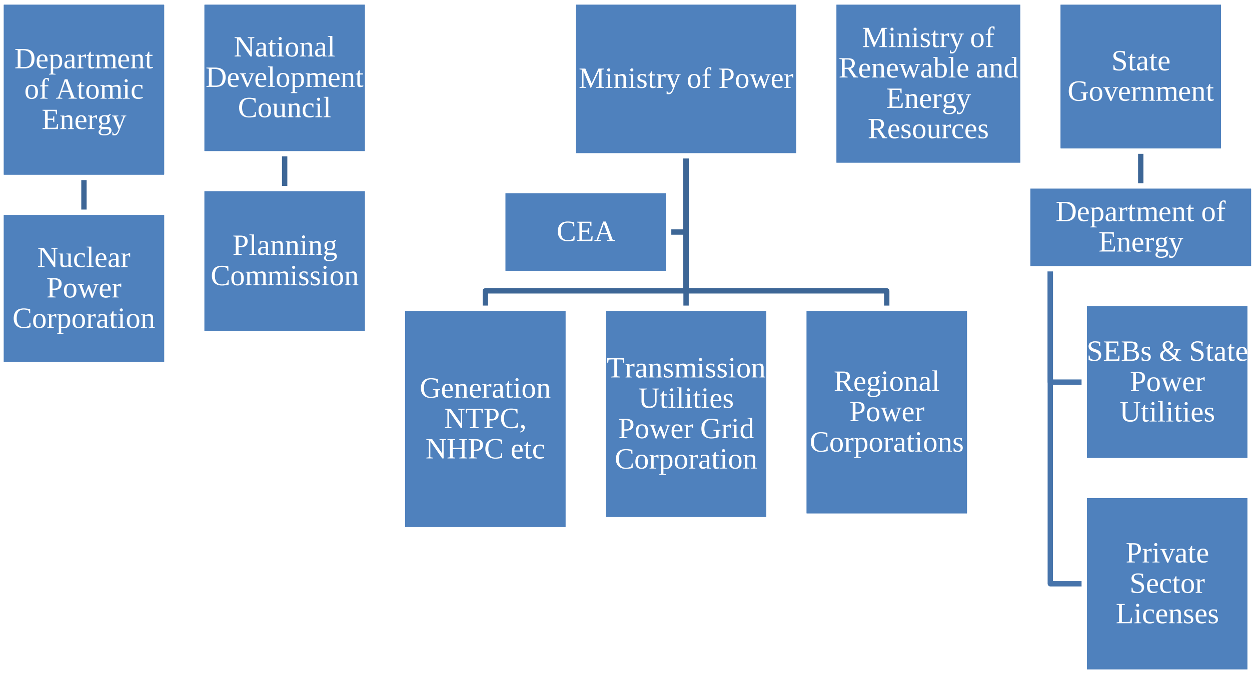
Policy Making	Central Government State Governments
Planning	Central Electricity Authority State Planning Departments
Regulation	Central Electricity Regulatory Commission State Electricity Regulatory Commission
System Operators	National Load Despatch Centre Regional Load Despatch Centres State Load Despatch Centres
Generation	Central Generating Stations Joint Ventures of Centre & State State Generating Stations Private Units
Transmission	Central Transmission Utility State Transmission Utilities Private Units
Traders	Traders designated to trade across borders Inter-state traders Intra-state traders
Distribution	Distribution arm of State Electricity Boards Distribution Companies Private Companies Franchises
Financial Institutions	Power Finance Corporation Rural Electrification Corporation
Energy Conservation	Bureau of Energy Efficiency

Source: *Energy Policy, India Energy Handbook, 2011*

INSTITUTIONAL STRUCTURE OF POWER SECTOR IN INDIA

The specified functions, internal organizational structure, roles and responsibilities, projects, services, programmes etc. in the area of generation, transmission, distribution, power trading, financing, training and consultancy of apex bodies, PSUs, JVCs, Statutory bodies, Non- banking financial organizations and Autonomous bodies in power sector are carried forward and looked after by different organizations present at central, state and regional level. The complete institutional structure of Indian power sector is illustrated below in figure a.

Figure a: Institutional structure of power sector of India



Source: *Asian Journal of Energy and Environment*

CEA: Central Electricity Authority

SEBs: State Electricity Boards

NTPC: National Thermal Power Corporation

NHPC: National Hydro Power Corporation

ORGANIZATIONAL STRUCTURE OF RENEWABLE ENERGY SECTOR IN INDIA

The organizational structure that is responsible for the administration of development of the alternate energy resources other than conventional power is as follows:

a) India's Ministry of New Renewable Energy (MNRE),
b) National Thermal Power Corporation Vidyut Vyapar Nigam Ltd., (NVVNL)
c) Energy development agencies in the various States and
d) The Indian Renewable Energy Development Agency Limited (IREDA).

The detailed structure is mentioned in Table b below.

Table b: Structure of renewable energy sector in India

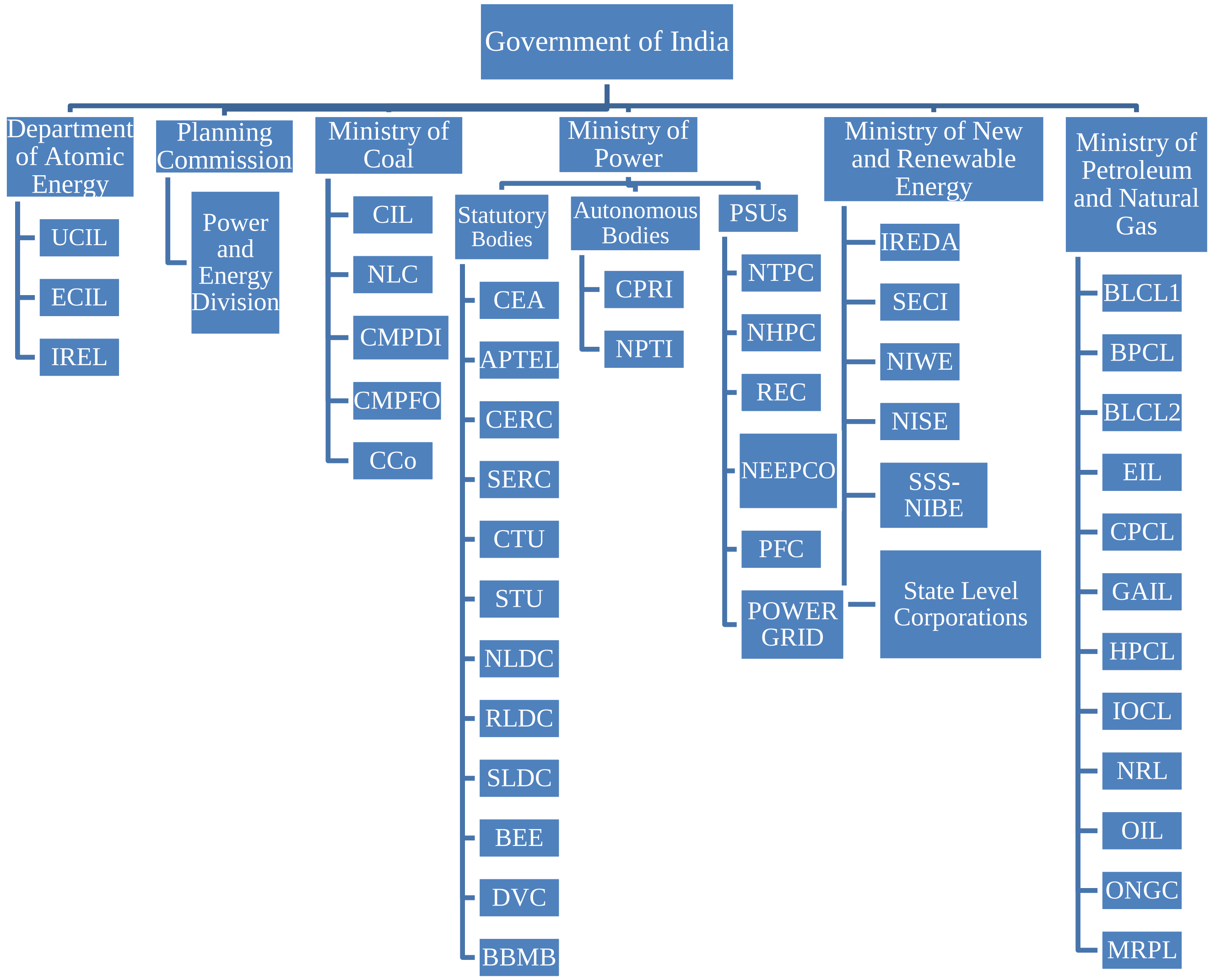
Policy Making	Central Government Ministry of New and Renewable Energy
Planning	Planning Commission Ministry of New and Renewable Energy
Regulation	CERC at the Centre SERCs at the State
Financial Institution	Indian Renewable Energy Development Agency

Source: *Energy Policy, India Energy Handbook, 2011*

ORGANIZATIONAL ARRANGEMENT OF ENERGY SECTOR

The government of India has designed the complete organizational structure of the Indian Power Sector formulating organizations, institutions, appellate and subsidiary bodies to regulate the smooth functioning and formulation of policies in power sector. In figure b the entire organizational structure is portrayed.

Figure b: Organizational structure of energy sector of India



Source: *www.powermin.nic.in*

UCIL: Uranium Corporation of India Limited

ECIL: Electronics Corporation of India Limited

IREL: Indian Rare Earths Limited

CIL: Coal India Limited

NLCIL: Neyveli Lignite Corporation India Limited

CMPDI: Central Mine Planning and Design Institute

CMPFO: Coal Mines Provident Fund Organization

CCO: Coal Controller’s Organization

CEA: Central Electricity Authority

APTEL: Appellate Tribunal for Electricity

CERC: Central Electricity Regulatory Commission

SERC: State Electricity Regulatory Commission
CTU: Central Transmission Utility
STU: State Transmission Utility
NLDC: National Load Despatch Centre
RLDC: Regional Load Despatch Centre
SLDC: State Load Despatch Centre
BEE: Bureau of Energy Efficiency
DVC: Damodar Valley Corporation
BBMB: Bhakra Beas Management Board
CPRI: Central Power Research Institute
NPTI: National Power Training Institute
NTPC: National Thermal Power Corporation
NHPC: National Hydroelectric Power Corporation
REC: Rural Electrification Corporation
NEEPCO: North Eastern Electric Power Corporation
PFC: Power Finance Corporation
POWER GRID: Power Grid Corporation of India
IREDA: Indian Renewable Energy Development Agency
SECI: Solar Energy Corporation of India
SSS-NIBE: Sardar Swaran Singh National Institute of Bio-Energy
NIWE: National Institute of Wind Energy
NISE: National Institute of Solar Energy
BLCL1: Balmer Lawrie and Co. Limited.
BPCL: Bharat Petroleum Corporation Limited
BLCL2: Biecco Lawrie Co. Limited
CPCL: Chennai Petroleum Corporation Limited
EIL: Engineers India Limited
GAIL: Gas Authority of India Limited
HPCL: Hindustan Petroleum Corporation Limited
IOCL: Indian Oil Corporation Limited
NRL: Numaligarh Refinery Limited
OIL: Oil India Limited
ONGC: Oil and Natural Gas Corporation Limited
MRPL: Mangalore Refinery and Petroleum Limited.

ANNEXURE III

SOLAR PV SYSTEMS SIZING AND PROJECT FINANCING: PRELIMINARIES

Life Cycle Cost Analysis of Solar PV

1) Deciding the system capacity (using case study I)

The plant has been commissioned already with the system capacity of 25 kW. We are intending to do the reverse calculation in order to learn how this capacity was decided.

No. of households = 100

L = Daily average household load = 121 W

Daily operational hours = 6 hrs (standard for solar photovoltaic systems)

Total load of village = 121 W × 6 hrs × 100 households (/1000) = 72.6 kWh per day.

PV capacity depends on load units.

No. of units generated annually = No. of units required annually

Therefore, 72.6 kWh ×365 = 26499 units

Hence,

Required PV capacity = $\frac{Total\ units\ generated\ annually\ (kWh)}{Availability\ factor\ \times 365\ \times Radiation\ (hrs)}$ **Eq. 1** (TERI, 2007)

Generally, Availability factor for solar PV is taken as 1; which means that PV is available all the time, which is not true. Therefore, using the formulae in Eq. 2 we calculate the availability factor for solar PV.

A.F. = $\frac{No. of days of annual sunshine}{No. of days in one year}$ × $\eta_{Battery}$× matching factor × $[1 - \beta\ (T_{Cell} -\ 25℃]$

Eq. 2 (TERI, 2007)

Where,

$\beta$is Temperature coefficient which is equal to 0.005/℃

No. of days of annual sunshine are around 300~330

$\eta_{Battery}$ is efficiency of the battery.

The matching factor is the ratio of electrical output under actual operating conditions to the electrical output if the array was operating at its maximum power point. It is also called module factor which has been taken approximately equal to 1 in this case.

A.F = $\left(\frac{300}{365}\right) \times 0.85 \ \times 1 \times \ (1 - 0.005 \times 25)$

A.F. = $\frac{300}{365}$ ×0.85×1×0.875

A.F. = 0.82191… × 0.85 ×0.875

A.F. = 0.611301

Using peak-sun method of sizing PV, generally the Radiation is taken to be equal to 6.92 kWh/m^2/day/hr (Nouni, Mullick, & Kandpal, 2008).

For the peak sun method based sizing of PV, the value of 6.92KWh/m^2/day/hr for the annual average daily solar irradiance for Barmer was taken.

Note: this value of radiation stands for a number of hours on a day when the sun is at peak (1000 W/m^2).

Putting all the values in Eq. 1:

Required capacity = $\frac{26499}{0.610 \times 365 \times 6.92} \cong 17.18\ kWp$

Dividing this with the safety factor relating to module system degradation:

Required capacity = $\frac{17.18}{0.85} \cong 20.21 kW$

Analyzing the increasing energy requirements in near future, the capacity must have been decided to be kept at 25 kW.

2) Cost of electricity generated

The life cycle cost approach is based on providing one representative value of energy cost over the years. The project cost depends on fixed cost (capital cost of PV system including the cost of the battery, module, and transmission lines), variable cost (Operational and maintenance cost and replacement cost) and negative cost (subsidy on capital cost and carbon emission benefits).

For a lifetime of 25 years of a project:

1…………………………	2	3	4	5	…………	25
Capital cost	R1	R2	R3	R4	………..	R25
Subsidy	O&M1	O&M2	O&M3	O&M4	……….	O&M25
Carbon Benefit	CV1	CV2	CV3	CV4	…………	CV25

In the first year, capital cost is invested and subsidy is received for the project, after which from the second year of the project the variable cost is invested every year in operation and maintenance and replacement of batteries.

Present Value or Present Worth:

Present value (P) is the current worth of a future stream of cash flows based on a specific rate of return. Future cash flows are discounted at the discount rate. It is important to note that, the higher is the discount rate; the lower will be the present value of the future cash flows. Determination of appropriate discount rate is the key parameter for calculating the present and future worth. In this case, the discount rate is taken to be 10.7% according to the CERC guidelines.

Present Value (P) = $\frac{Future\ Value}{(1+d)^n}$ (Willis & Scott, 2000)

Further, the O&M is usually expressed as a fraction of capital – β. The O&M fraction increases at a rate of e_0% every year.

$e_0$is the escalation of O&M.

$$OM_{PV} = OM_0 \left[\frac{1+e_0}{d-e_0}\right]\left[1 - \frac{(1+e_0)^n}{(1+d)}\right]$$

In the present case study, $e_0 = 0$, therefore,

OM$_{PV}$ = OM$_0\left[\frac{1}{d}\right]\left[1 - \left(\frac{1}{1+d}\right)^n\right]$

$OM_{PV} = OM_0 \left[\frac{1}{d}\right]\left[\frac{(1+d)^n-1}{(1+d)^n}\right]$ (Kolhe, Kolhe, & Joshi, 2002)

Therefore, as the present worth is used in calculating O&M fraction, from the above equation we derive present worth factor to be:

$$P = \frac{(1+d)^n - 1}{d\,(1+d)^n}$$

Now, LCC for PV is:

$$\mathrm{LCC_{PV}} = \frac{C_{PV} + C_B + C_{t\&D} + C_{subsidy} + (C_{PV} + C_B + C_{t\&D}) \times \beta \times P + C_R \times P}{Total\ units\ of\ electricity\ generated\ over\ lifetime}$$

In case study I, O&M is taken only for 5 years and the fixed amount for O&M is Rs. 3 Lakh.

$$\mathrm{LCC_{PV}} = \frac{C_{PV\,system} - C_{subsidy} + C_{O\&M} \times P_1 + C_R \times P_2}{25\ kW \times 6\ hrs \times 365\ days \times 25\ years}$$

P_1 = present worth factor for PV system; n=25 years

P_2 = present worth factor for battery; n=6 years

$$\mathrm{LCC_{PV}} = \frac{(56.5+20.5) - 22.5 + 3 \times 8.609 + 1.64 \times 4.26}{25 \times 6 \times 365 \times 25}$$

$\mathrm{LCC_{PV}}$ = Rs. 6.19/kWh (for the case I when O&M is taken for 5 years).

Now, if the tariff is Rs. 6.19 at which households are supplied electricity then monthly bill of one household would be = 121W×6h×30 days×6.19 = Rs. 134.81per month. This amount is higher than what the beneficiaries in the present case are paying. They pay a fixed amount of Rs. 100 per month for the same electricity consumption. As the system is free for them, this collection is used for operation and maintenance of the system after 5 years (as O&M was provided only for 5 years). Thus, this a business model adopted in the village by the implementing organization to generate revenue for O&M.

Further, if the carbon emission benefits are added to the cost then it is reduced to Rs. 2.04/kWh.

Life cycle cost analysis for Grid Extension

The data for LCC grid extension was collected from published and unpublished sources. The interviews were conducted with the concerned officials of power utilities in the state to get access to required data which is unpublished. The published data was extracted from the ARR of JVVNL, JDVVNL, and AVVNL and from reports of state power utilities along with the CERC guidelines.

The cost of grid line (11 KV) for remote areas (Rs. 9.9 lakh/km), arrived from interview method (the officials consulted RERC guidelines order no. 338).

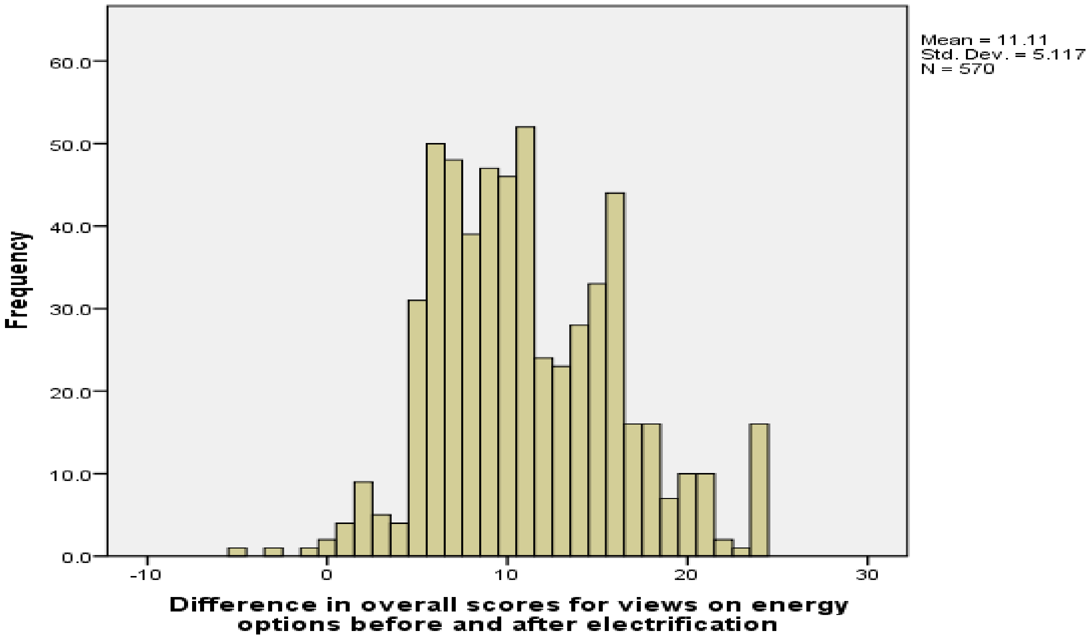
The cost of distribution transformer (Rs. 44150 for around 50 KVA) for 11/.04kv line also arrived from interview method.

The discount rate was taken to be 10.7% according to CERC guidelines. Transmission and distribution losses were taken from ARR of JVVNL and JDVVNL. The fraction of capital cost for operation and maintenance was also taken to be 0.5% according to the CERC guidelines.

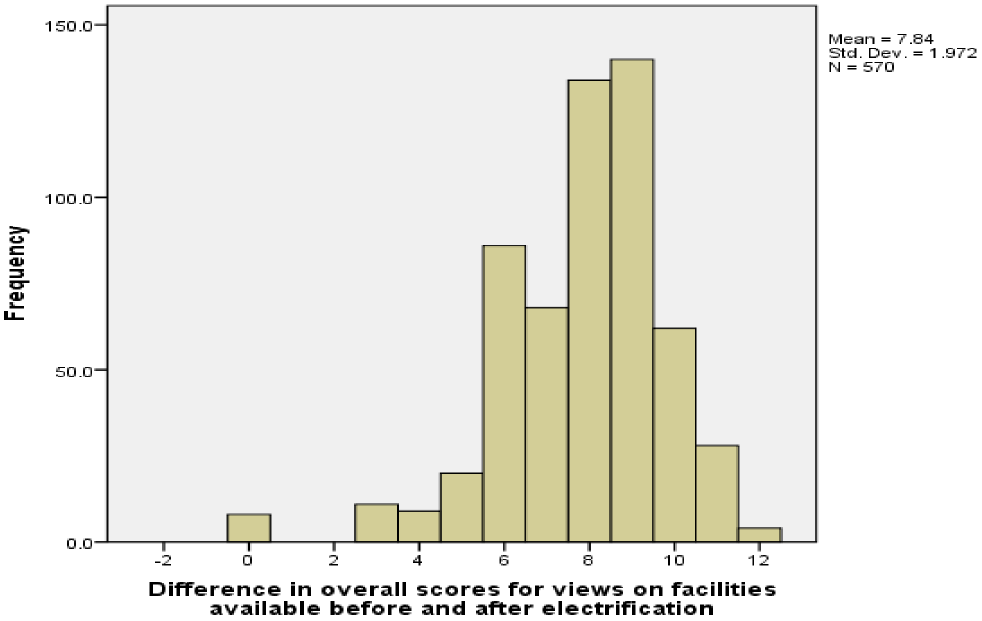
ANNEXURE IV

NORMALITY TEST GRAPHS

Views of Respondents on Energy Options

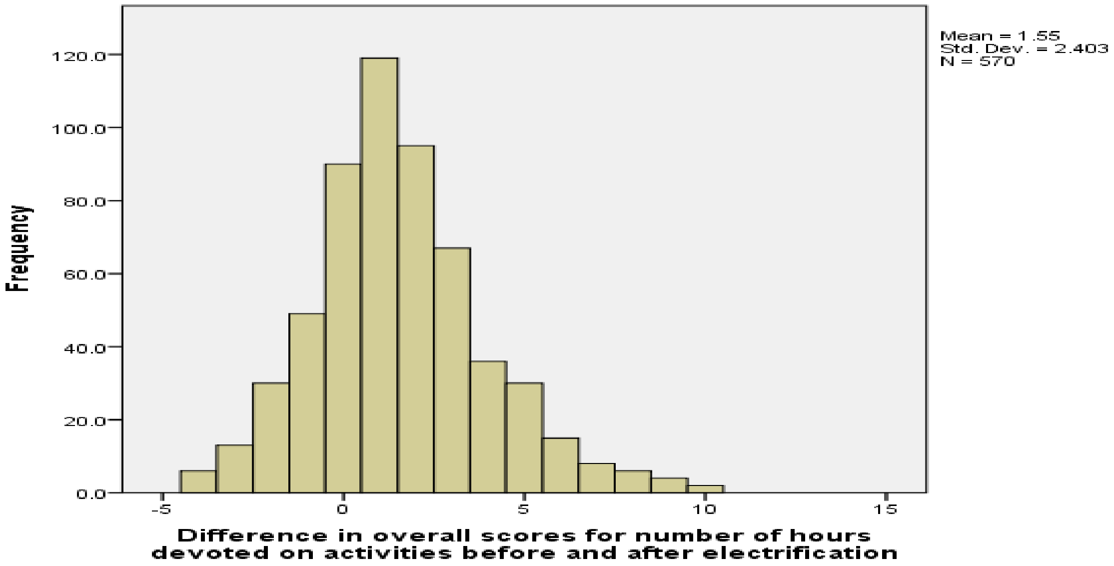


Benefits of Solar Electricity

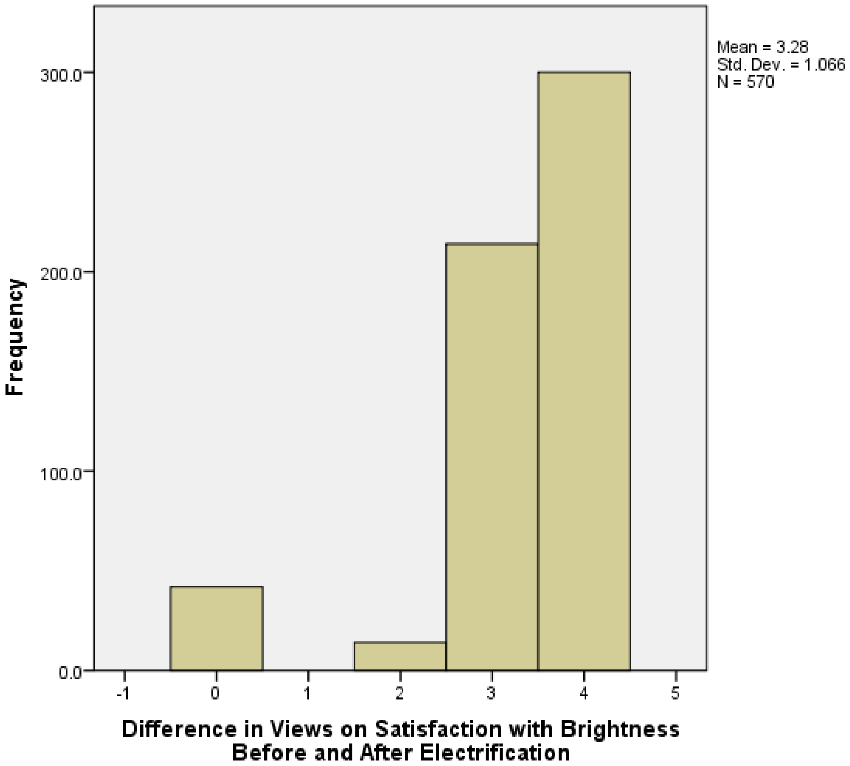


USES OF SOLAR LIGHT

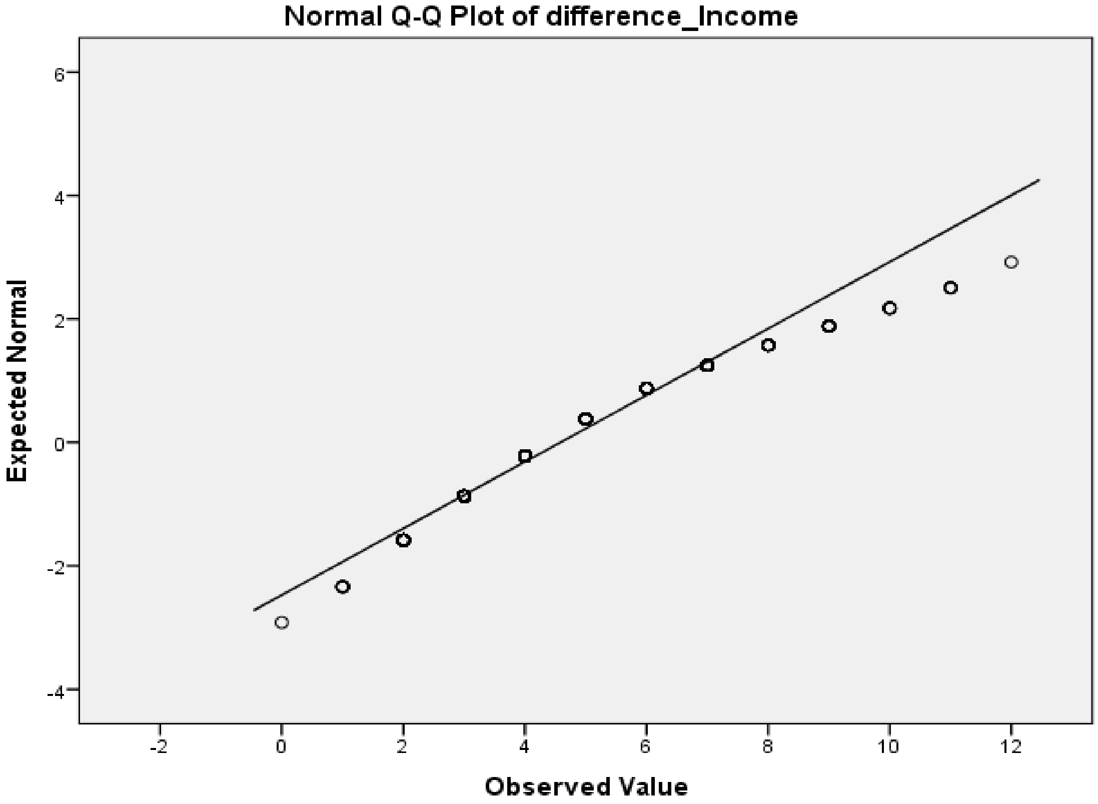
Hours Devoted to Activities by Households



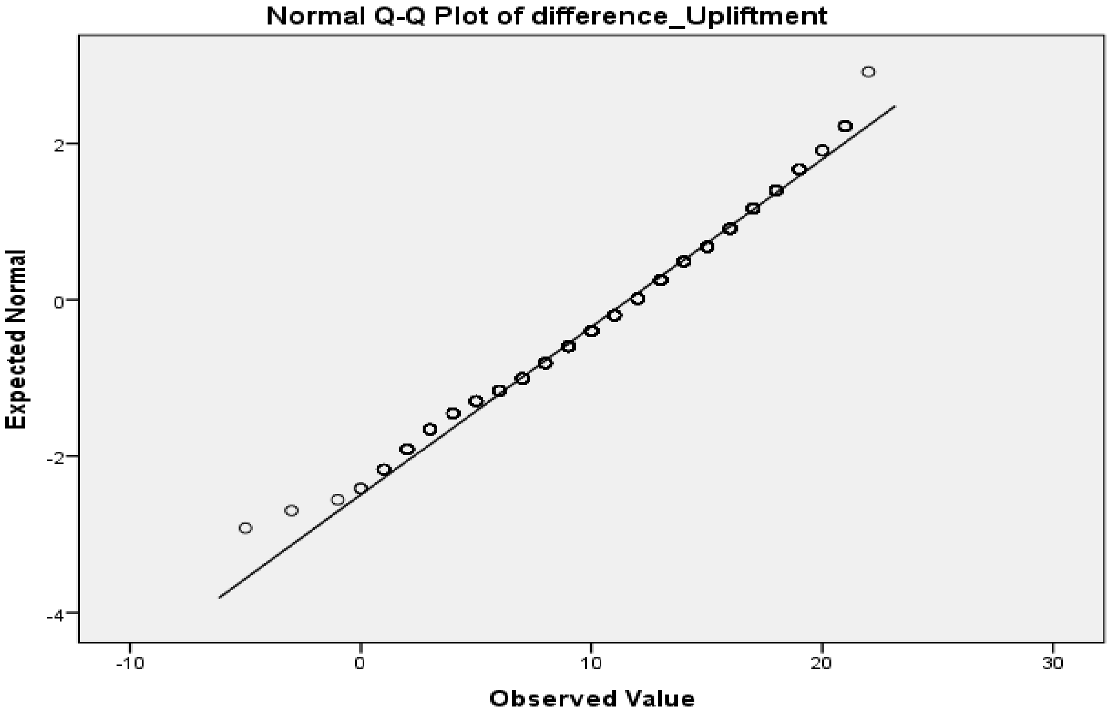
Brightness of Fuel



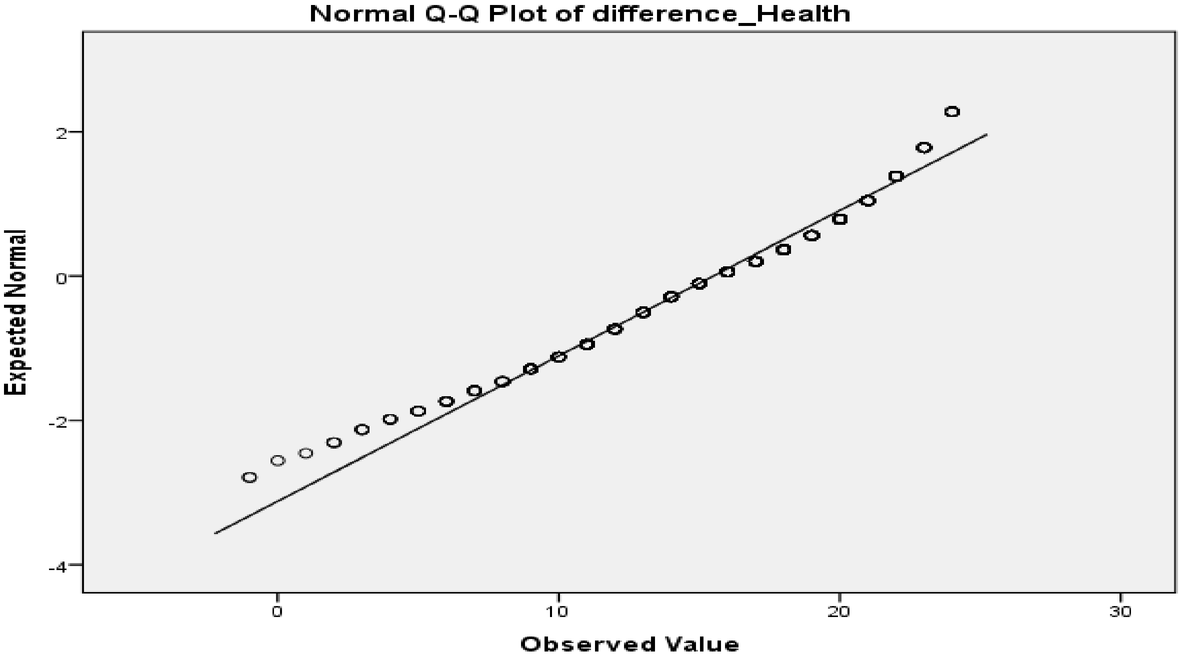
IMPACT ON INCOME AND LIVELIHOOD



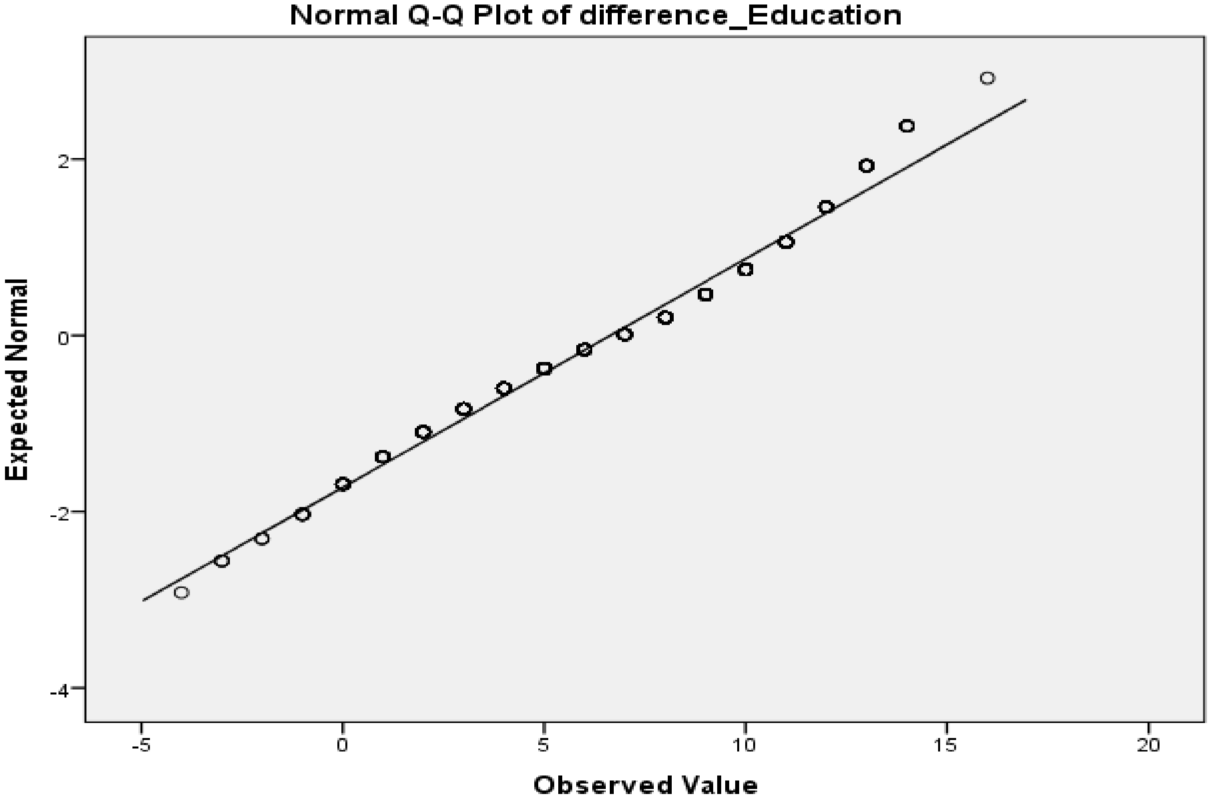
IMPACT ON UPLIFTMENT



IMPACT ON HEALTH

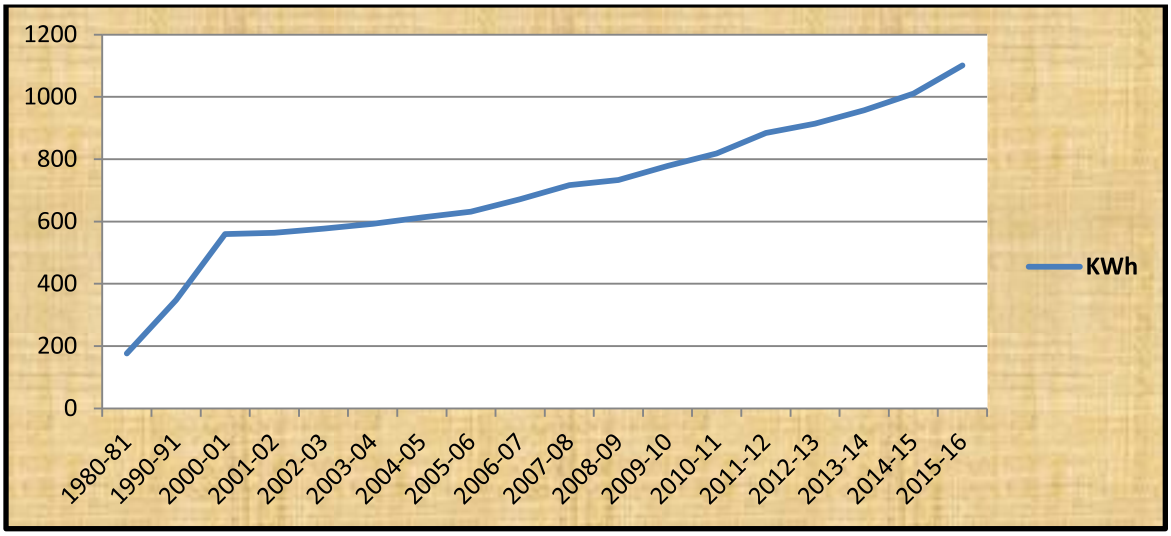


IMPACT ON EDUCATION



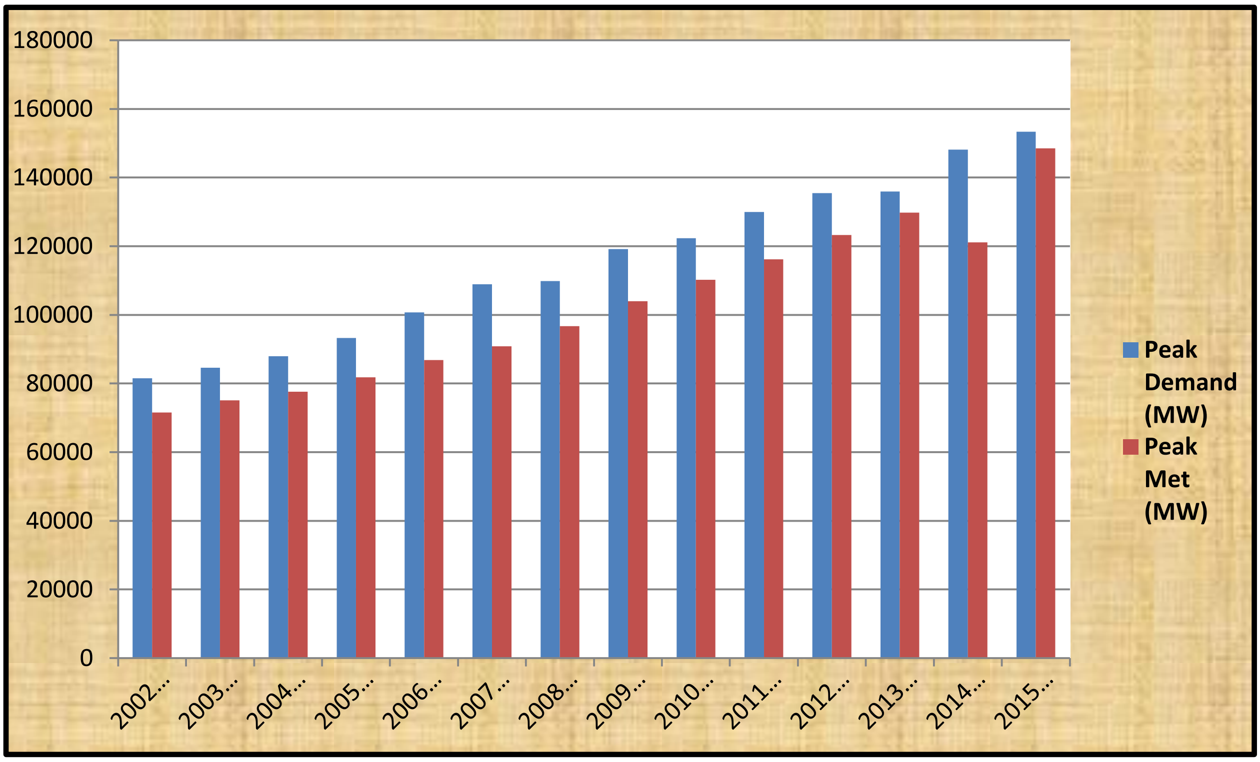
ANNEXURE V

Figure 1: Growth of per capita electricity consumption in India



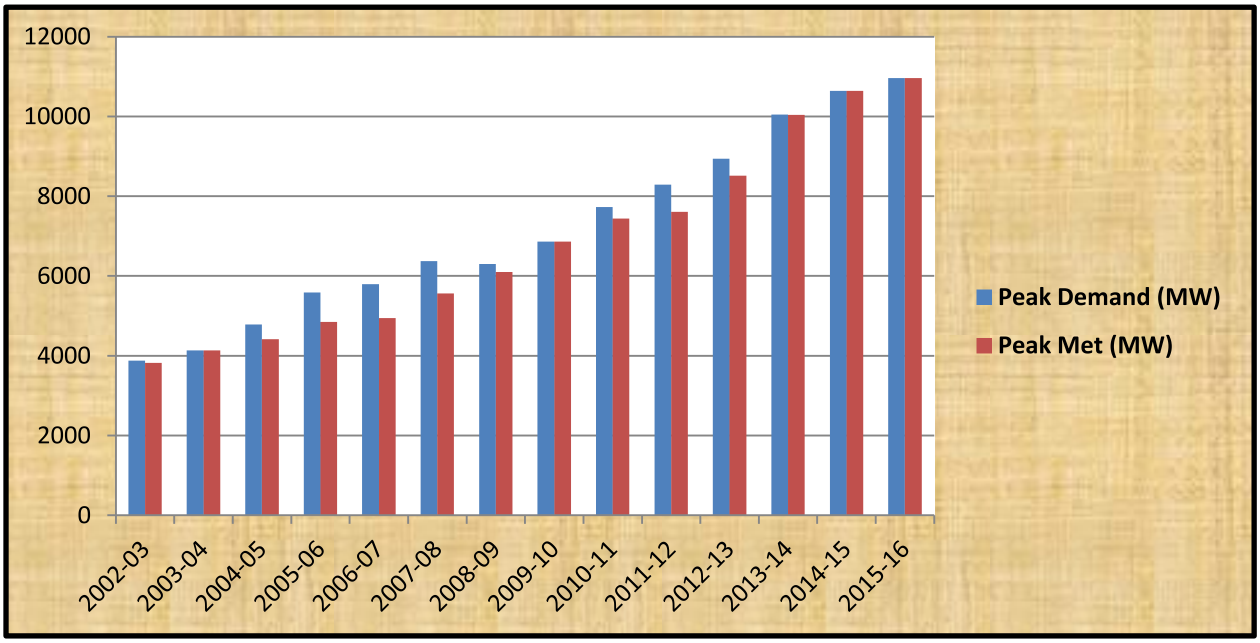
Source: *GoI, Central electricity authority report 2016*

Figure 2: Growing power deficit in India



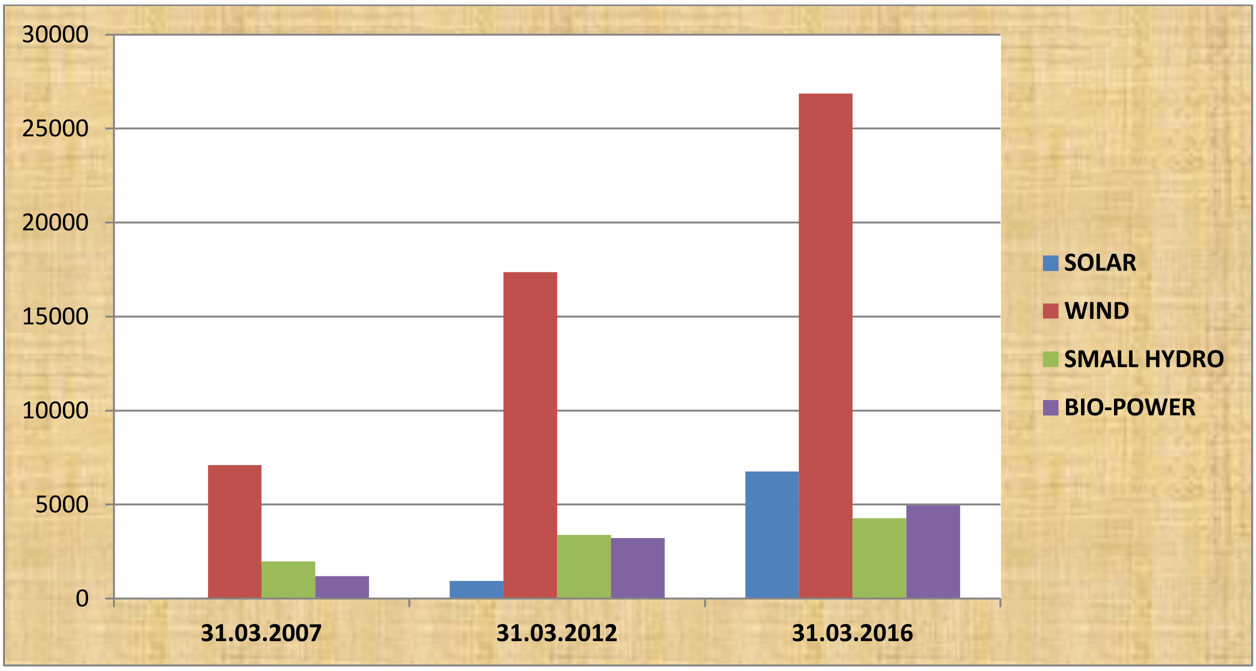
Source: *powermin.nic.in/en/content/power-sector-glance-all-India*

Figure 3: Power deficit trends in Rajasthan



Source: *Compiled from various annual Load Generation Balance Report, CEA.*

Figure 4: Development of renewable energy in India (Capacity in MW)



Source: *National electricity plan, 2016, CEA*

Figure 5: Gender-wise distribution of respondents (in %)

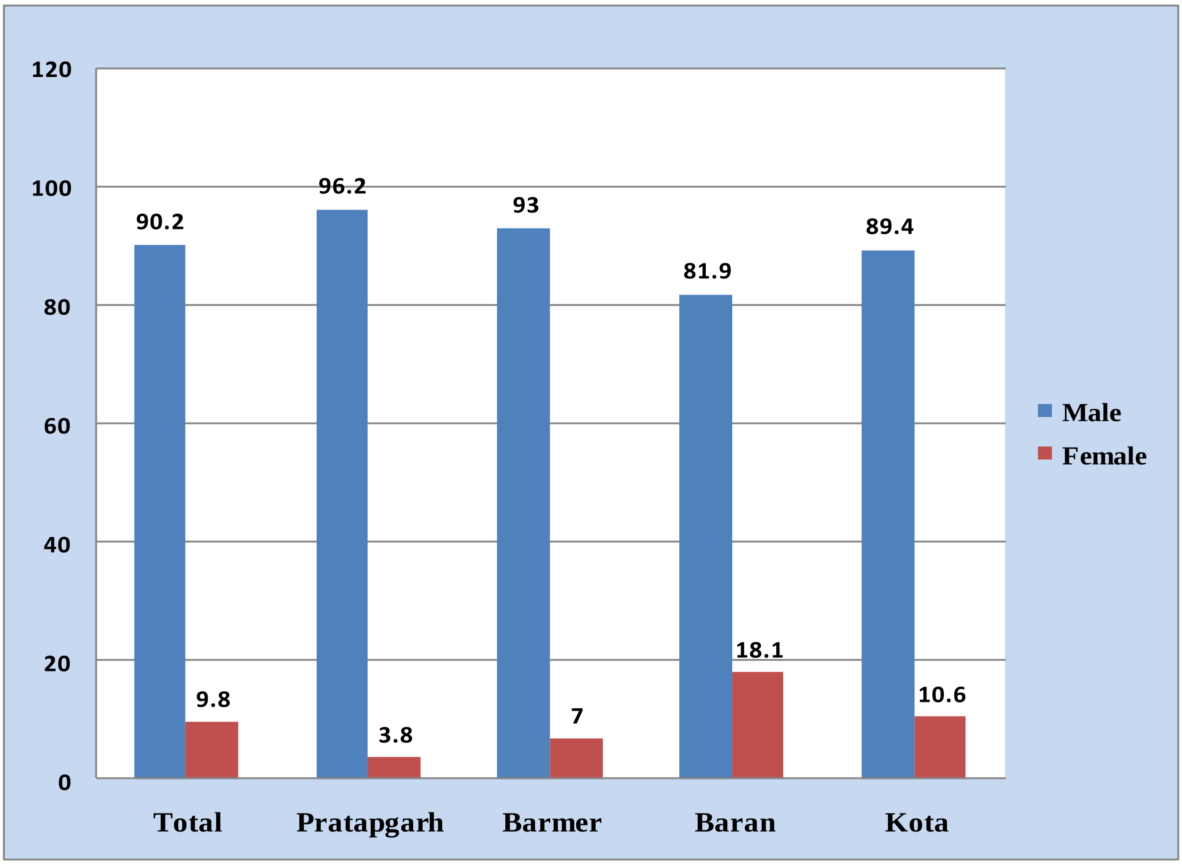


Figure 6: Age-wise distribution of respondents

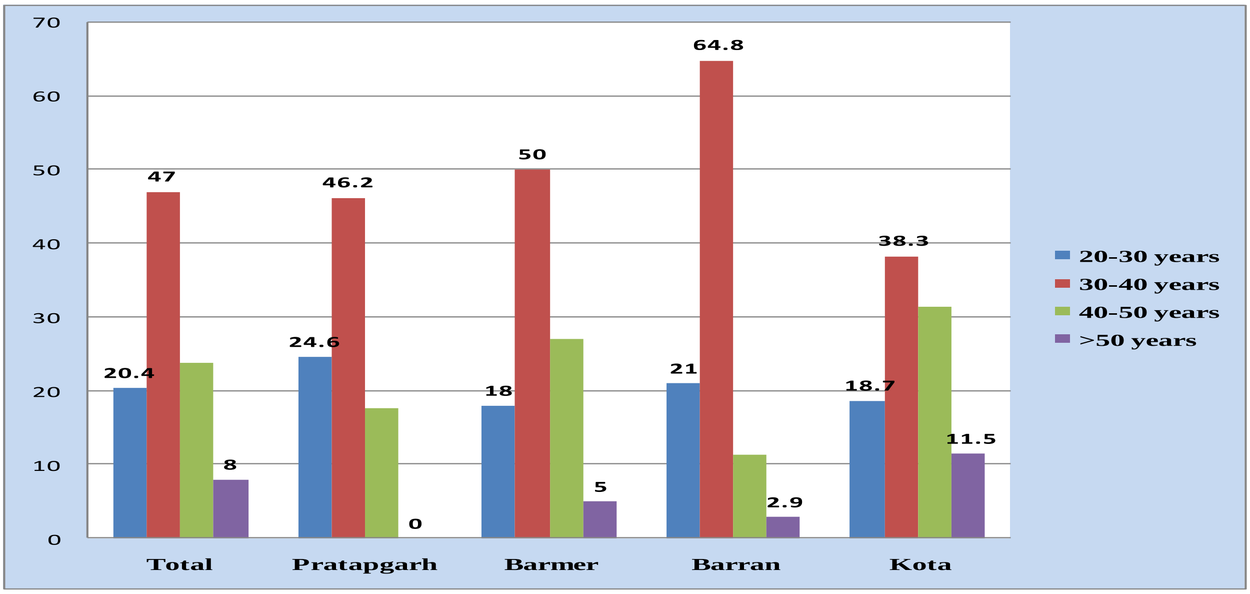


Figure 7: Education level wise distribution of respondents

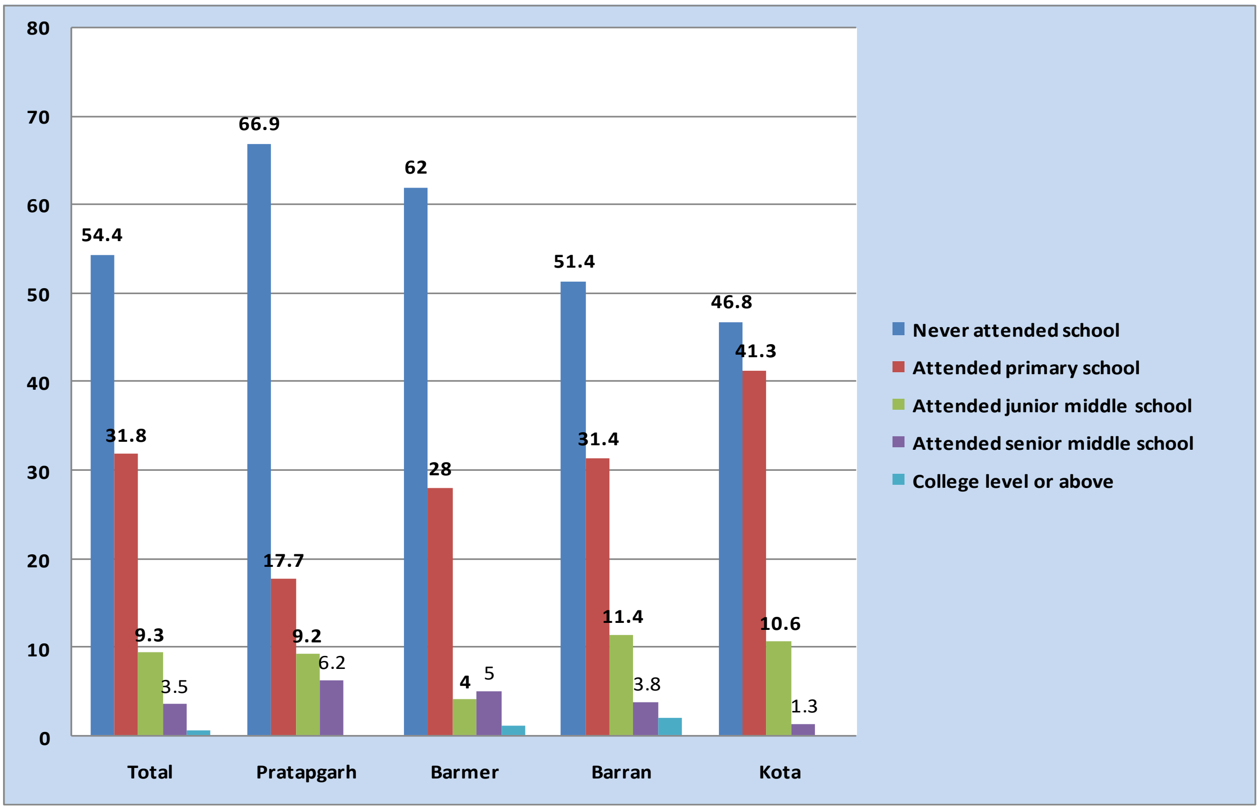


Figure 8: Occupations level-wise distribution of respondents

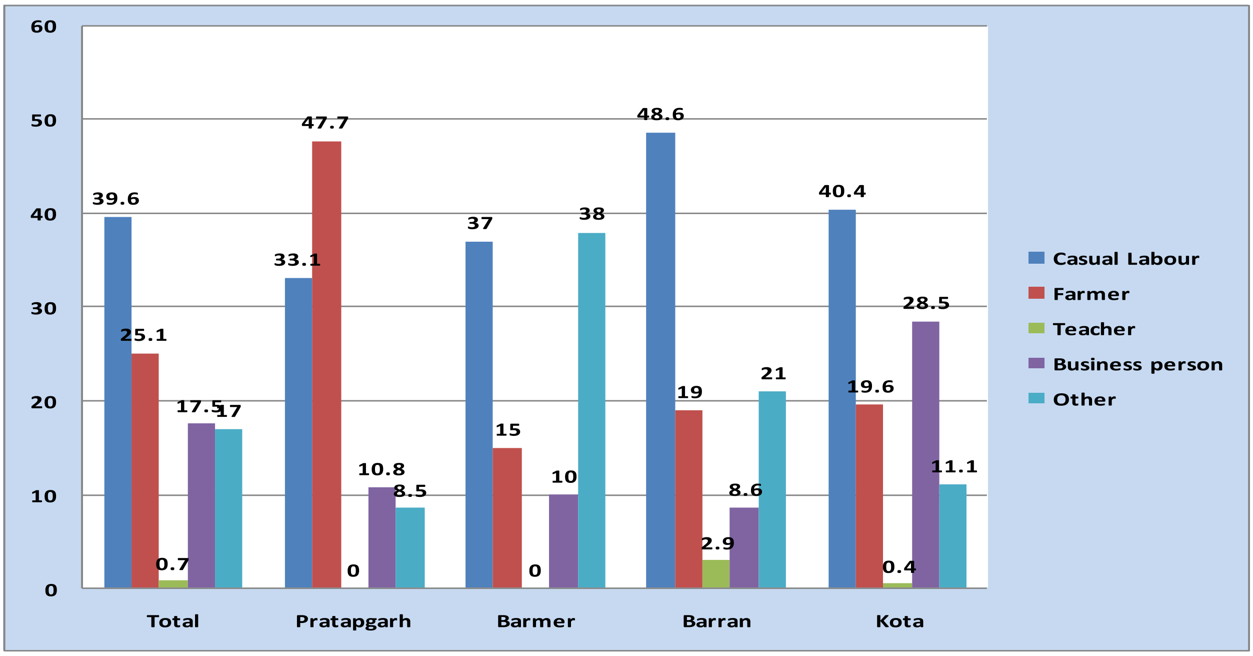


Figure 9: Monthly income-wise distribution of respondents (in %)

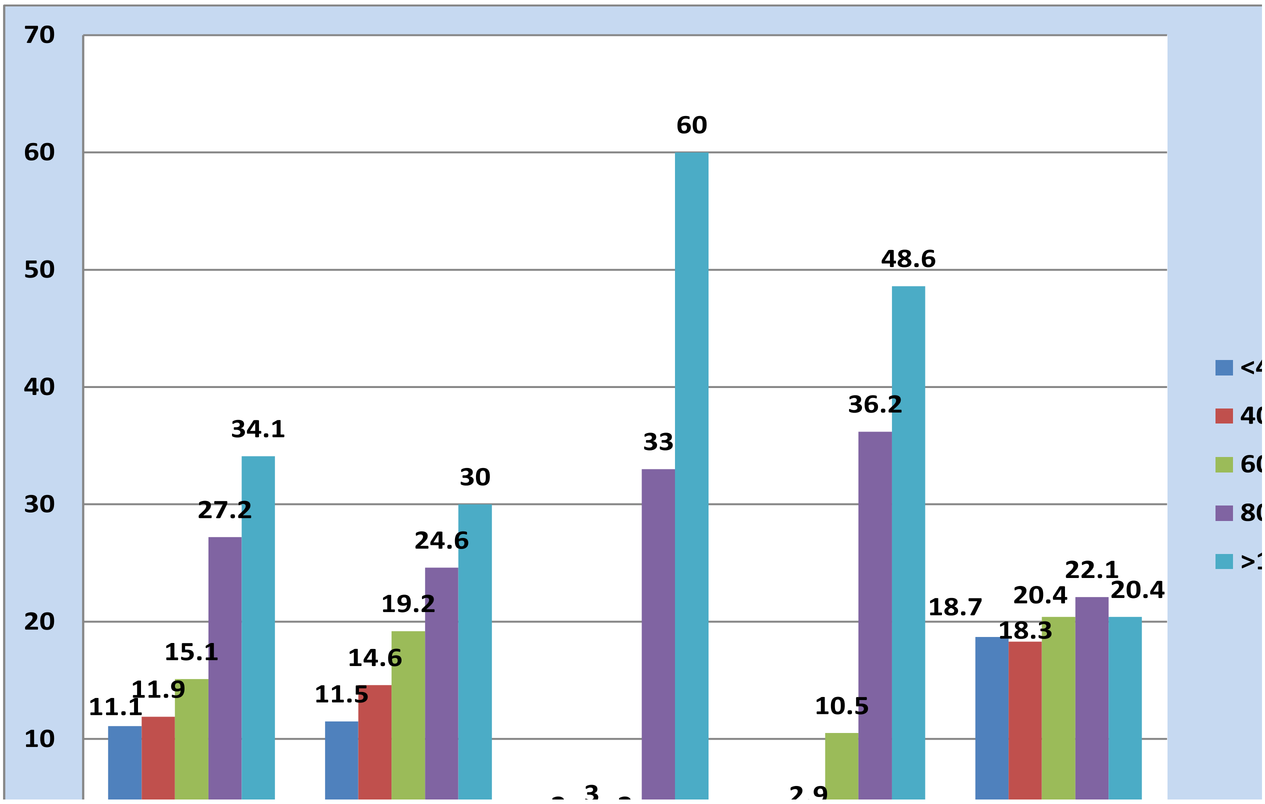


Figure10: Household size-wise distribution of respondents

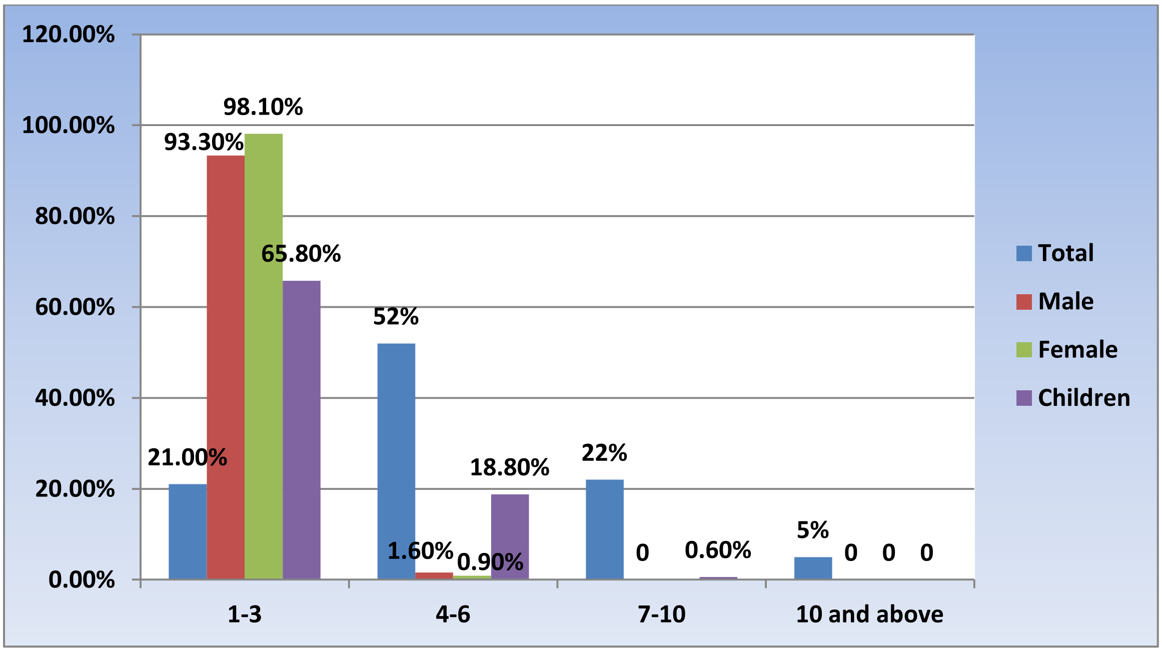


Figure 11: Monthly fuel consumption expenditure of households

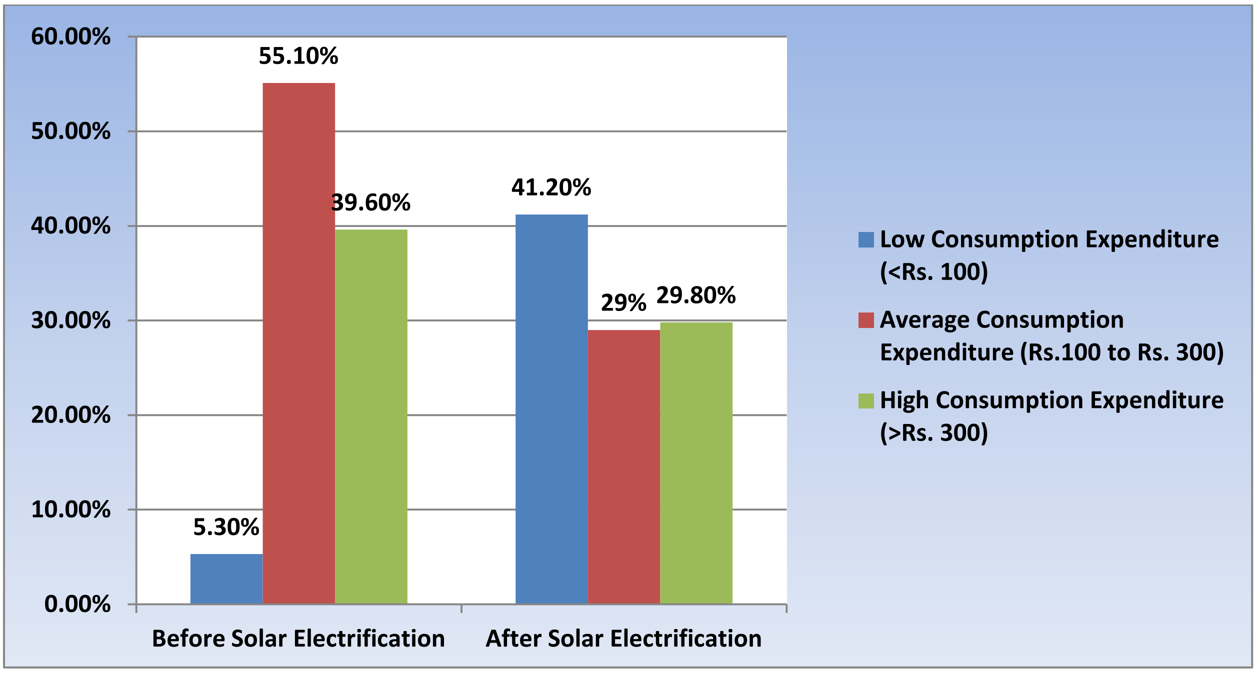


Figure 12: Views on energy for lighting from kerosene and firewood

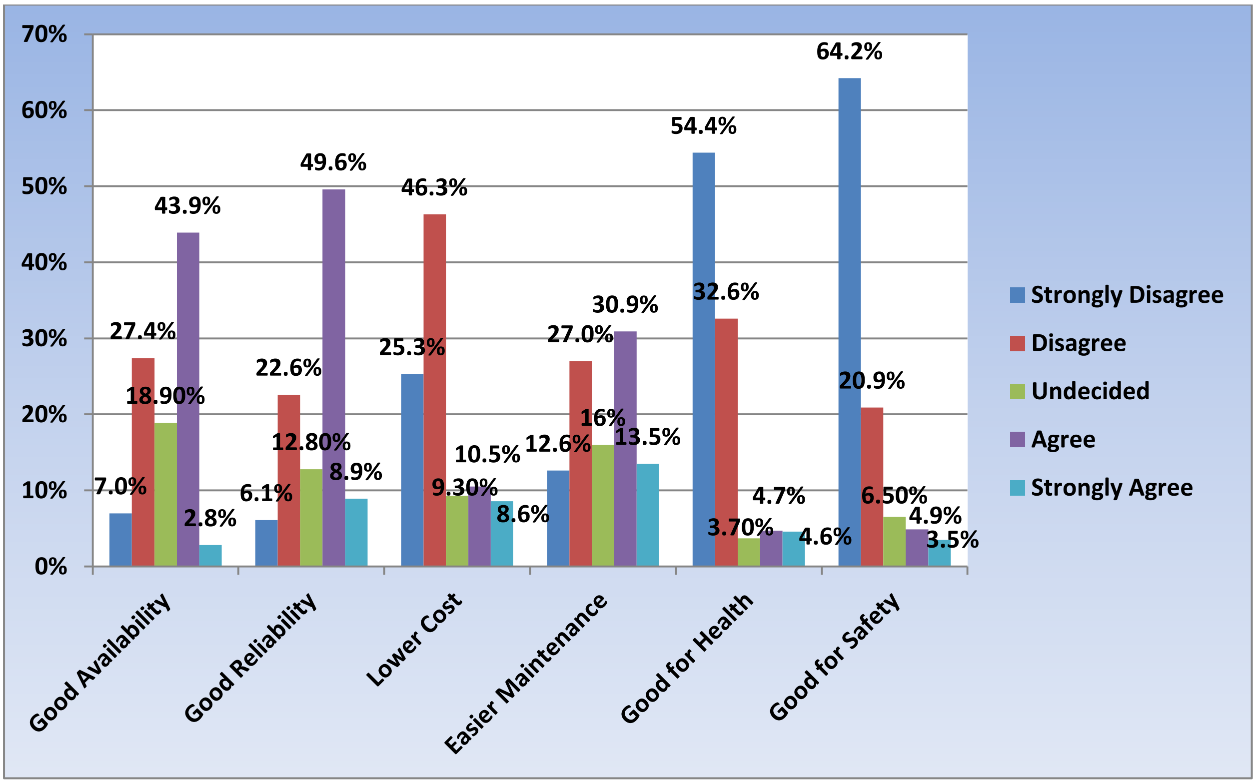


Figure 13: Views on electricity generated from solar energy

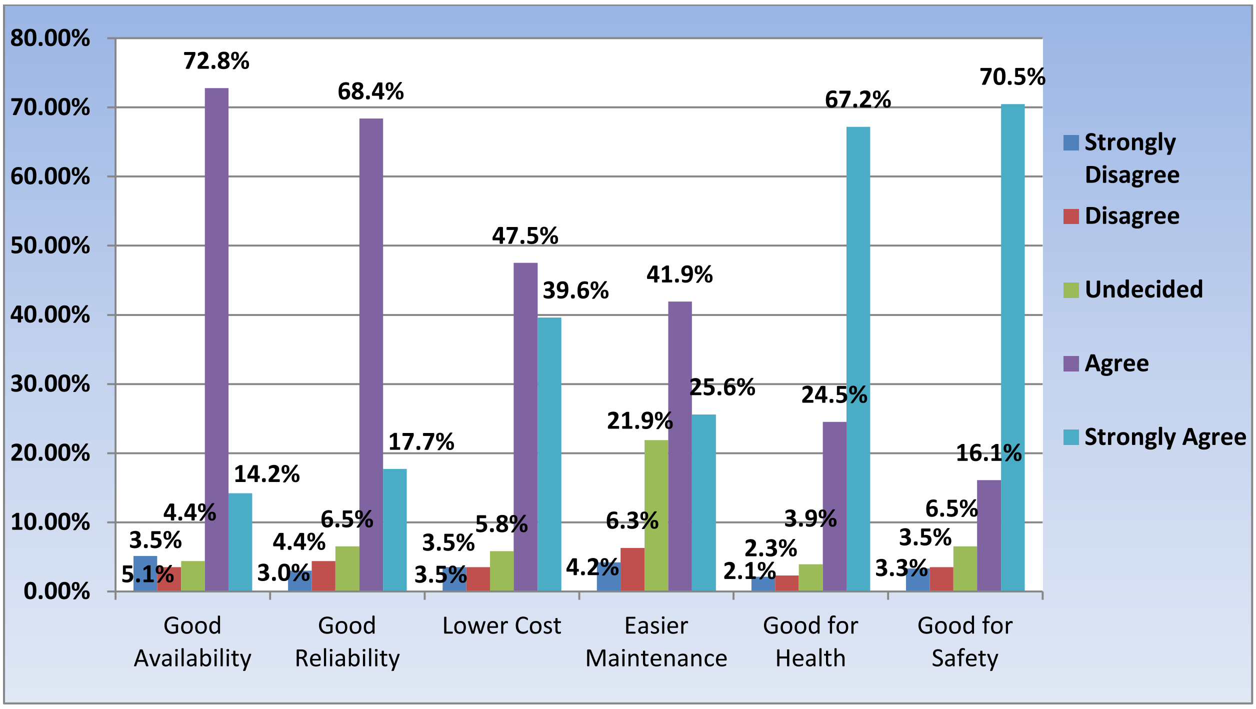


Figure14: Number of hours devoted to activities before and after solar electrification

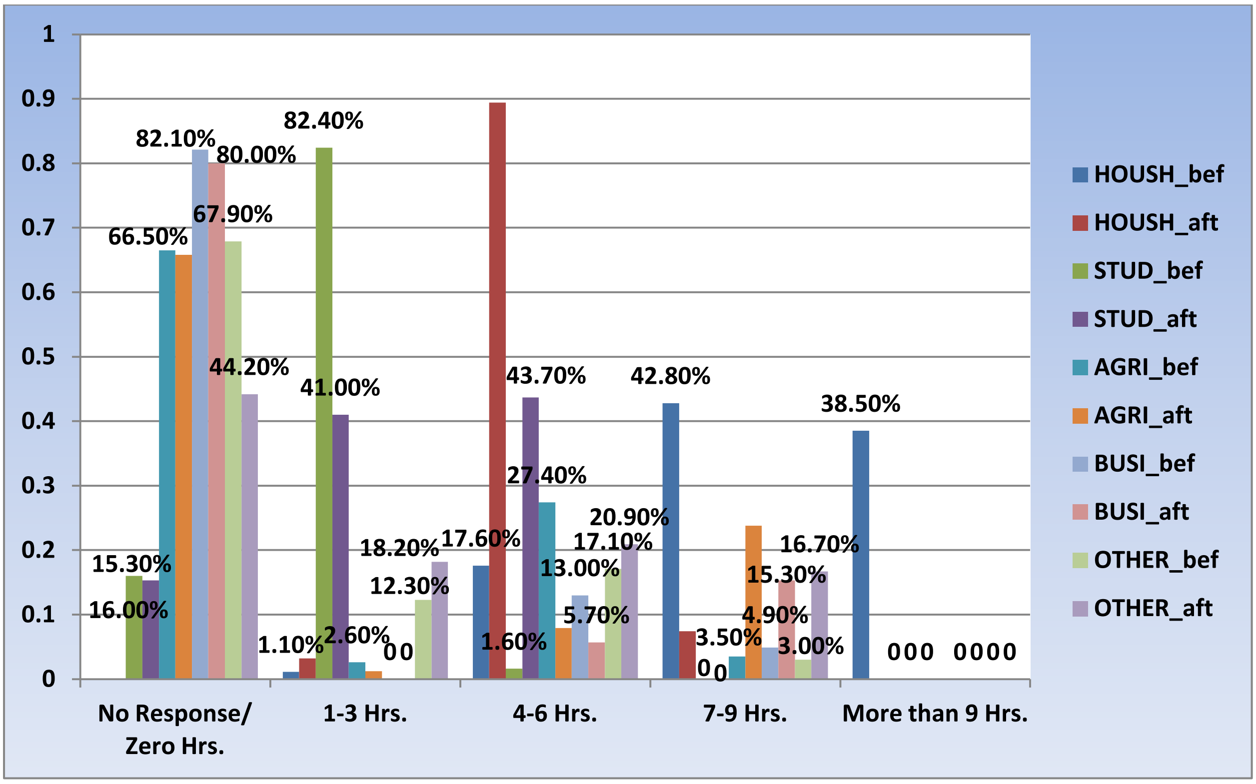


Figure 15: Hours devoted to livelihood activities in the evening before and after solar electrification

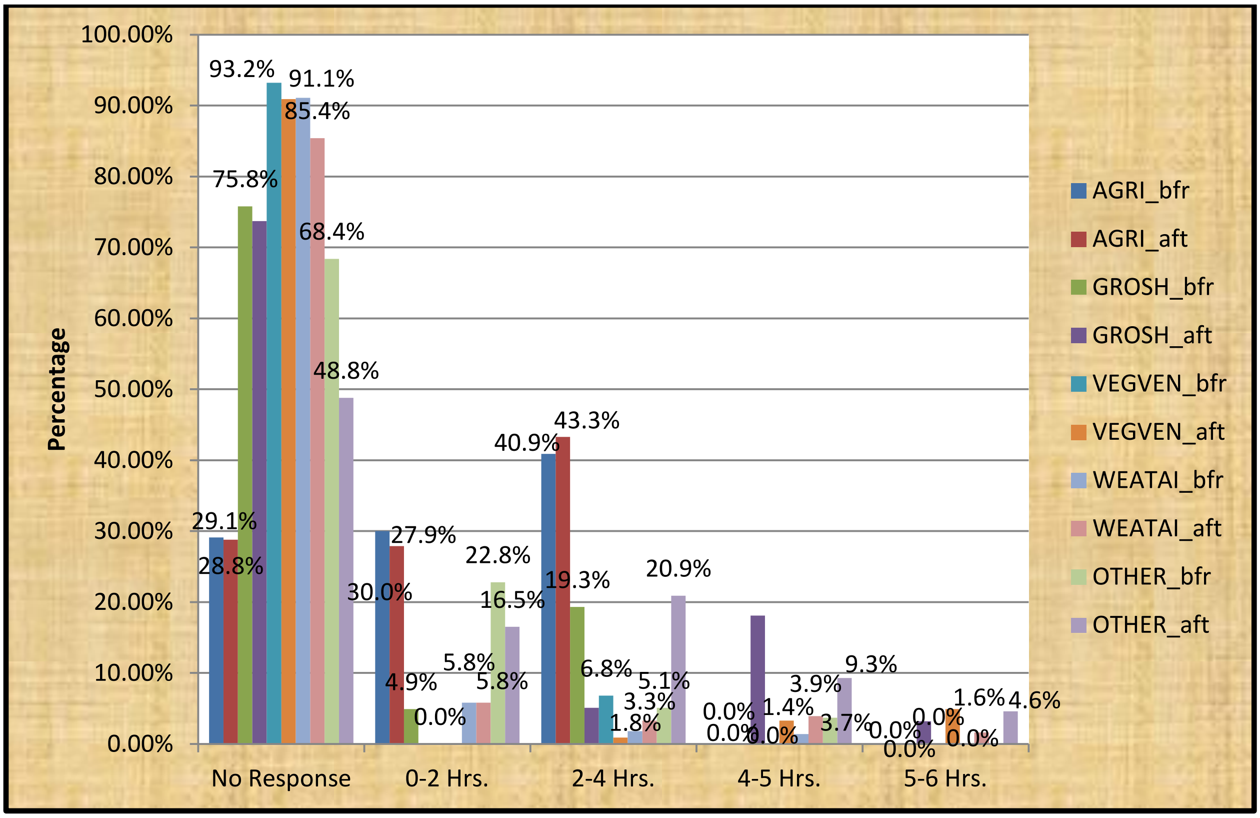


Figure 16: Average monthly income earned from livelihood activities before and after solar electrification

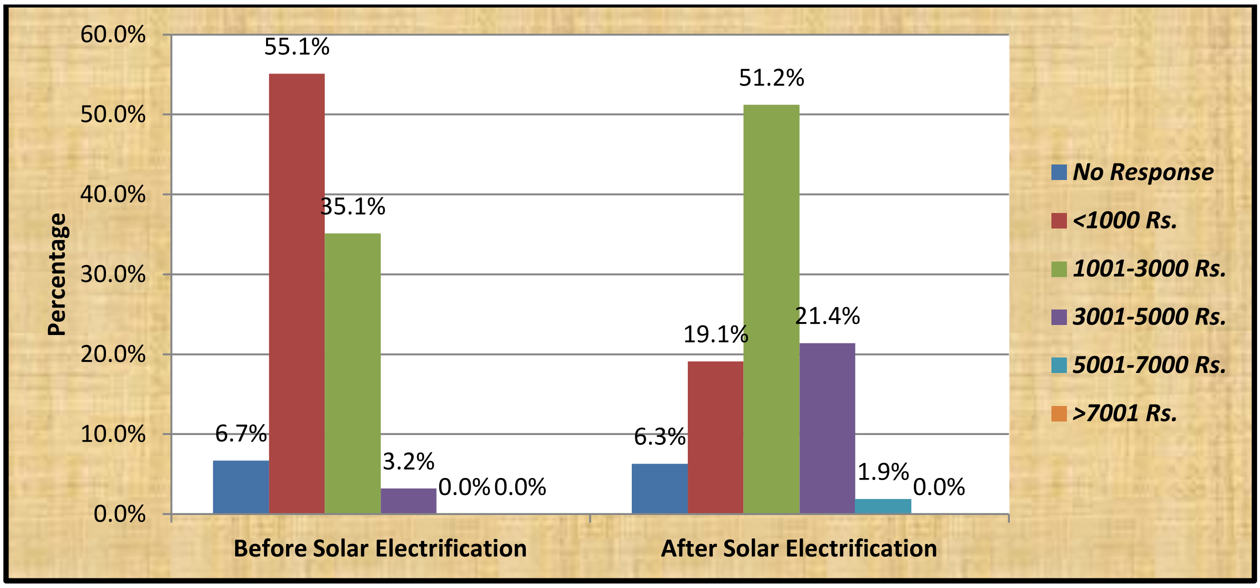


Figure 17: Monthly expenditure on lighting needs before and after solar electrification

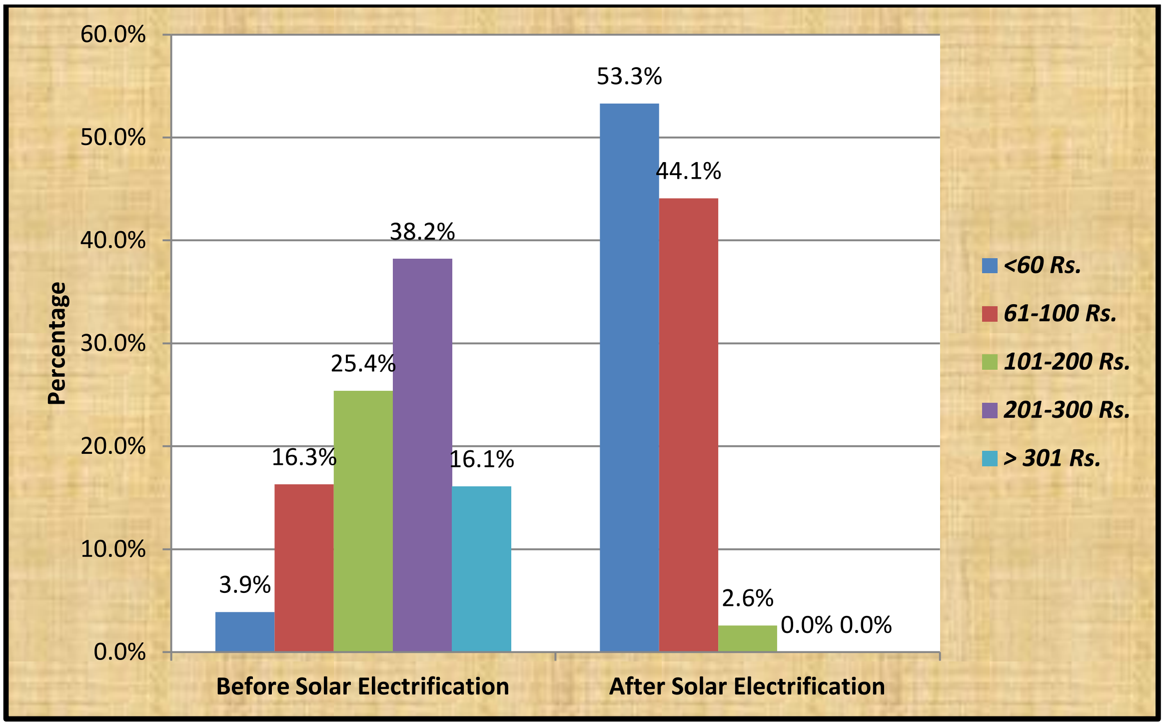


Figure 18: Family members involved in income generating activities before and after solar electrification

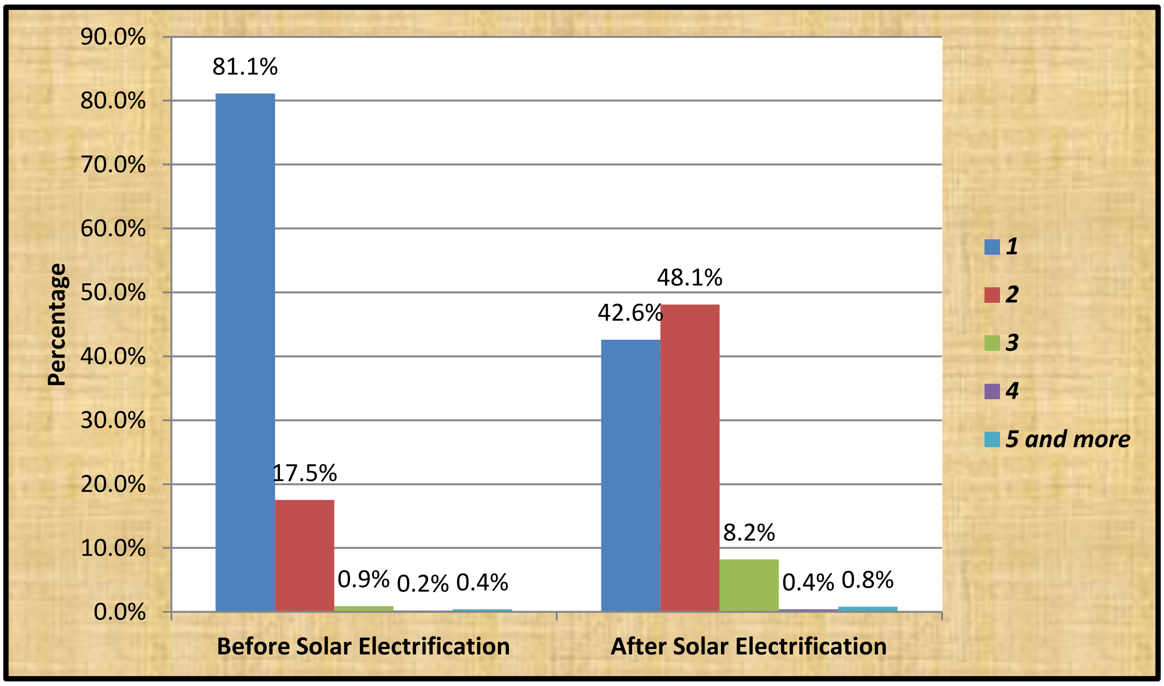


Figure 19: Views of respondents on workload comparison of women before and after solar electrification

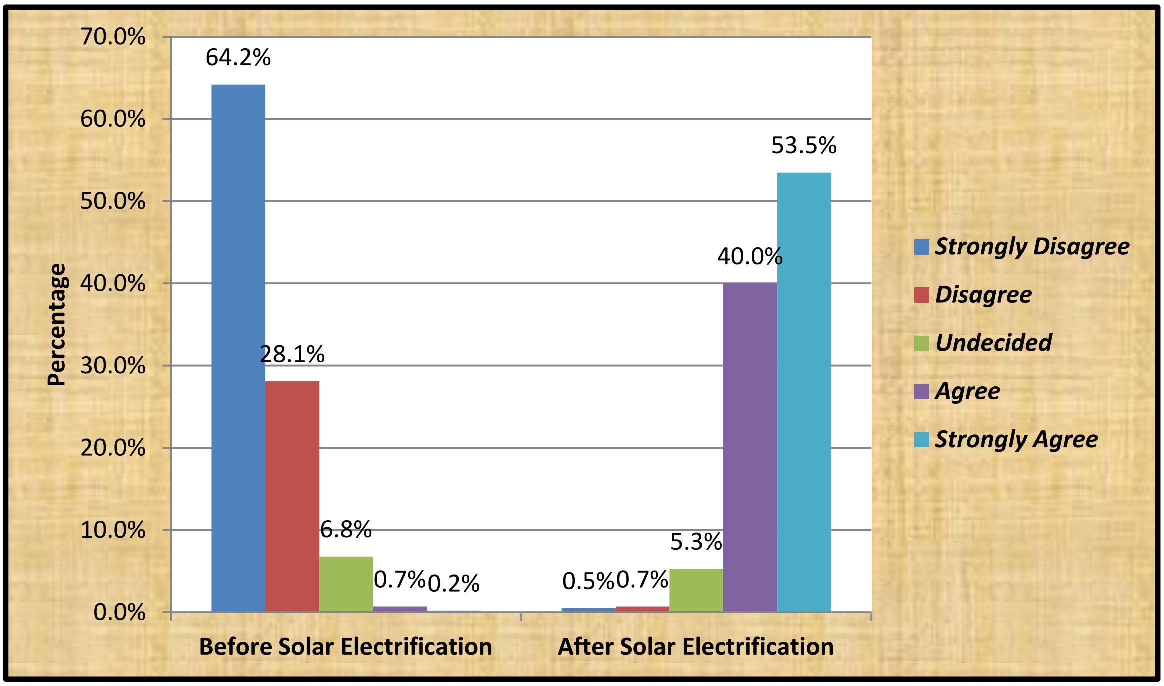


Figure 20: Views of respondents on availability of free time for women before and after solar electrification

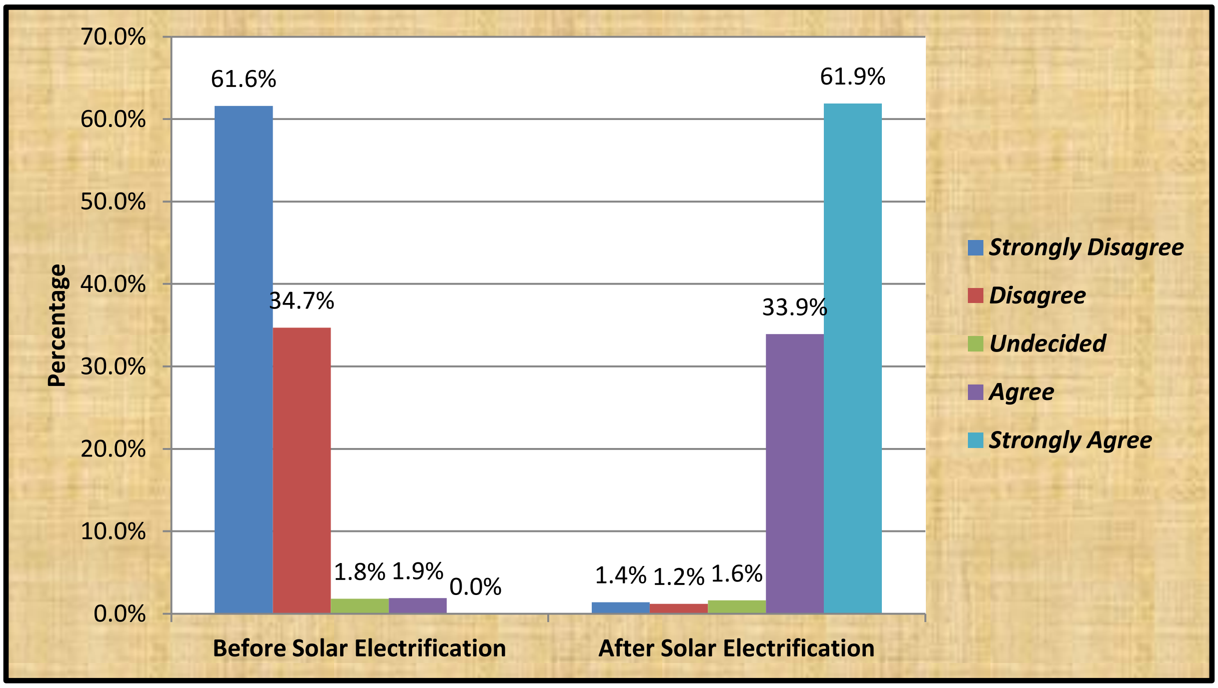


Figure 21: Views of respondents on involvement of women in various activities before and after solar electrification

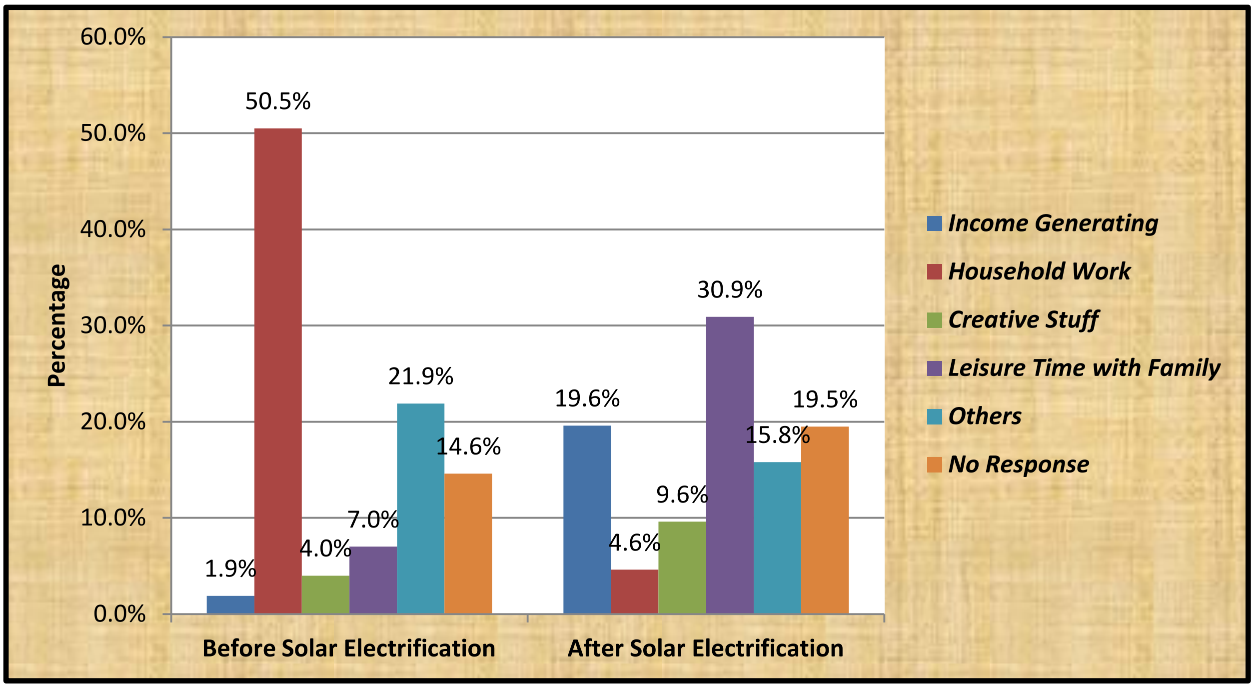


Figure 22: Views of respondents on contribution by women to family income before and after solar electrification

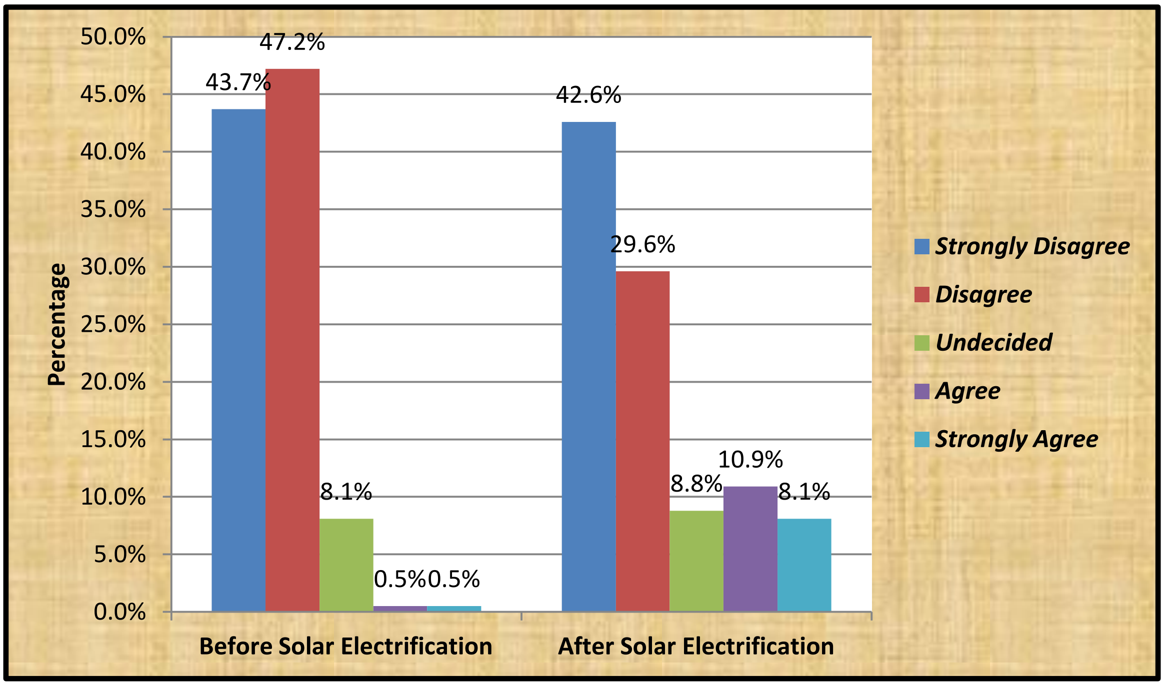


Figure 23: Views of respondents on safety of women in the evening/night before and after solar electrification

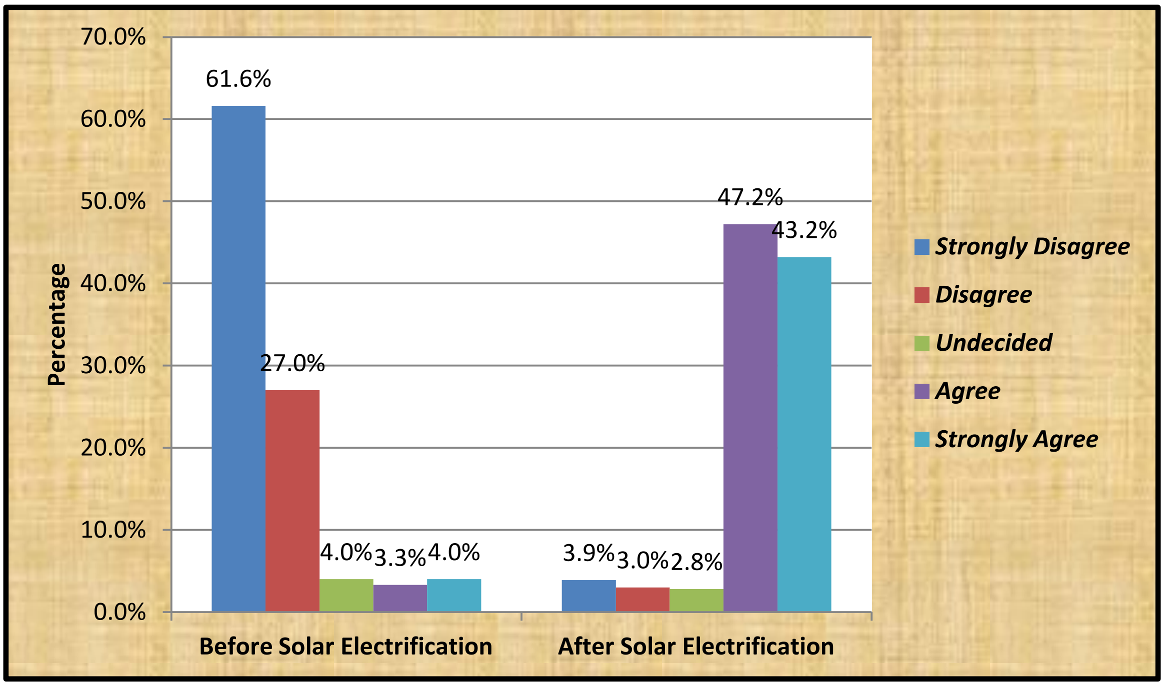


Figure 24: Views of respondents on women going out in the evening/night before and after solar electrification

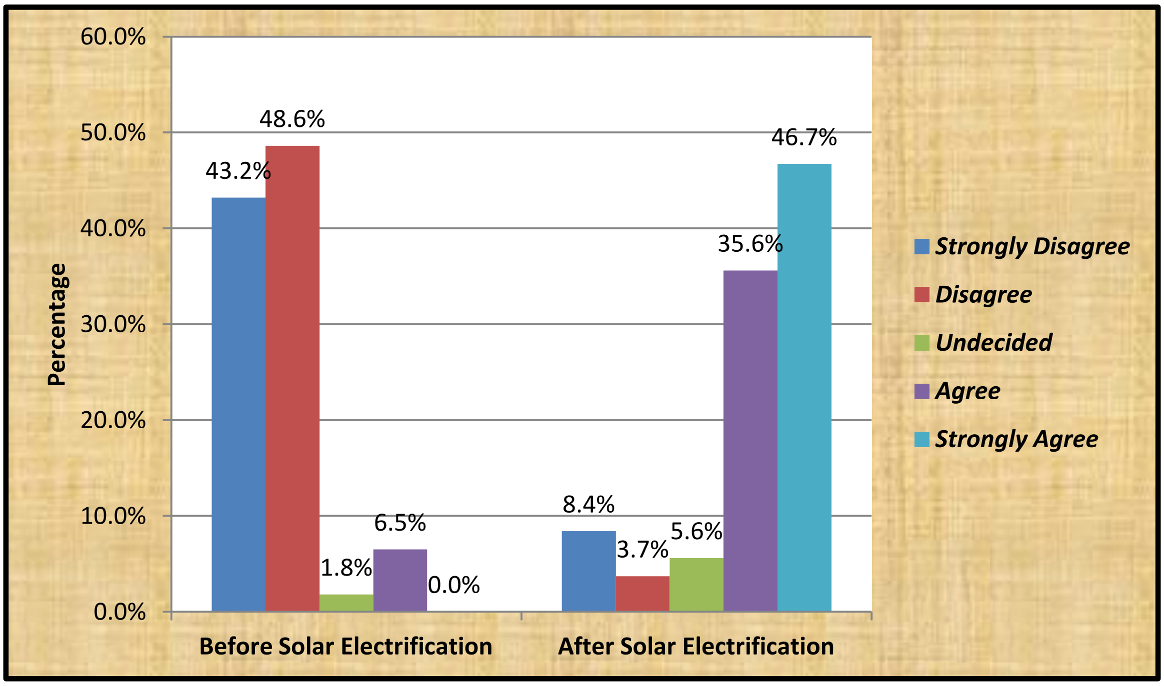


Figure 25: Views of respondents on health problems faced by women before and after solar electrification

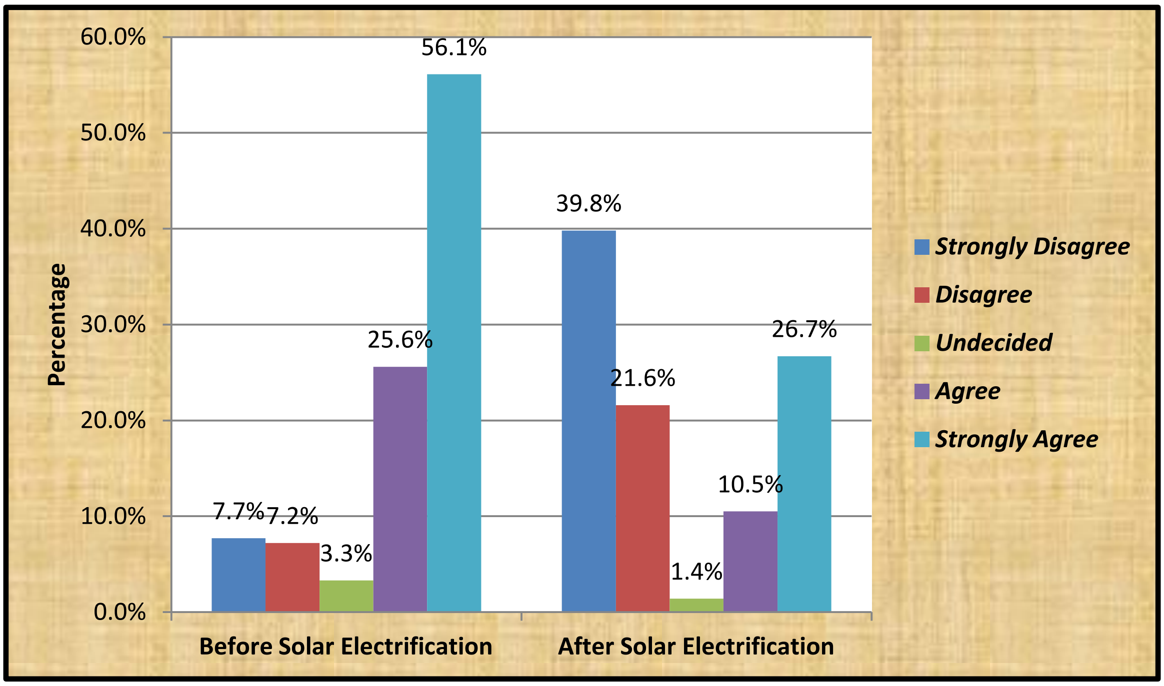


Figure 26: Views of respondents on visit to a doctor for health problems before and after solar electrification

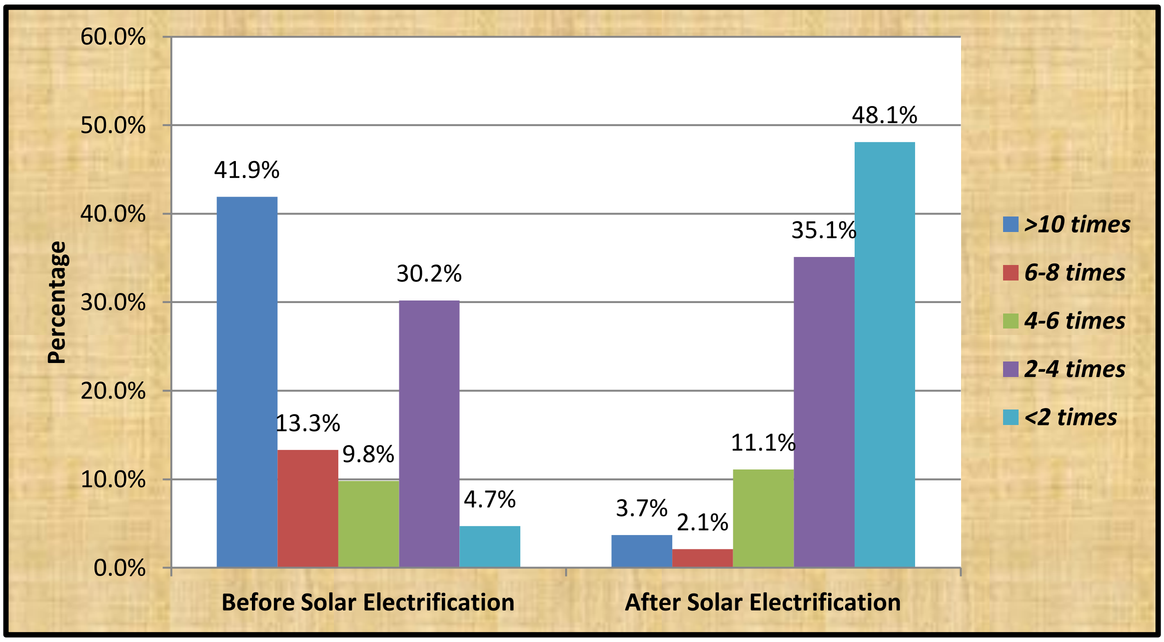


Figure 27: Views of respondents about savings on doctor visits before and after solar electrification

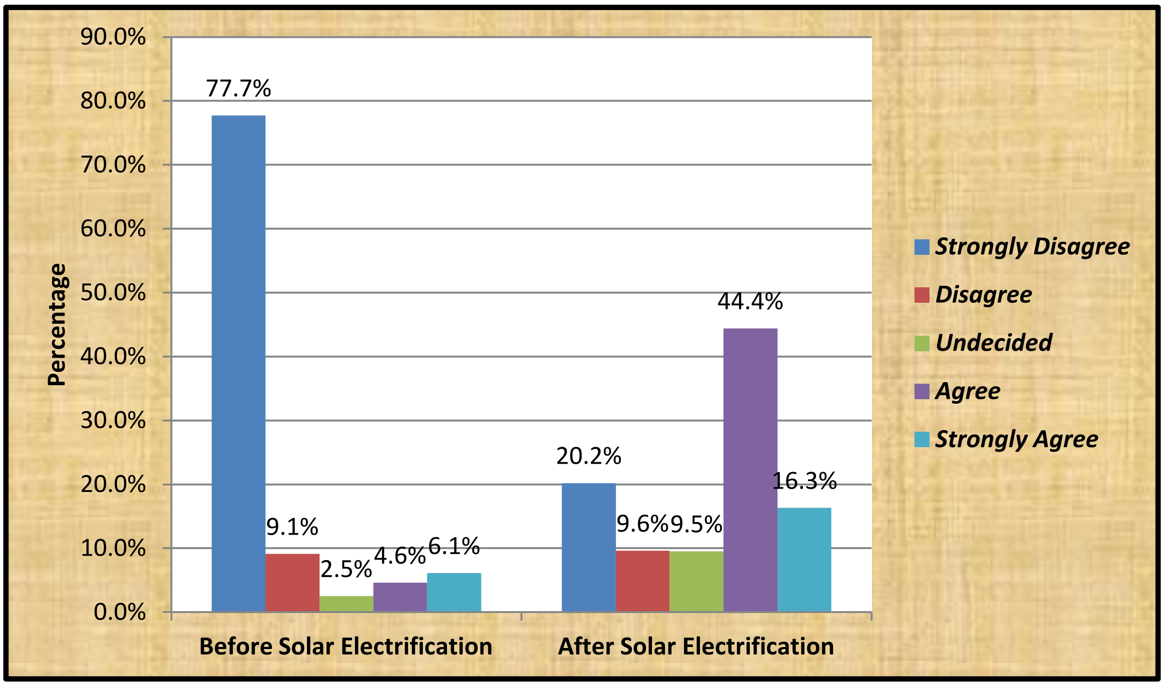


Figure 28: Views of respondents about safety before and after solar electrification

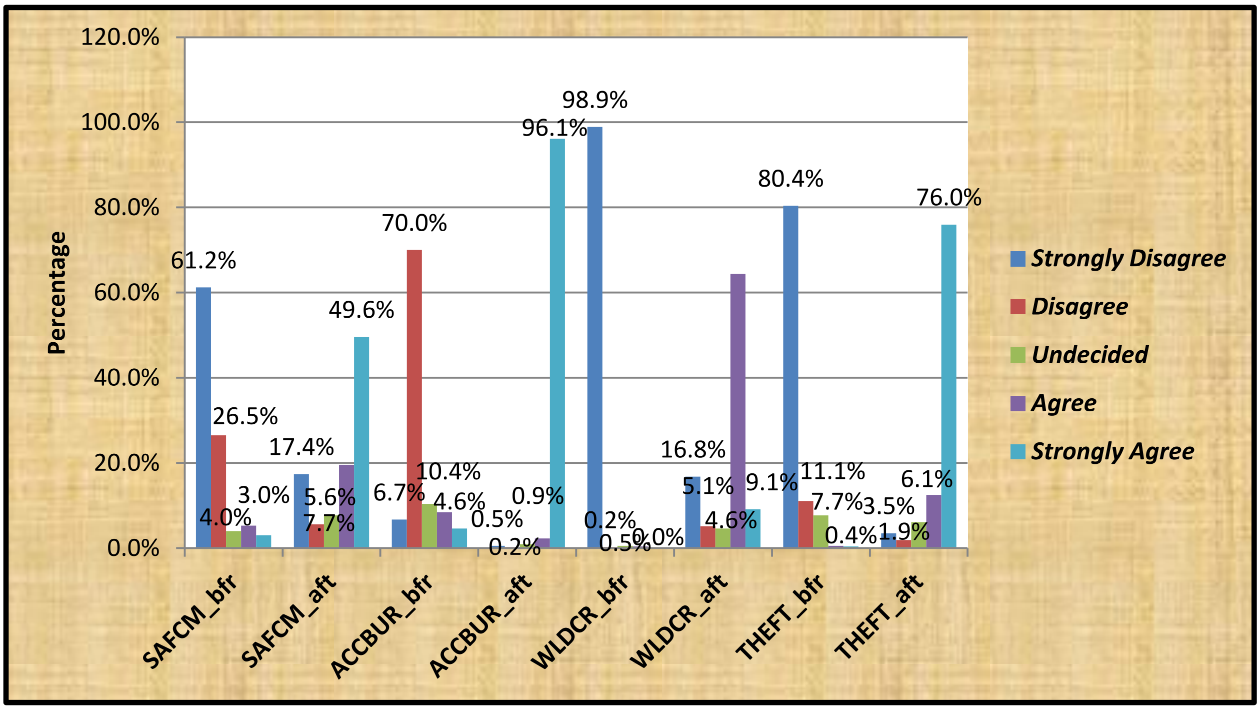


Figure 29: Number of hours children study in the evening and night before and after solar electrification

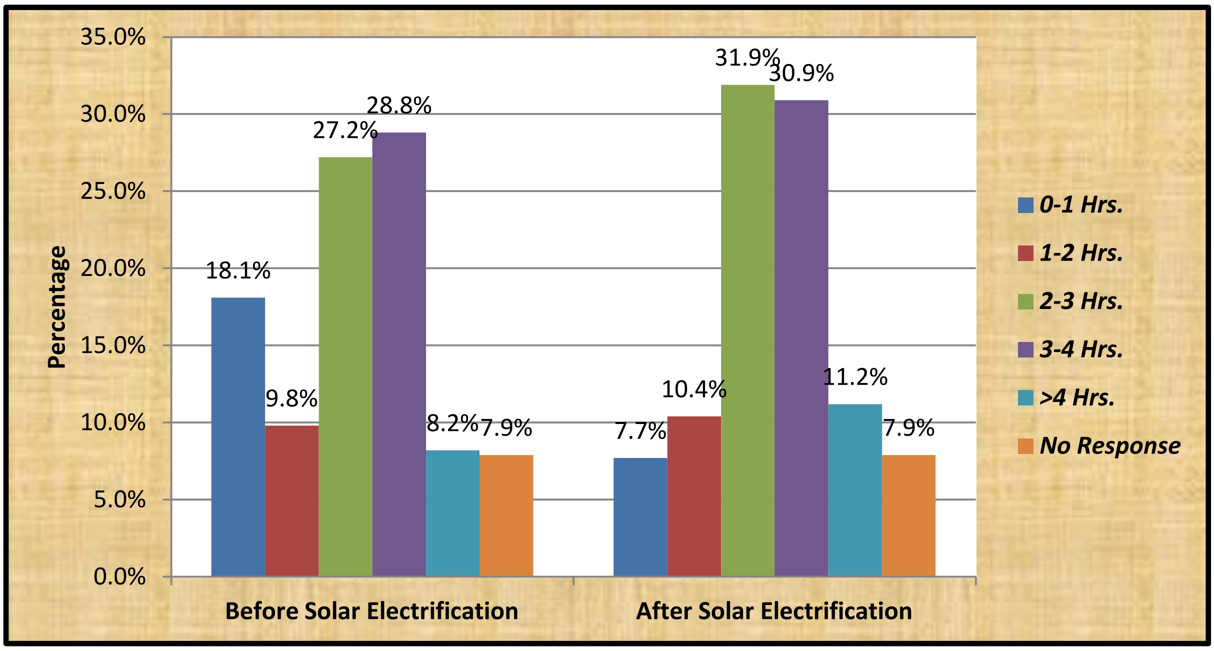


Figure 30: Interest of children in studies before and after solar electrification

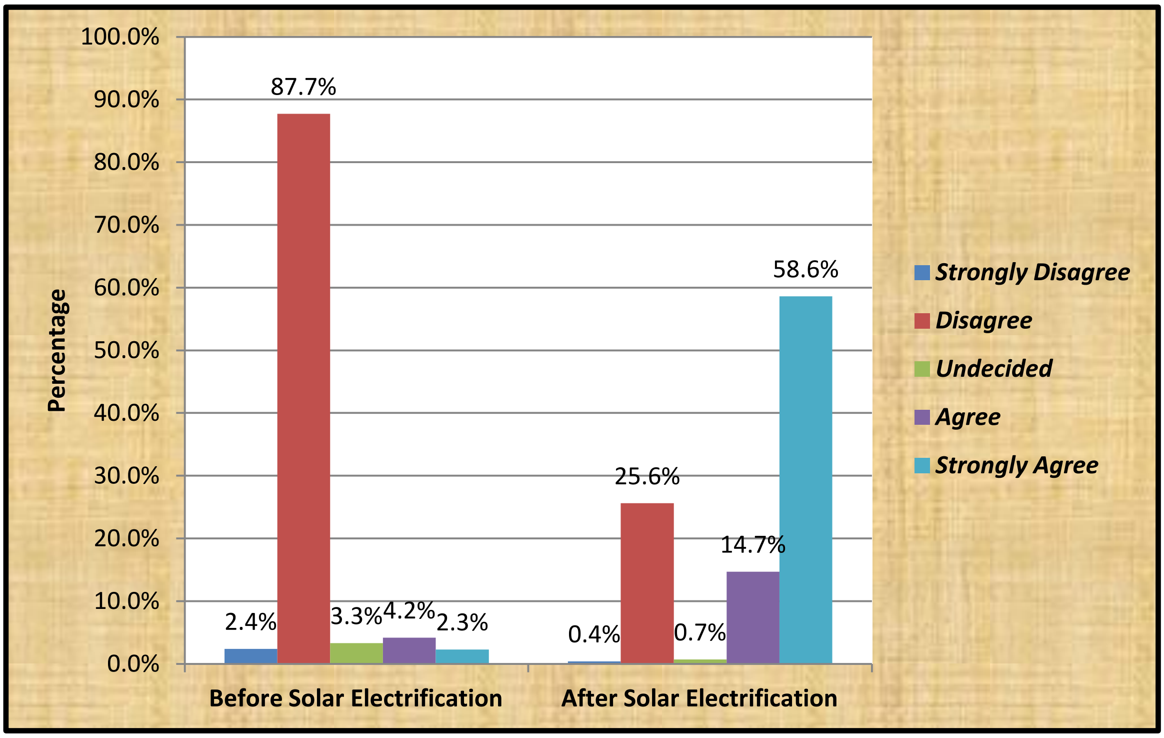


Figure 31: Performance of children in exams before and after solar electrification

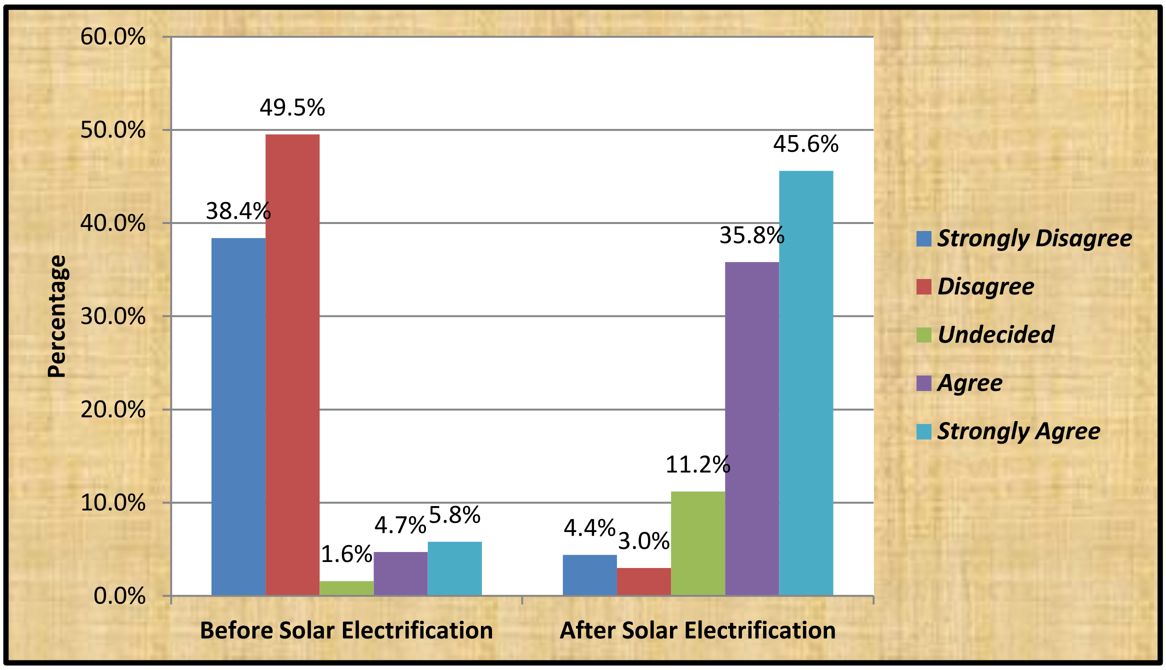


Figure 32: Condition of female education before and after solar electrification

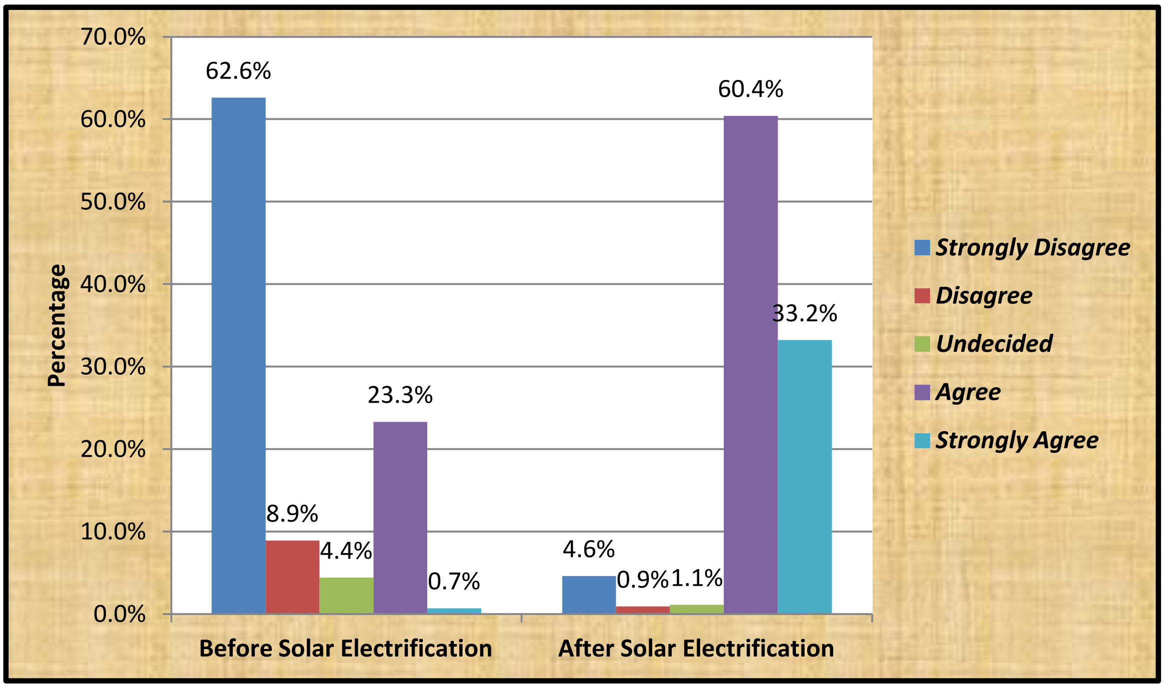


Figure 33: Skill development program implemented in village

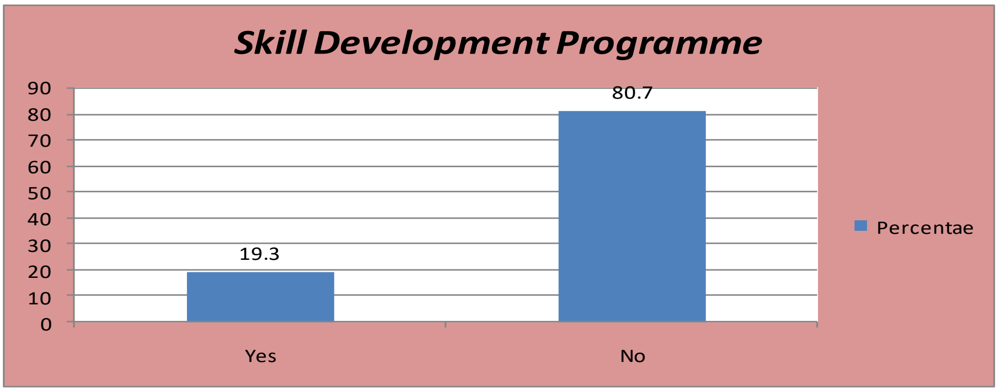


Figure 34: Willingness of villagers for such programs

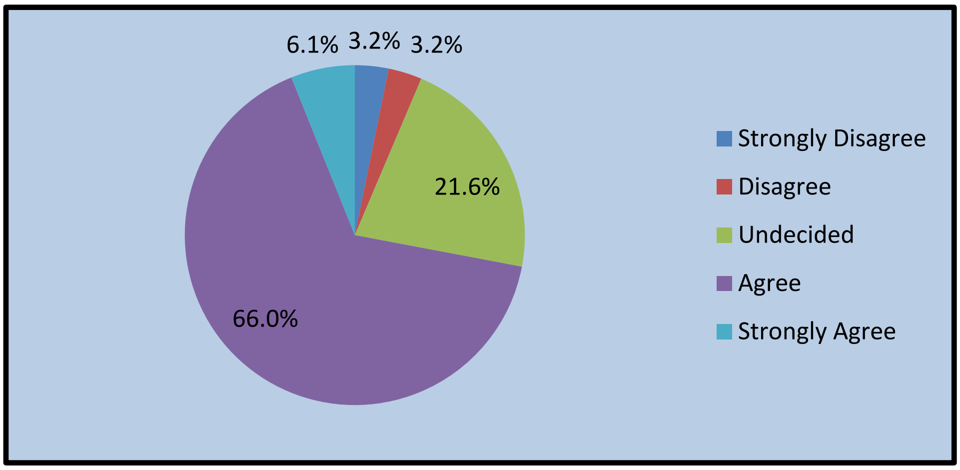


Figure 35: Training of youth for maintenance of solar lighting system

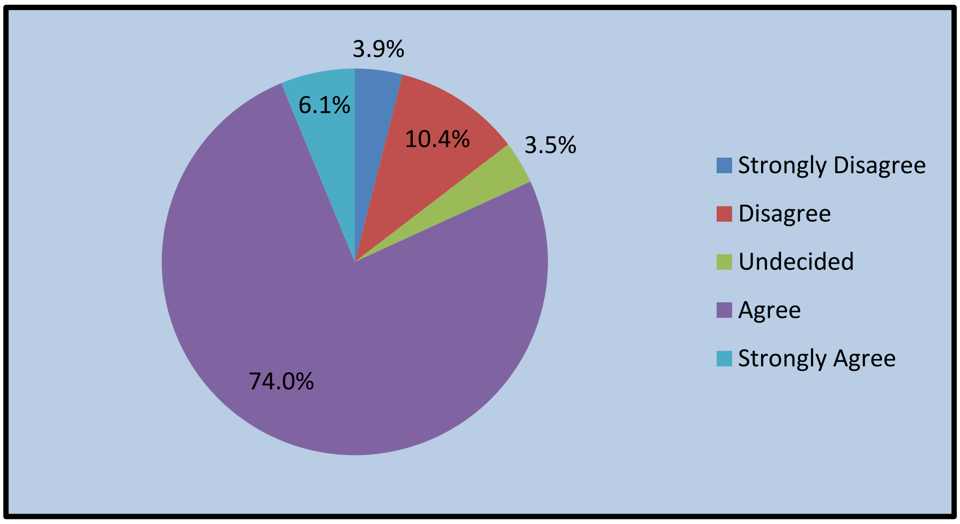


Figure 36: Availability of electric stoves for cooking

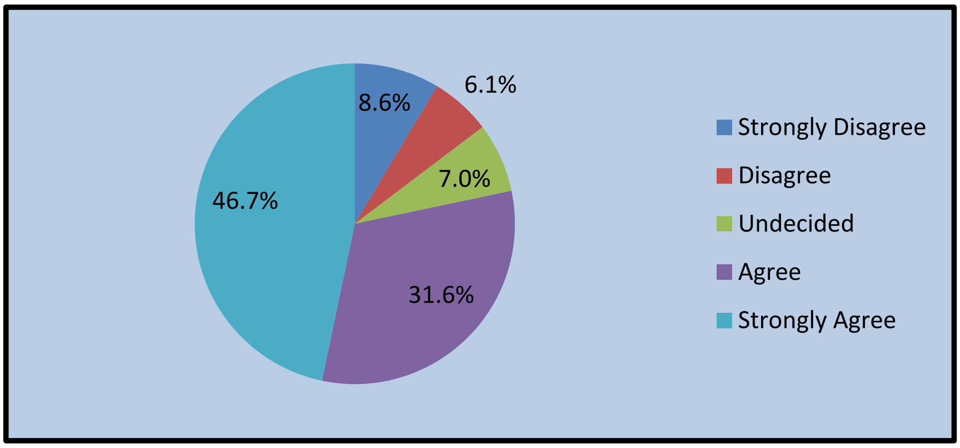


Figure 37: Willingness to pay more

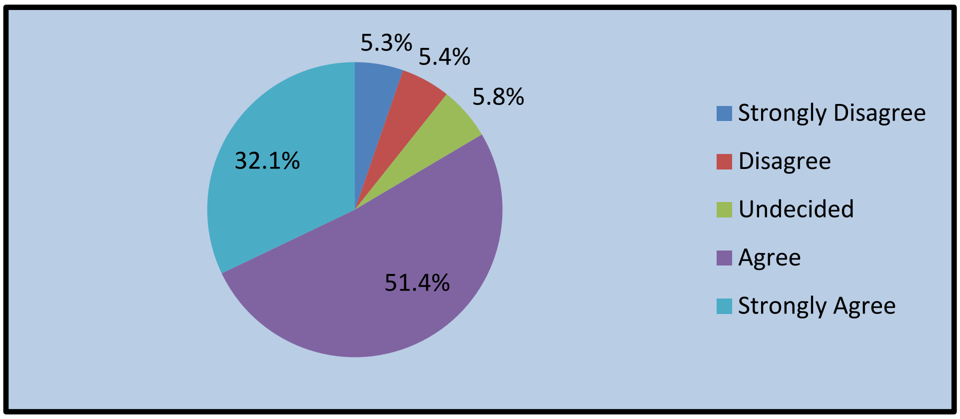


Figure 38: Ability to pay

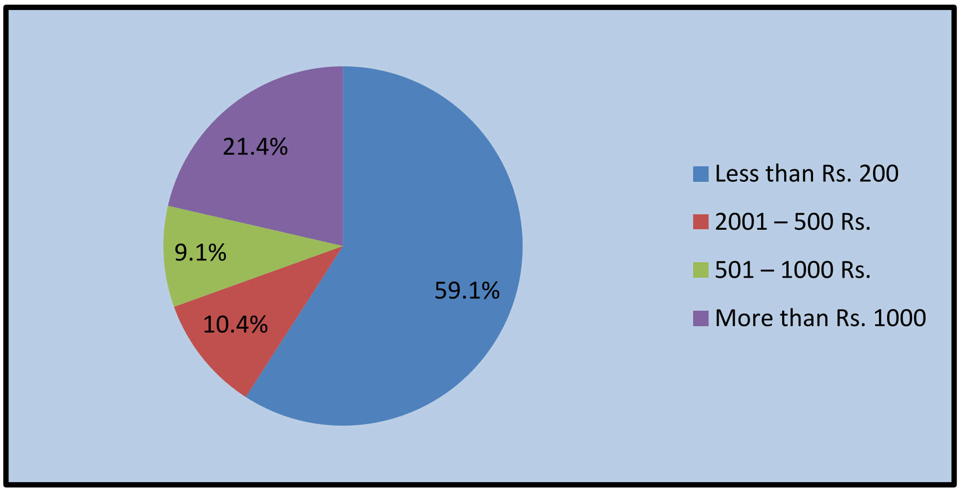


Figure 39: Willingness to pay

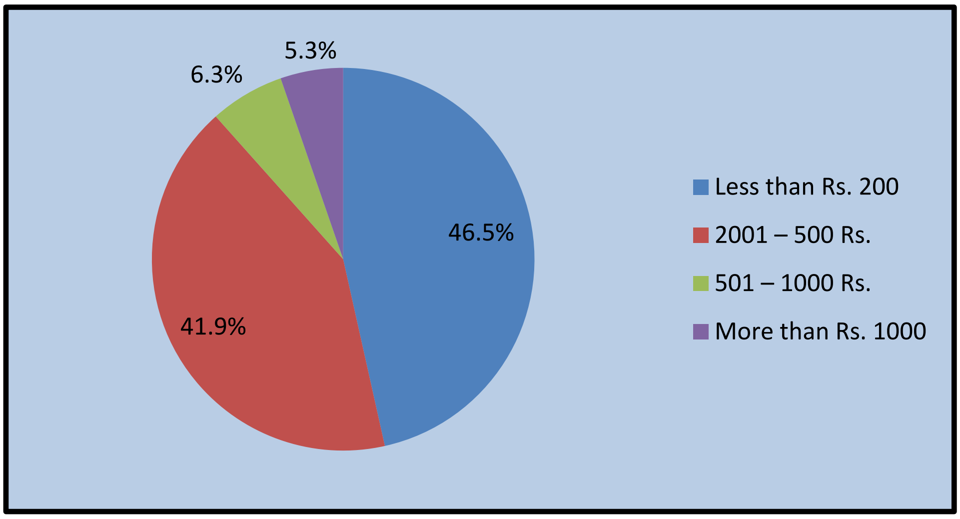
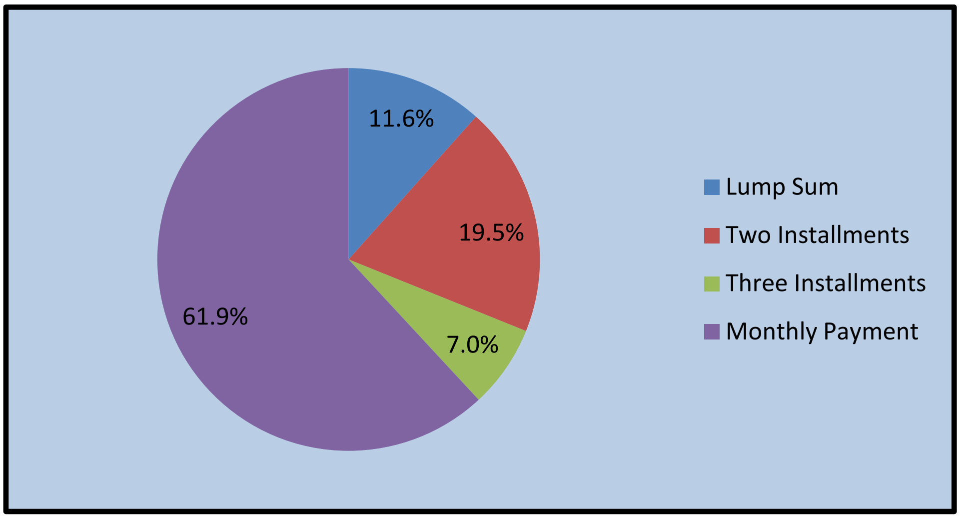


Figure 40: Cycle of payment



LIST OF PUBLICATIONS

A. Papers presented in peer reviewed conferences

- Choudhary, B., Sharma, D., & Singh, Y. (2017). Socio-economic assessment of off-grid solar technology based rural electrification in Upla Kota, Rajasthan India. *International Conference on Engaging Canada and India: Perspectives on Sustainability Organized by Shastri Indo-Canadian Institute*. New Delhi. Paper presented at International Conference on Engaging Canada and India: Perspectives on Sustainability Organized by Shastri Indo-Canadian Institute, New Delhi India Habitat Centre, New Delhi 11 – 12 May, 2017.

- Choudhary, B., & Sharma, D. (2015). Achieving Energy Sustainability in Rural Rajasthan through Solar Energy. *National Conference Organized by St. Xavier's College* . Jaipur. Paper presented in National Conference organized by St. Xavier’s College Jaipur held on 12-13 February 2015, which has been published in conference proceedings with ISBN 978-8-1929797-1-7.
- Choudhary, B., & Sharma, D. (2014). Water-Energy Nexus: Managing the Link between Energy and Water. *34th National Conference, Rajasthan Economic Association*. Jaipur: Flying Pen Publishers. Paper presented at Rajasthan Economic Association- 34th National Conference (17th-19th January, 2014). This paper has been published in conference proceedings.
- (Choudhary & Sharma, Potential of Renewable Energy and Suatainable Development in India, 2014). Paper presented at ‘National Conference on Environmental Issues and Climate Changes’ at University of Kota.

B. Journal Publication

- Choudhary, B., & Sharma, D. (2016). Decentralized Solar Power for Rural Electrification in India: A Review. *International Journal of Latest Technology in Engineering, Management and Applied Science (IJLTEMAS)*. ISSN 2278-2540

- Choudhary, B., & Sharma, D. (2015). Solar Energy for Sustainable Growth and Emplyoment Generation in Rural Rajasthan: A Case Study. *Indian Economic Journal*. Paper presented in National Conference organized by Indian Economic Association, held on Dec 27-29, 2015.

- Choudhary, B., & Sharma, D. (2014). Harnessing the Solar potential in Rajasthan to Achieve Energy Sustainability . *Indian Economic Journal*. Paper presented in National Conference organized by Indian Economic Association held on Dec 27-29, 2014.

C. Publication in Book

- Choudhary, B., & Sharma, D. (2015). Decentralized Solar Energy for Sustainability in Rural Rajasthan: A Case Study. In P. V. Singh (Ed.), *Indian Economy: A Raodmap towards Development* . Jaipur, Rajasthan, Indian. Paper presented in the National Conference (36th Annual Conference) on Indian Economy: A Roadmap towards Development, organized by NITI Aayog Chair, Dept. of Economics, University of Rajasthan in collaboration with Rajasthan Economic Association on 22-24 Jan 2015, published in an edited book, Indian Economy: A Roadmap towards Development with ISBN 978-81-929590-9-6.

BIOGRAPHICAL PROFILE OF THE AUTHOR

Boola Choudhary was born at Alwar on 3rd July 1989. She completed her school education (Science: Biology, Physics, Chemistry) from St. Anselm’s Sr. Sec. School, Alwar. She pursued her graduation in economics from Universities Maharani College, University of Rajasthan, Jaipur. She completed her master’s in economics from Department of Economics, University of Rajasthan, Jaipur in 2012. She is a gold medalist in economics. She served as a part time faculty for a session in Kanoria PG Mahila Mahavidhalaya, Jaipur and then joined Malaviya National Institute of Technology Jaipur as a full-time research scholar under Dr. Dipti Sharma in July 2013 to pursue Ph.D. in energy economics with teaching assistantship. She qualified UGC-NET examination in Economics in December 2015. She has an experience of organizing workshops and conferences in the capacity of organizing committee member. She has published various research papers in national and international peer reviewed journals (which are approved by UGC). The area of interest of the author lies in the field of energy economics, micro economics and econometrics.