Dissemination of Distributed Solar Photovoltaics in Kerala: Need for Technology, Planning, Financial and Institutional Model Innovations

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by

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Abstract

This thesis looks into the possibility of large scale dissemination of distributed solar PV (Photovoltaic) systems in the state of Kerala, India, through innovations in technology, planning, policy, financial models and institutional models. Kerala has immense potential (at least 317 MW_p (Mega Watt-peak) for distributed PV projects due to the availability of large number of 'pukka' shade free roofs, good power sector infrastructure, possibility to integrate solar pumping in the agricultural sector, and the presence of strong local self-governance in the state which can effectively plan and implement programs.

The study looks into the various technology adoption strategies and policy tools in PV sector by other countries, and the possibility to adopt some of these methods in a contextualized way in Kerala. Introduction of annual installation caps, year on year reduction of Feed-in-Tariffs, introduction and removal of tax holidays at appropriate times etc. are required for the development of a healthy PV market.The roles of state utility company, other government organizations in power sector like ANERT (Agency for Non-conventional Energy and Rural Technology) and Electrical Inspectorate, the PV developers, the end users etc. were identified in the context of PV dissemination.

The thesis proposes 'Gram Panchayats' (local self-governments) as an ideal meso-scale entity for planning and implementing distributed PV programs, supported through 'participatory' surveys involving the local educational institutions. A new methodology of GIS (Geographical Information System) based rooftop potential estimation backed with site surveys was developed during this research. It was identified that a typical Gram Panchayat in Kerala with an area of 10 sq. km. can accommodate 12 MW_p rooftop PV systems and can generate at least two times their required energy. Almost 60% of the houses in a Gram Panchayat were found to have strong, concrete, shade-free roofs with enough area to install PV systems to produce more energy than they actually consume.

The thesis also reviewed the status of past rooftop PV programs by the state and produced clear data on the inefficiency of the 'capital subsidy' schemes for dissemination.

Nearly 72% of the beneficiaries of such projects were from high energy consumption slabs (indicating their economic well-being, correlating to their electrical appliances ownership). The thesis proposes an alternate dissemination strategy with multiple packages containing both energy efficient equipment and PV systems, backed up with financial packages from banks. Introduction of 'smart' inverters with battery backup among residential consumers to help the utilities reduce the energy demand during peak hours was another option proposed.

Community based rooftop PV systems in tribal hamlets and grid-connected solar pumps owned by farmer co-operatives were studied as an alternative institution model for successful dissemination. Community solar irrigation project in the low lying lands of coastal Kerala can save around 20 million kWh a year. The capital expense for such installations were estimated close to Rs. 110/W_p. Still the project was found to be economically viable with payback period of 10 years at an IRR (Internal Rate of Return) of 6.9%. If technological innovation in power conversion equipments is possible, such that a single device can work as a grid feeding inverter as well as a VFD (Variable Frequency Drive), then there is scope for further cost reduction and improved yield from PV system.

An LCOE (Levelized Cost of Electricity) calculation algorithm for analysing the economic viability of PV projects was developed as a part of this research. The sensitivity of LCOE towards various inputs were studied and it was found that the capital expense (Rs/W_p, predominantly determined by the module price) and the CUF (Capacity Utilisation Factor) (determined by the radiation and geo-climatic conditions) were the most sensitive inputs for LCOE. For every 1% change in CAPEX (Capital Expenditure) and CUF, LCOE would change by 1% and 0.8% respectively.

Need for participatory planning with multiple stakeholder involvement and need for clarity in terms of liabilities, responsibilities and incentives for each stakeholders associated with the project is necessary in community based projects. The study also brings in the learning from the All India Survey of PV Module Reliability and emphasizes on t he 'performance' oriented planning of schemes, rather than 'target' oriented approach. The study has reported higher module degradation rates of the order of 3% of P_{max} (Maximum Power at standard test conditions per year) for those roof mounted systems which were poorly installed and maintained. The need for an institutional mechanism for ensuring quality of components, quality of design, quality implementation and quality post implementation support is identified in this study. The thesis also explains the role of state level policies and their effective implementation for the prosperity of distributed PV sector.

Table of Contents

List of Tables

List of Figures

Abbreviation, Notation and Nomenclature

3D	3 Dimension
AC	Air Conditioner
AD	Accelerated Depreciation
Ah	Ampere Hour
ANERT	Agency for Non-conventional Energy and Rural Technology
a-Si	Amorphous Silicon
AT&C	Aggregate Technical and Commercial (losses in power systems)
BEE	Bureau of Energy Efficiency
BOOT	Build-Own-Operate-Transfer
BOS	Balance of System
CAPEX	Capital Expenditure
CCAFS	Climate Change, Agriculture and Food Security
C-DIT	Centre for Development of Imaging Technology
CdTe	Cadmium Telluride
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFA	Central Financial Assistance
CFL	Compact Fluorescent Lamp
CGS	Central Generating Station
CIGS	Copper Indium Gallium Selenide
CRT	Cathode Ray Tube
DDE	Deputy Director of Education
DEO	District Educational Office
DISCOM	Distribution Company (power distribution company)
DPI	Directorate of Public Instruction
DPR	Detailed Project Report
DSM	Demand Side Management
DT	Distribution Transformer
DTH	Direct to Home
EHT	Extra High Tension

EL	Electroluminescence
EMI	Equated Monthly Instalment
EoI	Expression of Interest
EPC	Engineering, Procurement and Construction
ESCOT	Energy Saving and Co-ordination Team
FiT	Feed In Tariff
GBI	Generation Based Incentives
GEDA	Gujarat Energy Development Authority
GIS	Geographical Information System
GoG	Government of Gujarat
GW_p	Giga Watt – peak (1000 Mega Watt – peak)
HDI	Human Development Index
HIT	Heterojunction with Intrinsic Thin layer
HP	Horse Power (a unit of power, 1 HP = 746 W)
HT	High Tension
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IIM	Indian Institute of Management
IL	Incandescent Lamp
INR	Indian Rupee
IPP	Independent Power Producer
IRR	Internal Rate of Return
ITI	Industrial Training Institute
IWMI	International Water Management Institute
JNNSM	Jawaharlal Nehru National Solar Mission
KELTRON	Kerala State Electronic Development Corporation
KSEB	Kerala State Electricity Board
KSERC	Kerala State Electricity Regulatory Commission
kVA	kilo Volt Ampere
kW	kilo Watt (unit of power corresponding to 1000 Watts)
kWh	kilo Watt-hour (unit of energy)
kW_p	kilo Watt – peak (peak power output of PV modules at standard test conditions, corresponding to 1000 Watts)
LCD	Liquid Crystal Display
LCOE	Levelized cost of Electricity
LED	Light Emitting Diode
LSG	Local Self Government

LT	Low Tension
MGVCL	Madhya Gujarat Vidyut Company
MLA	Member of Legislative Assembly
MNRE	Ministry of New and Renewable Energy, Government of India
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MPPT	Maximum Power Point Tracking
MW_p	Mega Watt – peak
NASA	National Aeronautics and Space Administration (Govt. Of USA)
NCPRE	National Centre for Photovoltaic Research and Education
NGO	Non-Governmental Organisation
NPBD	National Project on Biogas Development
NPIC	National Programme on Improved Chulas (Chulas means indigenous cook stoves using firewood and other biomass based fuels)
NPV	Net Present Value
O&M	Operation and Maintenance
PCU	Power Conditioning Unit
PDS	Public Distribution System
PGCIL	Power Grid Corporation of India Limited
POSOCO	Power System Operation Corporation Limited
PPA	Power Purchase Agreement
PPM	Project Planning and Monitoring
PTA	Parent Teacher Association
PV	Photovoltaic
R&D	Research and Development
RAIDCO	Regional Agro Industrial Development Co-operative
RCC	Reinforced Cement Concrete
REC	Renewable Energy Certificate
RECI	Renewable Energy Corporation of India
RESCO	Renewable Energy Service Company (A service model in which a company installs PV systems at consumer's premises at their own cost and sells the energy generated from it to the consumer at a predetermined rate)
RKVY	Rashtriya Krishi Vikas Yojana (A central government scheme to promote agriculture based projects in the country through joint funding from state and central government.)
RPO	Renewable Purchase Obligation
Rs	Indian Rupee
SECI	Solar Energy Corporation of India (Renamed later as RECI – Renewable Energy Corporation of India)
SEEP	Super-Efficient Equipment Programs

SERC	State Electricity Regulatory Commission
SHG	Self Help Group
SHS	Solar Home lighting Systems
SLDC	State Load Dispatch Centre
SPICE	Solar Pump Irrigators Co-operative Enterprise
SPO	Solar Procurement Obligation
T&D	Transmission and Distribution (losses in power systems)
TERI	The Energy and Resources Institute
TFT	Thin film Transistor
THD	Total Harmonic Distortion
TNERC	Tami Nadu Electricity Regulatory Commission
ToD	Time of the Day
TV	Television
UDAY	Ujwal DISCOM Assurance Yojana
UT	Union Territory
VFD	Variable Frequency Drive
WBREDA	West Bengal Renewable Energy Development Agency

Chapter 1

Introduction

As civilisations grew and generations passed by, humanity has moved from an agrarian economy towards an industrialised and knowledge economy. Energy, in all its forms has been a driver for the economic development in the history of mankind. The quantity and quality of energy used and the usage pattern had a significant change along with the transition in economy and technology development. Per capita energy consumption is an important indicator towards the development of a nation. Countries with higher HDI (Human Development Index) have higher per capita energy consumption [1]. As and when the economies mature, the society moves from conventional forms of energy sources like biomass, to intermediate forms like kerosene, and finally towards modern fuels and energy sources like LPG (Liquefied Petroleum Gas), natural gas and electricity. Hence a well-established system of modern and commercial forms of energy services, especially electricity is inevitable for the economic growth and development of a nation.

India's installed generation capacity of electricity is 329 GW as on September 2017. It has grown by more than five times in 27 years from 63.64 GW in 1990 [2, 3]. The current fuel mix of installed capacities shows that there is an over dependency on non-renewable resources like coal, oil and natural gas (66.6% of installed capacity). 58.7% of installed capacity uses coal as a fuel [3]. But the fact is that India holds only 8% of the world's coal reserves, and just 0.35% of oil reserves [4 – 6]. With the current production levels of 677 million tons per year, India is left with coal reserves for only another 90 years [7]. Due to production and distribution inefficiency in coal mining sector, India continues to import coal from other countries and the demand-supply gap continues to rise at 2% per year. India spends nearly 7 to 8% of its GDP in importing crude oil and petroleum products [8, 9]. At the same time, India is supposed to be having a renewable energy potential of 900 GW, about 750 GW of which is expected from solar energy [10, 11]. Realising this potential, the government, in its attempts to attain energy security and sustainable low-carbon economic growth, has now started shifting its focus towards new and renewable energy sources. As per the CEA (Central Electricity Authority) and MNRE (Ministry of New and Renewable Energy) reports, the renewable energy generation capacity of India grew from almost nil to 58.3 GW during the years 1990-2017 [2], as shown in Figure 1.1. The share of renewables is now 17.7% of installed capacity and India ranks sixth in the world in total installed renewable energy capacity [12]. Starting with the Electricity Act 2003, India has come up with major reforms in legal and regulatory framework for the power sector and in particular for renewable energy. The national target is to achieve 175 GW of installed capacity from renewables by the year 2022. The targets have been distributed among different states and the technologies to be adopted are envisaged as solar (100 GW), wind (60 GW), small hydro projects (5 GW) and biomass (10 GW) [13].

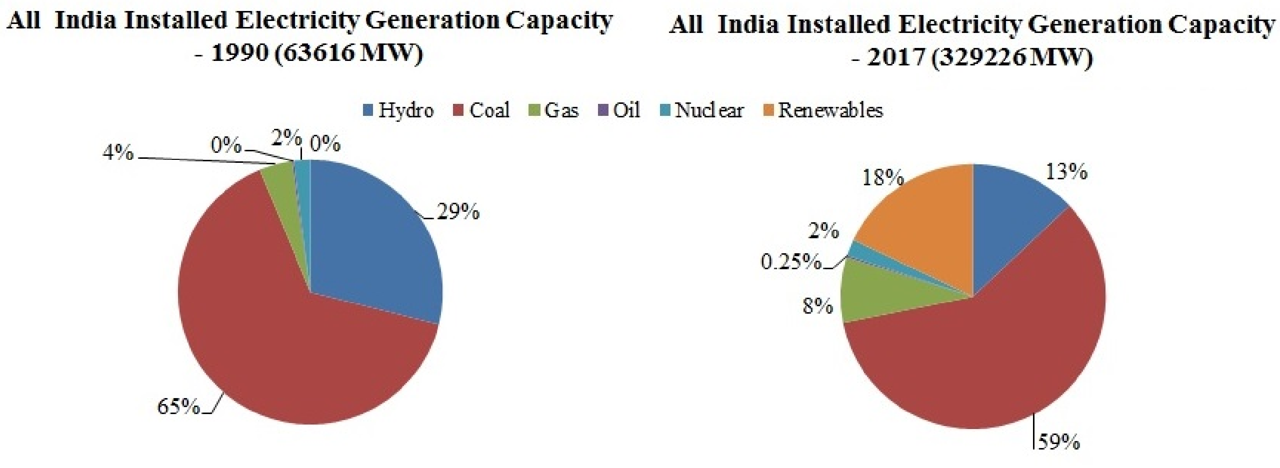


Figure 1.1: Comparison of installed capacity of electricity generation in India and their energy sources [2, 14].

The cumulative global installed capacity of power from solar photovoltaic had crossed 300 GW by the end of 2016, increasing nearly a hundred times from 3.12 GW in

2004 [15, 16]. Though the adoption of the technology was slow to begin in India, exponential growth has been observed in the Indian trajectory with the installed capacity of solar photovoltaics increasing from 36 MW in 2010 to 12,288 MW in 2017 [14, 17]. Similar trend is expected for the next decade or so with various national and regional pro-solar policies in place. A large number of initiatives under the umbrella of JNNSM (Jawaharlal Nehru National Solar Mission) are boosting the sector.

Distributed rooftop solar PV can be a solution for the two major needs faced by the power sector in India- capacity addition and grid extension. It not only adds to the current generation capacity, but also temporarily solves the requirement of conventional grid extension to remote areas. Rooftop PV systems help exploit the decentralised nature of solar energy with benefits to the consumer and electricity utility. Consumers can generate power by installing solar PV panels in their idle rooftop spaces thereby reducing their dependence on grid electricity. The electricity utility benefits as the transmission and distribution losses would be minimised. Off-grid systems are generally seen as a stop gap arrangement till the grid extension happens into certain areas. It has its own limitations such as expensive and recurring storage needs, poor load factor, limited loads, and uncertainty on the future of storage technologies [18].

Studies have shown that grid connected rooftop PV systems can improve tail end grid voltages and reduce system congestion and losses [19]. Such systems are also posing challenges to the utilities due to the variability in power production. Solar power integration to the grid at small scales does not really cause much system instability in the grid. But, proper power system modeling and analysis is required when we plan for large scale distributed PV system integration to the grid. The so called ‘duck curve scenario’ (high ramping rate of demand soon after the PV generation declines during the evening hours) was seen in many of the cities like California, which has very high PV penetration in the grid. In certain cases ramping rates were as high as 13000 MW in 3 hours [20].

As a result, the utility companies will have to resort to more natural gas based and other fossil fuel based ‘peaking power plants’ to manage the ramp rates and peak demand. In effect, the advantages of renewable energy generation through PV may be nullified by such fossil fuel based peaking stations. The way out may be to depend on pumped storage, hydroelectric plants or huge battery banks for ramping support. In either scenarios, the utilities are bothered about the additional investment for setting up peaking plants.

Globally, India is among the nations with very poor share of rooftop solar *vis-à-vis* utility scale solar as evident from Figure 1.2. The revised targets of the national solar policy to achieve 40 GW of installed rooftop solar PV capacity can be seen as a policy response to increase the penetration of rooftop solar PV in India [21]. For achieving such an ambitious target, there has to be proper planning and implementation strategies in place at various administrative and governance levels. In addition to the high level decisions taken at the national administrative level, active participation and execution of rooftop PV schemes by the state and local self-governments also decides whether these targets are achieved or not. Again, rather than meeting the 'installation targets', the schemes should also consider the successful operation of the rooftop systems for its expected life time of 25 years.

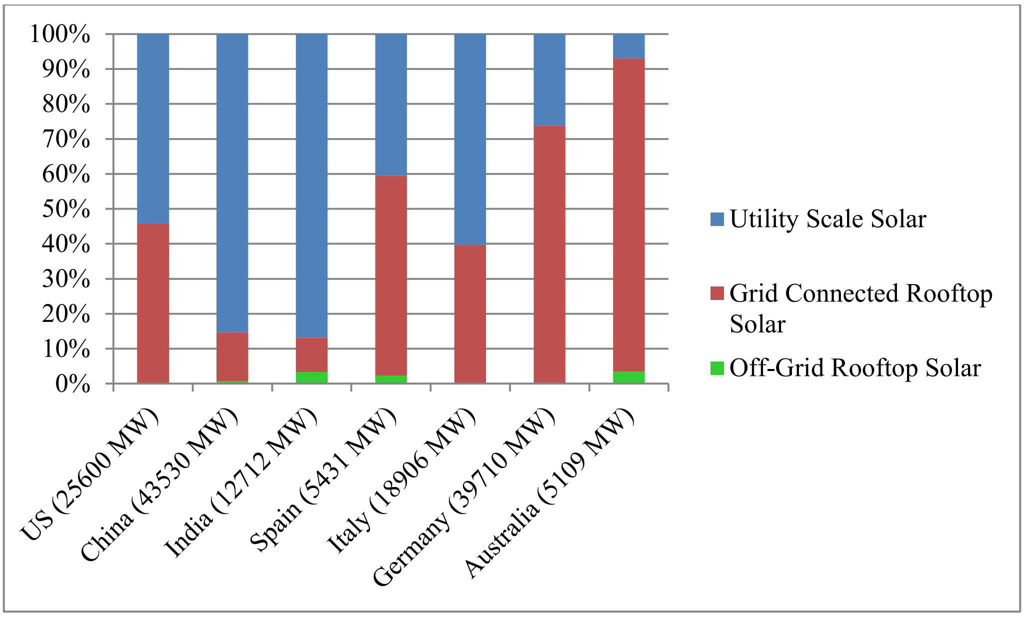


Figure 1.2: Comparison of installed capacity of PV systems across top 7 countries w.r.t. scale and type of system [22 – 27].

This thesis explores the factors affecting the dissemination of rooftop PV systems in the context of India and in particular, in the state of Kerala. Various techno-economic and socio-cultural elements which affect the adoption of this technology are investigated in detail. The study also looks into the different policy initiatives across the states in India and its implementation level challenges, which hinders the growth of rooftop PV. A planning and project implementation strategy for rooftop PV systems at a regional scale (administrative area under a local self-government) is also explored. This planning methodology starts with a 'resource assessment' phase where the rooftop solar installation potential of a region (it can be a gram panchayat, a municipality or a corporation) is being assessed at a fine grain level.

Wherever it is possible, the method tries to collect the 'demand' and 'supply' scenario of power in that region and information from the regional power utility companies so that the planners can come up with a v ery detailed project plan where solar PV can fit in appropriately.

1.1 Motivation

Globally, there were more off-grid PV systems when compared to grid connected systems during the initial years of technology adoption in the market. Later the volume of off-grid applications had drastically fallen as a percentage of cumulative PV installation. Figure 1.3 shows how trends in off-grid *vis-à-vis* 'grid connected centralised' *vis-à-vis* 'grid connected distributed' systems that had happened during 1997 to 2015 across the globe. Majority of these data comes from those countries reporting to International Energy Agency's (IEA) photovoltaic power systems program [28]. Historically most of the countries initially adopted 'grid connected distributed' systems as against 'grid connected centralised' systems until the recent past.

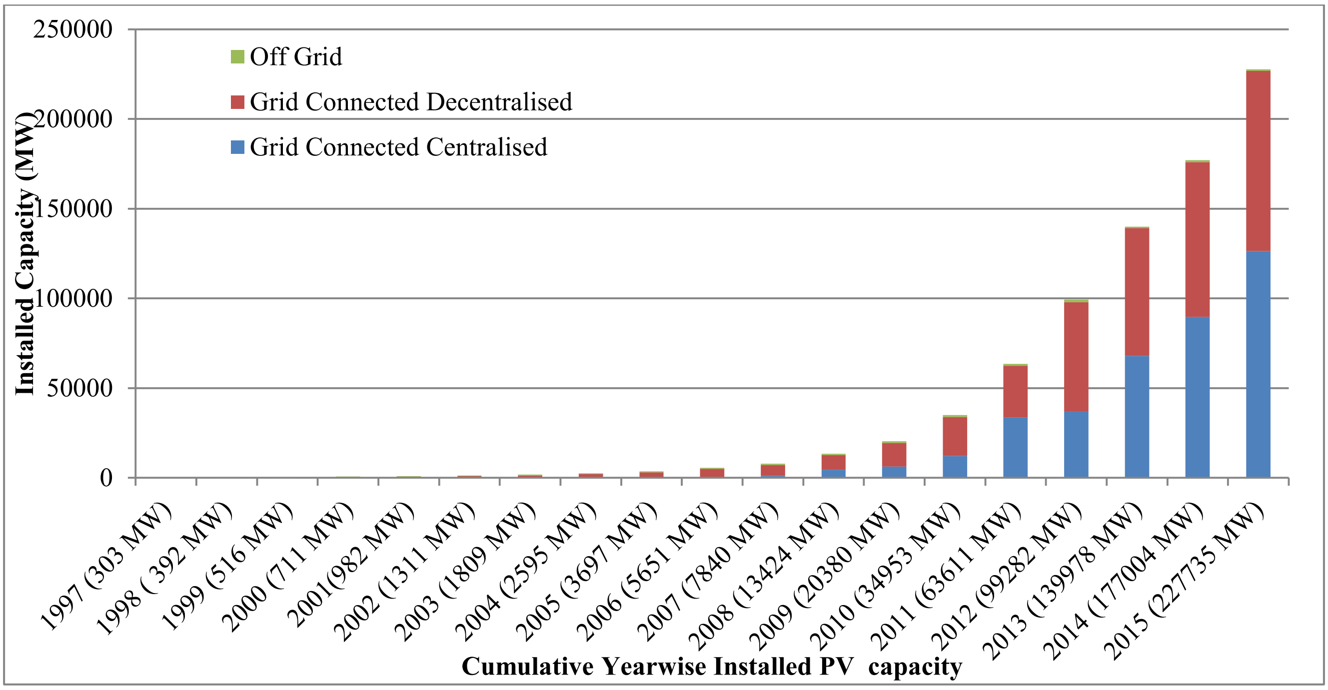


Figure 1.3: Year wise cumulative installed capacities from 1997-2015 and their nature of application across the globe [28].

India has adopted a reverse strategy of embracing grid connected ultra mega solar power projects in the initial years. The reasons being: a) The need to quickly bridge the supply-demand gap in the power sector and to ensure India an energy secure future through rapid ramping up of the installed capacity and energy generation, b) The non-readiness of the utility companies to quickly adapt to such highly variable distributed generation systems and their fear for 'loss of revenue' from cream customers who would adopt self-generation from PV, c) Lack of policy and regulatory framework for distributed rooftop PV systems in different states. In a resolution released in July 2015, MNRE had announced a target of 40 GW grid connected rooftop PV systems by the year 2022. Figure 1.4 shows that the installation targets for rooftop PV projects are gradually increased year on year and the share of ground mount systems are to be gradually decreased. This clearly indicates a plan to shift the priority from large ground mounted systems to rooftop segment. However the data from MNRE shows that the achievements in the past years are far below the targets as far as rooftop segment is concerned. When the ground mounted systems are considered, their targets are fairly met. As on February 2019, the cumulative installed capacities of rooftop systems have reached 1443 MW_p (which is only 9% of the target) and ground mounted systems have reached 24582 MW_p (which is almost 85% of the target) [29]. The ease of doing big ticket business with big energy players in setting up ultra-mega utility plants as against dealing with many stakeholders in case of distributed systems is also a reason for India embracing ultra-mega solar power projects in the initial years.

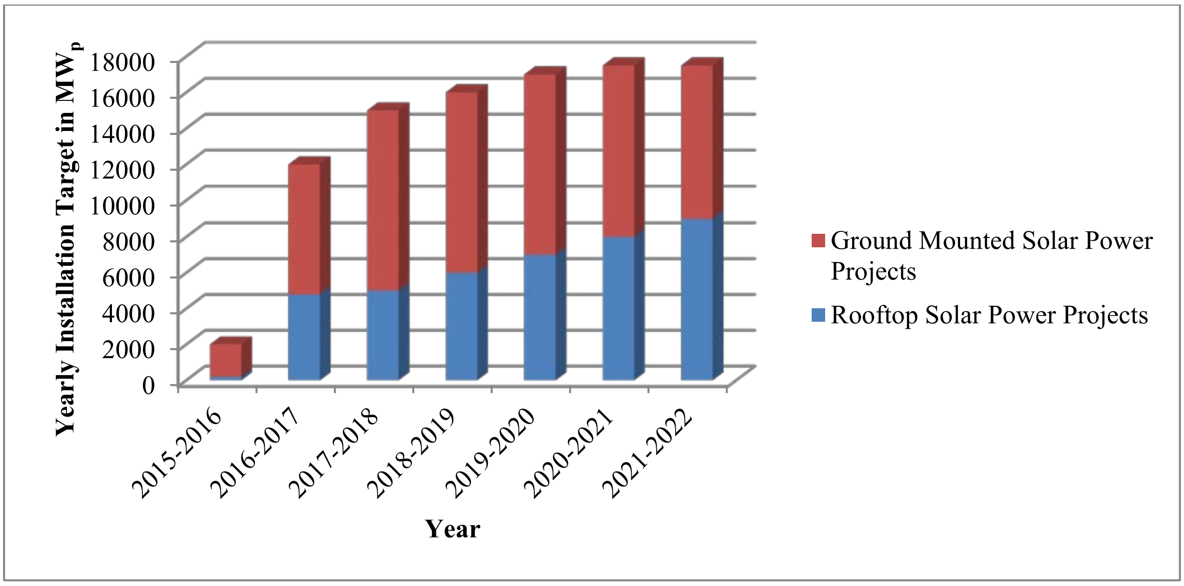


Figure 1.4: Year wise targets of MNRE to achieve the 100,000 MW installation target by 2022 [29].

The motivation for my research comes from the fact that rooftop PV power plants and decentralised generation will play an important role in India's energy sector in the coming years. With most parts of India having an annual average of 4 to 6 k Wh/m^2/day Global Horizontal Irradiation (GHI) [30], rooftop solar PV installations offer an excellent solution to cater to the energy demands at a regional level. MNRE is currently focusing on ramping up grid connected solar energy through large power plants in a phased manner. If the yearly targets of rooftop PV installations as per the resolution from MNRE [29], as shown in Figure 1.4 are to be achieved, major efforts have to come from the side of the state and local governments and state owned power utility companies. So, if we can develop a methodology for planning rooftop PV schemes in a local area, with the participation of these stakeholders, it can be helpful for realising the goals of national solar mission.

Irrespective of the fall in prices for PV modules, inverters and other components used in the systems, rooftop PV market had not picked up in India, the way it was expected. Many states had come up with supporting policy framework during the period 2013-2016. There are 2770 system integrator companies or agencies registered with MNRE as on November 2017 to execute grid connected rooftop projects in India [31]. Component suppliers from all over the world had started operating in India during this period. The supply ecosystem has matured than before and the public awareness about PV has also gone up. Still there are some major stumbling blocks present in this segment which limits its growth. This thesis holistically looks into the rooftop PV segment, and tries to figure out the issues affecting the growth of this sector and intends to contribute constructively, within limited capacities to resolve some of these problems.

1.2 Rooftop PV in the Kerala Context

Kerala, one of the southern states in India is very well known for its ‘development model’ and even spread of socio-economic development in the rural as well as the urban areas. In the power sector, the state has achieved 100% grid extension. According to the economic review report 2012, by state planning board, Kerala has achieved full electrification in all villages [32]. As per the latest census report of 2011, 94.4% households in Kerala use electricity as the primary source of lighting [33]. Hence the scope for off-grid solar rooftop PV systems is very less in Kerala since there are very few houses without grid access. Generation, transmission and distribution of electricity in the state are done by a single public sector utility company, the Kerala State Electricity Board (KSEB) Ltd. KSEB has their own generation capability of 2880 MW and they mainly resort to their hydel based projects for power generation within the state [34]. The maximum demand from the system is reported as 3860 MW during the year 2015-2016. In terms of energy produced, KSEB's own power stations contribute to only 30% of the total energy injected into the system, whereas the remaining 70% is purchased from Central Generation Stations (CGSs), Independent Power Producers (IPPs) and power traders from exchanges [35].

Table 1.1: Statistics of consumers of Kerala State Electricity Board as on March 2016 [35].

Consumer Category	No of Consumers	Connected Load (MW)	Annual Sales of Energy (Million kWh)	Annual Revenue (Rs. In Crore)
Domestic Consumers	91,24,747	13,349.76	9,943.50	3,744.10
Commercial Consumers (LT Category)	19,23,402	3,309.08	2,735.36	2,448.50
Small Industrial Consumers (LT Category)	1,36,693	1,647.07	1,103.23	746.63
HT and EHT Consumers (Large Commercial Complexes and Industries)	5,005	1,445.81	4,106.10	2,816.90
Public Lighting	4,281	124.13	366.62	156.36
Agricultural Connections (Pumping, Aerators etc.)	4,73,882	950.19	279.48	65.62
Other Distribution Licensees	12	88.99	578.08	347.04
Railway Traction	9	65.79	212.83	120.86
Exports			53.48	41.70
Total	**1,16,68,031**	**20,980.82**	**19,378.68**	**10,487.71**

As per the annual power system statistics report 2015-2016, 78.20% of the KSEB's consumers are from residential sector. 16.48% are from commercial sector, 1.17% from small industries, and 0.04% are from large industries, railways and distribution sub-licensees. Table 1.1 shows the number of consumers present in each category and their corresponding energy usage statistics. When we consider the energy consumption and revenue part, domestic consumers contribute to 51.31% of energy consumption and only 35.70% revenue of KSEB. Industrial and commercial consumers contribute to 41% of energy consumption and generate 57.33% of the revenue. There are 12 distribution licencees buying power from KSEB and they consume 3% of total energy supplied by KSEB and contribute 3.3% of their revenue. Remaining 4.31% consumers use power for agriculture, public lighting, public water distribution and other miscellaneous purposes. Due to subsidies provided to domestic and agriculture sector and due to various operational inefficiencies, KSEB faces huge financial loses every year. The revenue gap of KSEB for the financial year 2014-2015 was 2931 crores Indian Rupees (29310 million INR) [36]. The average pricing of electricity for the domestic consumers in 2012 was Rs. 1.99/ kWh. The average 'cost' of supply of electricity was Rs. 4.64/kWh at the same time. Even though this tariff rates were revised in 2017, the domestic consumers still pay Rs. 3.75/kWh on an average and the cost of KSEB has reached Rs. 5.87/kWh [36]. Selling more electricity to domestic consumers would then always increase the revenue gap for KSEB. So for more profitability, KSEB would like the domestic sector to produce more and more of their own power. Solar PV is one of the best options to go for distributed power generation systems at a domestic level. But the fact is that, these domestic consumers are highly stratified and dispersed, and most of them do not have the technical expertise or financial arrangements to buy, own and operate rooftop PV systems all by themselves.

Kerala is densely populated and the land availability and land cost are not in favour of promoting large ground mounted PV projects. According to census of India 2011, 94.8% houses in Kerala are good or liveable [37]. Also, 82.8% houses have either concrete or machine made tile roofs. Considering the large number of 'pukka' houses with roofs suitable for PV installation, highly matured power sector in terms of infrastructure and the high acceptance levels of people of Kerala towards new technology (by virtue of their high levels of education, awareness and economic wellbeing), it is worth looking into the scope for large scale dissemination of grid connected rooftop PV systems in the state.

1.3 Broad Problem Statement

The broad problem that this thesis is trying to address is: "*What are the factors affecting large scale dissemination of rooftop solar PV systems in India and particularly in*

Kerala and how can we facilitate faster adoption of rooftop PV systems through technology, planning, financial and institutional model innovations?”. This broad question can be split down into many sub questions such as, “What are the factors preventing the dissemination of rooftop PV systems?”, “How can we effectively plan for rooftop PV schemes at a regional level?”, “How can the process be adapted to various regions, namely rural, semi-urban and urban areas?, “Whether the process has to be only a technical feasibility study or should it consider various financial, implementation level (institutional models), post implementation management (O&M) details?”

1.4 Research Objectives

Specific research objectives during the course of this research were:

- To find out the factors affecting the acceptance and spread of rooftop PV.
- To identify the stakeholders in this sector, their roles and responsibilities.
- To find out how well does the rooftop PV sector fit in the Kerala scenario.
- To develop a techno-financial evaluation tool for rooftop PV systems.
- To identify the underlying socio-cultural aspects which are related to the acceptance and proper ownership of distributed PV systems.
- To develop a planning and dissemination methodology considering all stakeholders, their priorities, and based on t he learning from techno-economic, socio-cultural aspects related to dissemination of distributed PV.
- To identify the policy and governance challenges and possible solutions for the above mentioned dissemination strategy.

1.5 Research Methodology, Tools and Research Flow

This research followed a mix of quantitative and qualitative methodologies in generating, collecting, evaluating and analysing data and information prevalent to technology dissemination of rooftop PV systems in India and Kerala. The research progressed along six major tracks related to the potential assessment, acceptance and adoption of rooftop PV.

1. Potential assessment method for regional planning for rooftop PV schemes.

2. Scope for integrating Demand Side Management (DSM) and demand response with rooftop PV schemes.
3. Linking the socio-economic aspects and ownership model on the sustainability of PV systems, institutional models of ownership and implementation.
4. National and state level policies facilitating or preventing the adoption of rooftop PV and its implementation level hurdles.
5. Economic viability, business models and financial modelling for rooftop PV systems.
6. Identifying new applications where rooftop or distributed PV would fit in.

1.5.1 Participatory Action Research

The research was mainly driven through field surveys and stakeholder interactions and interviews. Data collection from secondary sources like local self-governments, utility companies, and other census data available in public domain was also a part of the research. From a research methodology perspective, the approach can be categorised as 'Participatory Action Research (PAR)'. PAR is considered as a subset of action research where "systematic collection and analysis of data for taking action and making change" is achieved through interactions and collaborations with the stakeholders [38]. The researcher, as a 'participant observer' gets involved in the activities of the organisation or a community to identify and solve their problem. This is a dynamic learning process and generates practical knowledge and information which can be critically reflected and applied back on the field of study for improvement of situation. PAR is a widely adopted research methodology in the fields of education, health and social work where community-based problems and solutions are inquired.

In this thesis, researcher was a participant in the activities that were aimed at a 'change' in the existing situation of rooftop and distributed solar PV in India, especially in Kerala. Whenever it was possible, the knowledge that was generated during the process was reflected and applied back in the system.

The major tools used in research are as explained below:

- **Literature Review** – Review of literature from peer reviewed journals and conference proceedings were extensively done on topics like adoption theory (of new technology by society), energy planning, rooftop PV systems, decentralised energy systems, participative planning for distributed energy projects, policies and initiatives to promote rooftop PV across the globe and in India. Other than journal publications, reports available in public domain from reputed energy sector organisations such as International Energy Agency (IEA), International Renewable Energy Agency (IRENA), The Energy Research Institute (TERI), Prayas Energy Group, Pune etc. were also covered in the review.

- **Questionnaire Surveys –** Questionnaire surveys were carried out while developing a methodology for assessment of the rooftop potential at a regional level. There were both sample surveys and entire population surveys. There were mostly questions with restricted set of answers from which a respondent can select one. These kinds of questionnaires were more effective and easier for post survey analysis (since the types of responses were limited and precise).
- **GIS based studies** – Geographical Information Systems such as Google Earth was extensively used in studies related to rooftop PV potential analysis. Free and open source software and tools were intentionally used in this process, so that it can help in easy replication and propagation of knowledge by other researchers and stakeholders.
- **Simulation and Coding** – Simulation was an important research tool used while predicting the energy generation and performance of PV systems in certain areas. Impact of dust on energy generation and hence on levelized cost of electricity from PV systems were studied through coding and simulation. Similarly, the effect of large scale PV penetration on the load curves of the power distribution system in cities and regions were studies through simulation. Similarly, the impacts of DSM and smart inverters on the peak loads were studies by data generation through coding.
- **Semi Structured Interviews** – Semi structured interviews were mainly used while interacting with energy experts, energy sector practitioners and system integrators in the market. Similarly while interacting with people in positions of responsibility in major institutions – the Kerala State Electricity Board Ltd., Agency for Nonconventional Energy and Rural Technology (nodal agency for MNRE in Kerala) etc., similar approach was followed. Interview with beneficiaries of the projects which were undertaken as case studies were also conducted to develop an understanding of their 'perspectives'.
- **Focus Group Discussions** – Focus group discussions were useful in understanding the priorities and felt needs of people regarding adoption of rooftop PV systems. The

method was found effective while developing a methodology for estimation of rooftop potential of cities. The same tool was found useful while studying the impact of community based rooftop PV systems in tribal hamlets.

- **Secondary Data Collection** – Maps, census data, information regarding the type of buildings, rooftops, land use etc. were collected from local self-government offices and departments.
- **Web Based Data Collection** – Census data from the government of India and energy usage statistics from utility companies were available for download from their web servers. Detailed bill information about selected customers was also available from the billing servers of the Kerala State Electricity Board Ltd.
- **Site Visits and Observations** – While undertaking case studies and project evaluation, site visits were done and observations were noted.

1.5.2 Research Flow

The research started off with an exploratory phase when the focus was on the study of available literature and previous researches in similar lines. The literature survey covered various topics related to rooftop PV systems such as barriers for renewable energy technologies in the market, basics of 'adoption theory' (which deals with how society accepts or rejects a newly introduced technology), solar city master plans, technical guidelines for distributed power generation systems by regulatory bodies, comparison of national solar policies of various countries, history and status of wind energy sector in India, and influence of 'socio-economic' and behavioural aspects of system owners on t he sustainability of rooftop PV systems.

Later the research entered into mostly field survey based studies with focus on developing a methodology for assessing the rooftop solar potential of a region through crowd-sourcing the data collection to school and college students. The methodology was first tried out in a rural scenario, at Chendamangalam gram panchayat, Kerala. Subsequently, an attempt was made to understand the limitations of a utility company in promoting grid tied rooftop solar PV. During this phase, a joint project was done with the Kerala State Electricity Board where a new dissemination strategy for rooftop solar was tried out through the invention of an 'intelligent' solar inverter. The project also proposed a dissemination strategy where the capital subsidy for PV systems can be re-directed towards the cost of energy efficient equipments, which could be bundled with the PV scheme. The method for rooftop assessment was experimented in a s ub section of the city of Thiruvananthapuram, Kerala during this phase.

The ‘crowd-sourcing’ method developed for rooftop potential assessment was later tested out in a much larger scale in the city of Mumbai. The method was further refined and updated through the use of GIS tools and 3D modelling and simulation of urban built up areas. Even though there are no chapters or sections in this thesis detailing this study, an executive summary of this study report is available in Annexure XII.

During the second and third phases of research, a parallel study on the ‘performance of rooftop PV systems’ and its relationship with the ownership model, financial model and the true motivation behind the installation of systems was conducted through the ‘All India Surveys of PV module Degradation”, an extensive field survey of PV systems all over India.

The fourth phase of research was more into economic and financial viability of rooftop PV systems. During this phase, a Levelized Cost of Electricity (LCOE) calculation tool, with inputs from module, inverter, other component manufacturers and system integrators in the industry was developed.

The final phase of research looked into identification of new applications suitable for rooftop and distributed PV, especially through business model and policy level innovations. The need for technology innovations which can assist in developing new business models and policy approach were also looked into.

1.6 Solution Overview: Integrated Planning and Implementation Methodology

As explained in section 1.1, the governments are currently in a process to ramp up the installed capacities of PV systems. But the focus is currently on ‘ meeting the installation targets’. Whether or not these targets are met in a ‘sustainable’ way is not really looked into. This thesis looks into the possibility of developing an integrated planning and implementation approach of rooftop PV systems through active participation of various stakeholders and beneficiaries. Wherever possible, the involvement of the local self-governments, the user co-operatives, utility companies and component suppliers are ensured so that the projects envisaged are in line with the interests of majority of the stakeholders.

Figure 1.5 depicts the research approach and process flow followed in the development of this thesis. It shows the different factors and aspects affecting rooftop PV dissemination and the need for an integrated planning and implementation model for wider disseminating and adoption of PV.

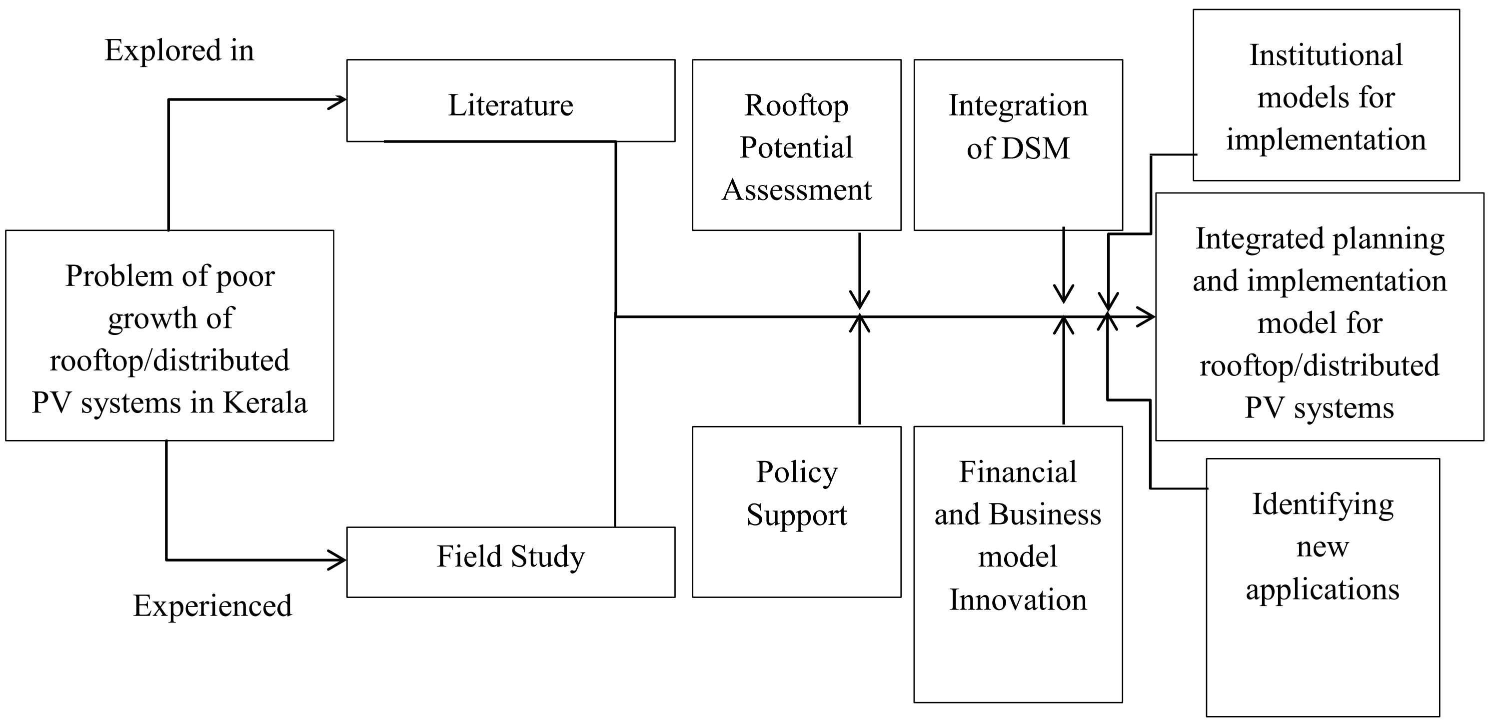


Figure 1.5: Development of an integrated approach towards rooftop PV dissemination.

1.7 Organisation of Thesis

This thesis is organised into nine chapters with the first chapter introducing the motivation for this research, research objectives, methodologies and contributions from the thesis. The second chapter collates the knowledge available from literature on major areas to be looked into while dealing with a ‘technology dissemination research’. It looks into the basics of ‘adoption theory’, barriers for PV technology, previous experiences in decentralised planning of energy projects, global and Indian policies and schemes for promoting PV.

Third chapter explains the scope for rooftop PV in Kerala, major stakeholders involved in the sector and their roles and responsibilities in taking forward the rooftop PV sector. A discussion on different market segments and potential market size of rooftop PV segment in Kerala is presented. Chapters four and five details of methodology and results of two rooftop potential assessment field surveys done in Kerala, in two different settings. Hence these chapters cover most of the aspects on 'potential for rooftop and distributed PV system' in Kerala.

After assessing the potential for rooftop PV systems, chapter six does a review of the experiences from the past rooftop PV projects and schemes implemented in Kerala. This chapter looks into the reasons for success and failures of the projects and tries to identify the scope for improvement in planning and implementation.

Chapter seven takes a step back from Kerala and looks into the experiences from projects and implementation models of rooftop and distributed PV systems from other parts of India. This study is supported by the data from 'All India Surveys of PV Module Reliability' by the National Centre for Photovoltaic Research and Education (NCPRE), IIT Bombay. Issues such as the poor quality of components and higher degradation rates of PV modules used in rooftop installations, the linkages between ownership model of the systems, financial models and cash flows, need for local trained manpower etc. are discussed here. This chapter also reviews a project implemented in Anand, Gujarat, where a farmer co-operative owns and operates 'grid connected' solar water pumps.

Chapter eight discuss the business models in practice for rooftop PV systems, and the financial viability of rooftop PV for various consumer segments in Kerala and other states of India. The chapter also contains the details of development of an LCOE calculator for PV based projects and the sensitivity of each factor contributing to its cost.

Chapter nine brings out the salient features of state level rooftop PV policies of all states in India. It then compares the state policy of Kerala with other states and brings out the advantages and disadvantages it has over the others. It also discusses the implementation level hurdles involved in the existing policy and norms and ways to ease the process of rooftop PV adoption through amendments in policies.

After covering various aspects of dissemination of rooftop PV systems, including the potential assessment, planning, technical designs and products, economic viability, policy support, implementation models etc. from literature, secondary data, primary data from surveys and case studies, chapter ten discuss on the possible ways forward for the successful dissemination of rooftop and distributed PV systems in Kerala. Based on the findings of these studies, this chapter answers the research questions stated in chapter one.

Chapter eleven concludes the findings and consolidates the important points discussed in each chapter. Recommendations towards the need for an integrated planning and implementation approach for rooftop PV systems in Kerala are outlined.

1.8 Contributions of Thesis

This research developed a methodology for rooftop potential assessment for a region through crowdsourcing the survey and GIS based activities by student community. The methodology was improved and scaled up from a village level to a city level and even up to a mega-city level through minor adaptations at each level.

A detailed study on degradation rates of PV modules used in rooftop PV systems and its linkages with the type of ownership, financial model and cash flows and the end use categories were undertaken as a part of this research. Identification of community owned systems linked with regular cash flows as the best model for rooftop/distributed PV dissemination was an outcome of this study. The plight of poor quality control on t he modules used in smaller rooftop projects, as compared to large installations was an important finding of this study. Need for trained technicians and the requirement to include PV based education content at the ITI levels were pointed out based on the statistics from the surveys undertaken in this research.

Even though, it was a by-product of this research, the process came up with a very clear dataset of the equipment ownership and energy consumption pattern of different consumer classes among the residential electricity customers in Kerala. This provides valuable input for energy planning and policy decisions. Similarly, the rooftop PV potential for the city of Mumbai was estimated as a result of scaling up experiment of rooftop PV potential identification exercise. The executive summary of this study report is available in Annexure XII

Even though there were previous researches suggesting the adoption of energy efficient technologies along with renewable power sources, this research has gone into the details of economic viability and modelling for optimisation of packages and financing schemes for the proper implementation of schemes. This thesis proposes a model for disseminating PV in parallel with energy efficient equipments, with the help of real consumer appliance data from field surveys and economic viability analysis.

Identification of issues related to ‘community’ based rooftop PV systems and community water pumping systems were also done as a part of this study. Promotion of the idea for grid connected solar water pumping schemes is one of the highlights of this research.

An exhaustive comparison of rooftop PV policies of all the states in India was carried out and brought out the salient features of each state policy. The economic models and viability analysis for different rooftop PV business models developed as a part of this research can be used as a business development tool for system integrator companies.

Through the process of active involvement with various stakeholders in the rooftop PV segment in Kerala, the research has also helped in the upbringing of renewable energy verticals in two major public sector organisations in Kerala. The green energy and technology centre, which was incorporated in the Centre for Development of Imaging Technology (C-DIT), a government sector company and the formation of ‘Raidco Renewables’, the renewable vertical for Raidco Kerala Limited, a co -operative sector organisation in Kerala with 95% government shares are the results of constant interactions and contributions from this research.

With this brief overview of the structure, content, methodology and research questions addressed in this thesis, the next chapter covers the review of literature. The chapter discuss on the knowledge assimilated through review of published journal articles.

Chapter 2

Literature Review

This chapter consolidates some of the knowledge and experience from past works in distributed energy planning and studies undertaken by various research groups all over the world regarding PV technology dissemination. This section reviews about the barriers for PV technology penetration, public policies and schemes adopted by various countries to promote rooftop PV and decentralised planning experiences in energy sector in India. It also briefly touches up on the basics of 'adoption theory' – how societies respond to introduction of a new technology.

2.1 Barriers for Dissemination of PV

Most of the innovations in the non-conventional energy technologies take more than a decade to prove themselves commercially viable. Considering the limited amount of time to react to the challenges of climate change and other environmental degradation issues, we have to replace the less efficient conventional technologies at a faster rate. We cannot wait till the non-conventional technologies attain adequate level of market acceptance through reduction of prices. The current costing schemes do not reflect the environmental and social values of innovations. Historically there were a number of barriers for PV to penetrate into the energy market, especially in developing countries. Some of the barriers which were very often mentioned in the literature are listed in Table 2.1.

Table 2.1: Barriers affecting the penetration of PV and other renewable energy technologies [39].

Barriers	Remarks
1. Market Failures	
a. Energy sector is highly regulated	Generation, transmission and distribution of power were highly regulated or a monopoly of the government. This caused lack of private sector investment and trial of new technologies.
b. Inadequate information and lack of awareness about advancement in renewable energy technology	Inadequate information about technologies, products, costs and availability of finance. Agencies that were responsible to bridge this gap were inefficient and there were no feedback mechanism from the field about the need of the society.
c. Technologies are not easy to access	The technology developer was either unwilling to freely share it or the policies were restrictive and makes it costly to import a technology.
d. Lack of competition	Government monopoly did not allow other entries and this did not allow any competition and thereby reduction of cost.
e. Poor market infrastructure and supply chain	Lack of proper supply channels and logistics for the marketing of renewable energy technology products hampered its market.
f. High investment requirements	Economies of scale work at only high investment level. Whereas the market size and demand for renewable technologies were

	limited, unless boosted by policies.
2. Market Distortions	
a. Non consideration of externalities	Negative impacts of conventional power such as pollution are not considered in pricing of conventional technologies. Subsidised rates of conventional energy make it look cheaper than PV.
3. Economic and Financial Barriers	
a. Economically non-viable	Levelised cost of electricity from PV is high.
b. Small market size	This limits cost reduction through economies of scale.
c. High cost and lack o f access to capital	Initial investment is high and the existing commercial banks perceive higher risks in releasing loans due to the uncertainty in the technology. H igh discount rates and long payback periods discourages investors.
d. Lack of access to credit to consumers	This will again reduce the market size.
4. Institutional Barriers	
a. Lack of an institutional mechanism for knowledge dissemination	Existing institutions lack capacity to generate and disseminate proper information.
b. Lack of legal and regulatory framework	Such frameworks are required to overcome some of the barriers stated above, especially in realising the financial incentives from government and inviting private investment.
5. Technical Barriers	
a. Lack of standards, codes and certification for quality control	This causes lesser acceptability of the products and increases commercial risk which in turn gives a negative perception about the technology.
b. Lack of trained manpower	This can be solved by introducing training institutes and integrating new programs in existing institutes.

c. System constrains	Lack of infrastructure and grid connectivity is also a constraint in wider dissemination of renewable technologies.

J.P. Painuly, in his paper ‘Barriers to renewable energy penetration; a framework for analysis’ argues that a public policy driven approach is needed to correct these market failures, market distortions, techno-economic and institutional failures to ensure a level playground for the green technologies [39]. He suggests that the primary role of the governments should be to formulate favourable policies and to create public awareness about the potential of PV in future energy scenario. The policies should be focusing on t he development of a healthy market by restricting monopolies and aimed at formulating standards and codes of practices and hence overcome the barriers identified in Table 2.1.

2.2 Difficulties in Framing National Policies for Renewables

As discussed in the previous section, renewables need a policy driven market establishment in the initial phase. But to come up with appropriate strategy and policies itself is a difficult task. Lack of adequate information such as the required capital investment and the duration required for the economies of scale can bring down the unit production cost often forces the policy makers to support technologies which may never become commercially viable [40]. Industry lobbies often try to take advantage of this situation by overstating their support requirements. Governments have to make a trial and error approach and watch the market developments to finally reach an appropriate policy. Some argue that the government does not know which technology will succeed, but the market better understands this. But the counter to this argument is that the decisions made by private investors do not have the perspective of public welfare and environmental externalities. The challenge for policymakers is thus to accelerate the development and deployment of renewable technologies in ways that minimise the ‘political capture’ [40] and waste of taxpayer and consumer money. In short, the ideal nature of government incentives can be summarised as below:

- It should be able to balance various competing objectives (such as climate change mitigation, local pollution , energy security and technological learning) while promoting a technology.

- It should be able to determine and allocate appropriate amount of yearly subsidies based on available information.
- It should show a long term commitment and genuineness in support of a technology (to build confidence in investors).
- It should not only introduce subsidies, but also revise them from time to time, introduce caps in allocation, and finally withdraw them when the technology is mature enough.

2.3 Strategies and Policy Tools Adopted by Various Countries to Promote Rooftop PV

Most of the industrialised countries in Europe like Germany and France adopted PV, basically to meet their emission reduction targets and to find alternatives to nuclear energy. Some others have focused on solar energy due to their concerns on energy security [41]. China has boosted their PV industry for achieving self-reliance in energy sector and up to an extent, to make economic benefits out of the increasing demand for PV in Europe and the USA [42]. Cost reduction is one of the major objectives of public support to PV in most of the countries. The global prices for PV modules have come down to 0.4$/W$_p$ in 2016 as compared to 4$/W$_p$ in 2006. System prices have also fallen by more than 75% since 2006 [23], through investments in this sector made with government support. Two types of approaches were seen in the attempts to reduce cost in the industry

- ***Supply enhancement or Technology push approach***:

It involves the public support given to the R&D and manufacturing industry. Public support is essential in R&D since there is a risk of under investment from the private sector for such commercially nonviable technologies, unless there are any incentives from government. Some of these policy instruments include tax exemptions, reduced interest loans and public guarantees. A reduction in cost is expected through technology improvement (e.g. through new or optimised processes resulting in reduction on material requirement) [41].

- ***Demand Pull or the Keynesian approach:***

Technology push policies are often followed by demand pull policies for simulating the market and re-establishing employment and production. Grid connected decentralised PV systems were found to have the dominating share of global installed capacities till 2010 [43].

There are generally two ways of subsidy schemes followed in promoting PV distributed-generation projects. One is to subsidize the equipment cost and the other support is to support market price of electricity derived from PV. Feed in Tariffs (FiT), net metering, subsidies on initial cost, issue of renewable energy certificates etc. are some examples of such policy instruments.

Another way of classifying the support measures offered by the governments for PV are as deployment support, investment support to the industry and R&D support.

Deployment support: There should be clarity in the deployment targets and the future costs involved in it, while framing a deployment support policy. The rate and duration for which feed in tariffs are announced and their timely revisions do have a crucial implication on the future costs of the policies.

Investment support: Investment support measures are to be designed based on the existing structure of the industry in the country. It should be able to encourage existing industries to use their core knowledge and expertise in initiating activities in PV sector.

R&D support: The amount spent by the government in promoting R&D in PV sector during the various phases of technology growth is important. Most of the countries have spent very low share of their public expenditure on P V research. They expect that the deployment support and the investment support will indirectly encourage the R&D, especially when the industries try to reduce the cost of production of PV. The virtuous cycle between R&D, market growth and cost reduction was illustrated through the case study of Japan by Watanabe *et al.* [44].

Some of the learnings from the review of international policy approaches in promoting rooftop PV are summarised below [41, 42].

FiTs need to be dynamically adjusted in a transparent process from time to time: German experience shows that high FiTs can result in over deployment and unexpected profit to the PV installers due to fall in module prices. In France also, there was a mask effect on prices of PV systems due to over support from government, in terms of capital subsidies. The prices in the market remained stagnant even though there was a significant reduction in actual cost. Experiences from Spain also indicate timely downward revision of FiT is effective in bringing down the market price of PV systems.

Introduction of upper caps for installed capacity is necessary: Spanish experience says that uncontrolled development of PV power plants can result in higher prices due to over demand. Also a later downfall in market will affect the local employment as well.

Integration of Demand Management programs with PV policies works well: Italy was successful in introducing FiTs at the right time, when the renewable energy certificate market was not efficient enough to promote the PV sector. They have also incorporated the demand management programs along with the PV policies which is a good model for others to follow.

Investment on R&D and demonstration projects is required in the initial stages: The high amount of R&D support and its timely reduction from as high as 50% to 5 % in 12 years is a notable approach in the United States' PV policy. Japan also channelized high amount of public investment on R &D and demonstration projects in the initial stages of technology dissemination.

Cost and responsibility sharing between central and state governments: Another important aspect regarding the support policies for PV is the effective cost sharing between the federal and state governments. In US, most of the demonstration programs were supported by central aids, but the market incentive programs were supported by the state and regional government. China also followed similar structure and provincial governments were more responsible for the implementation of support mechanisms.

PV policies in the Indian context: In India, utilising scarce public resources for projects which are not directly feeding into poverty alleviation, that too using a non-price competitive technology like PV, when government owned power utility companies are already running at losses is a difficult task. The Government of India launched the Jawaharlal Nehru National Solar Mission in 2009 and this was the first comprehensive policy till then to promote solar technology in the country. Primary focus of the JNNSM is to ramp up grid connected solar energy through large power plants in a phased manner. Most of the incentives from the federal government are in terms of FiTs for 25 years. Renewable Purchase Obligations (RPO) and the Renewable Energy Certificate (REC) mechanisms are also in place. Other incentives include tax holidays, accelerated depreciation of investment, soft loans, simplified project clearance schemes and long term lease of land at nominal rates. The reverse bidding procedure for allocation of JNNSM projects has been found to be an efficient method than predefined FiT especially when the lack of information about project parameters makes it difficult to policy makers to fix a value. Small and medium scale rooftop installations have not received enough attention in the first phase of JNNSM. The government has tried to address this issue by initiating rooftop specific projects through Solar Energy Corporation of India (SECI). With a little more attention given to the grid tied distributed PV s ystems and by establishing an active REC market, Indian PV sector can definitely achieve the JNNSM targets well in time, irrespective of the initial glitches in phase 1 due to delay in project commissioning [40].

2.3.1 Comparison of Policy Tools Used in Various Countries

Various policy instruments have been tried across the world and they have been instrumental in the deployment of solar energy in various countries. Table 2.2 summarises some of the major policy tools adopted by various countries. A detailed study on the different policies used in India, differences between net metering, gross metering, feed in tariffs, etc. are presented in chapter 7 of this thesis.

Table 2.2: Various policy instruments used world over for promotion of solar energy [45-47].

Policy Instrument	Explanation	Remarks: Countries
Feed-in-tariff	Premium or tariff or payment to new and renewable energy technologies which are relatively expensive or may not be competitive with conventional technologies for electricity generation.	Played an instrumental role in Germany and Italy.
Investment tax credits	Accelerated cost-recovery system through depreciation deductions	United States, Bangladesh.
Subsidies	Capital subsidies funded either through donor and/or government funds	Developing countries like India.

Renewable energy Portfolio Standard (RPS) or Tradable Green Certificate (TGC)	Electricity suppliers (e.g., utilities, distributors) are required to have certain percentage of their electricity supply coming from renewable energy sources.	In the United States, 31 out of 50 S tates have introduces RPS.
Financing facilitation	Banks and financial institutions financing renewable installations at low interest rates	Microcredit financed facilities in Bangladesh , Shell foundation in Kerala and Karnataka through Canara Bank and Syndicate Bank.
Public investment	Main drivers of solar energy development in developing countries are public investment.	The rapid development of the PV industry and market in China is mainly due to government support.
Net metering	System where households and commercial establishments are allowed to sell excess electricity they generate from their solar systems to the grid.	Implemented in Australia, Canada, United States and some European countries including Denmark, Italy and Spain.
Government mandates and regulatory provisions	Laws mandating transmission companies and electricity utilities to provide transmission or purchase electricity generated from renewable energy technologies, including solar.	China issued the Renewable Energy Law. In Germany, all renewable energy generators are guaranteed to have priority access to the grid.

2.3.2 How Can We Measure the Effectiveness of Policies?

There are many indicators to evaluate the effectiveness of the policy support instruments by various countries. In general, a policy is effective if it could drive a significant PV installation at 'acceptable' cost. Avril *et al.* [41] has suggested that the analysis of annual expenses by government per installed capacity of PV in a year can give us the indication of support policy's durability. If the annual expenditure on a particular support policy is too high, it cannot be continued for too long. Other indicators for measuring the effectiveness of PV support policies mentioned in various literature are:

- Average cost of installed capacity
- Average cost of produced energy
- Gap to grid parity

2.4 Decentralised Planning/Participatory Planning for Rural Energy Projects in India

In India, the first concentrated efforts considering rural energy as a separate sector began in the 1970s in response to the oil crisis. The major thrust of these early efforts was on fuel substitution by supplying kerosene through the Public Distribution System (PDS) and power through rural electrification [48]. In the 1980s, with the identification of the 'fuel wood crisis' the government launched the National Project on Biogas Development (NPBD) and the National Programme on Improved Chulas (NPIC). The Energy and Resources Institute's (TERI) study about this program in 2011 lists the following as the main reasons for the limited success of these rural energy programs [49]:

- The absence of a mechanism for ensuring the genuine participation of the local inhabitants.
- With little flow of information or feedback between the laboratory and the field performance, the choice of options for the rural masses remains very limited.

- Centralised Planning*:* Government initiatives have largely been in the form of national level rural and renewable energy programmes.
- No assessment of the felt need for these technologies at the local level.
- Technology driven rural energy programmes: The emphasis is on di sseminating technologies rather than a package of products and services.

2.5 Technology Dissemination – The Learning Curve and Adoption Theory

Availability of a new technology does not ensure an early adoption of the same by the society. 'Adoption theory' deals with the study of the factors which will influence the decision making and adoption of a new technology by the potential users in a market. If we try to link the process of dissemination of PV with the basic concepts of adoption theory, 4 stages of decision making can be identified. The potential adopters first become 'aware' about a technology, assimilate more knowledge about the same and 'generates some interest' in it, then they 'evaluate' the technology or innovation according to their level of knowledge and understanding, finally they 'accept or reject' the technology. Hence the 4 stages are ***awareness, generation of interest through knowledge assimilation, evaluation and adoption/rejection***. The level of knowledge that the society could imbibe is a key factor since it decides the views and attitudes they develop towards a technology. The views thus developed will then persuade them to make a decision, either to adopt or reject a technology. The more informed and knowledgeable the societies are about a technology, the more will be the probability of adopting that technology [50].

Everett Rogers, in his book 'Diffusion of Innovations' [51] proposed a new model of technology adoption by replacing the awareness phase by a knowledge phase and adding a post adoption evaluation process called '***confirmation***'. 'Confirmation' phase decides whether the society will continue to prefer the adopted technology based on its performance. The paper also identifies a set of pre-knowledge phase decision variables such as motivation, product characteristics and context which are built into the model. Another study from Curtin University, Australia [52] has incorporated some other socio-techno-economic factors such as finance, supplier characteristics and government initiatives into the conceptual framework for the promotion of PV technology.

A brief explanation of the various factors affecting the decision making and technology adoption process in the context of PV is given in this section.

Motivation: It can be the "felt need" which prompts the society to develop knowledge about a new technology. It can also be economic factors such as tax incentives which motivate the private sector to invest. Commercial entities explore PV as an option to free themselves from utility companies. Hass *et al.* [53] reports that the predominant motivations for investing in PV are environment protection, especially as a substitute to nuclear power, technical interests and financial incentives.

Technology or Product Characteristics: T his includes superiority of the new technology to existing options, consistency with adopter's values and needs, complexity, trialability, and observability (results should be seen by others). PV technology is superior to existing technologies in terms of down scalability and cleanliness. But it may be less superior in controlled production (firmness) of power. In terms of complexity, PV definitely has an advantage and it is extremely trial-able.

Government Initiatives: Government's role in promoting PV technology through financial incentives and developing an institutional framework is extremely important.

Supply Ecosystem: Product quality, reliable delivery, competitive price, and parts availability. This depends on the level of maturity, the industry has achieved in a country.

Finance: Since PV is a capital intensive technology, availability of long term credits is a requirement for its growth. Conventional banks have limitations in issuing long term capital.

Knowledge: Knowledge can be of three types - awareness, basic information and principles knowledge. After being aware of a technology, the potential adopters seek information such as the basic features and applicability of the technology to their problem. Principles knowledge refers to the principle which governs the working of an innovation and mostly technical knowledge [50]. Generally principles knowledge is not a prerequisite for adoption of a technology. But the adoption of a technology is generally boosted, once the reliability of the same is field proven.

The role of government with respect to the knowledge element is to ensure the dissemination of information about the renewable energy benefits and other financial aspects of PV. Resource assessment, demonstration projects and providing industry training can also be supported from the side of the government. Generation of knowledge through R&D should also be funded by government.

Experience: Experience of the early adopters can feed into the knowledge of others. Three levels of experience are identified by Kaplan [50] – exposure, direct and indirect experiences. The innovativeness experienced from a n ew technology is a m ajor factor affecting the promotion of a technology

Familiarity: The combined result of experience and knowledge is familiarity.

Persuasion or Interest and Decision Making: When knowledge and experience reaches a particular level of maturity and depending on the influence of other variables, the adopter develops a 'belief' about a technology and jumps to the final state of decision making.

Rogers [51], in his study on di ffusion of technologies suggested an 'S'-curve model for the temporal data of percentage of consumers adopting a new technology. The diffusion model has an introduction phase, early adoption phase, and market growth phase. The model categorises the adopters as 'innovators' – those who tries the technology in the early introduction phase itself, followed by 'early adopters' – those who adopts the technology in early growth phase, 'majority' – those who accepts the technology during the market take off phase and the laggards and non-users who continues to wait till the market is established and the costs are stabilised. Figure 2.1 s how the relation between adoption levels with time as proposed by Rogers.

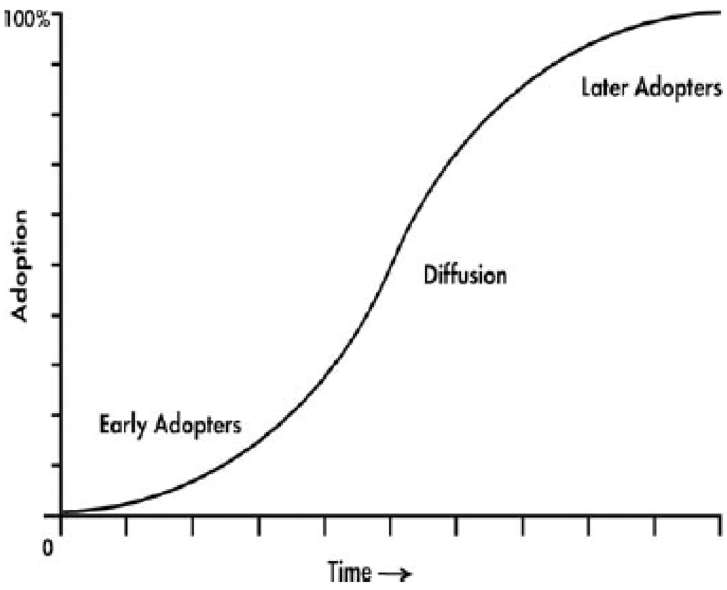


Figure 2.1: The diffusion 'S' curve [51].

Innovators are mostly technically educated and have a genuine interest in the technology, comparatively high income, are aware up to a certain level about environmental issues and have a strong belief that the technology can solve environmental problem. They will try out the technology even if there are no considerable support measures from the government.

The number of early and majority adopters depends mainly on the attractiveness of the government incentives. The initial investment is a major inhibition among the laggards and non-users. The study by Sauter *et al.* [54] point out that the individuals often do not consider much about future savings and revenues. False information about the pricing of renewable technologies is also a major setback for the diffusion of technology. Their survey results states that 50% of the users assumed the price of solar water heaters as 5000£ but the actual cost was only 2500£. Hence the role of government in educating public should be considered in framing policies.

To conclude, the policies should have incentive structures to support all kinds of models of PV microgeneration and should have an education element to clear the ambiguities about the technology among the consumers. Timely introduction, operationalization, updation and informed withdrawal of policies are important for the intended results from them.

2.6 Conclusions

Like any other innovations, renewable energy technology innovations and hence solar PV also needs a policy driven dissemination methodology during its initial phase. The government has to frame policies within a reasonable period of time, based on unbiased appraisals of the inputs from the technologists, market players, and end users. A supportive policy environment can help PV to overcome its barriers for dissemination such as market failures, economic and financial incompetency, lack of institutional frameworks, lack of infrastructure support, and technical immaturity.

The major supportive measures offered by governments all over the world for promoting PV technology can be classified into deployment support, manufacturing support and R&D support. During initial stage of the technology development, governments need to generously spend on R&D support and later into manufacturing and deployment support. Over a period of time, PV would be reaching market acceptance through cost reduction and through familiarisation of technology. Hence, during these periods, the amount of public investment and the response from the society towards the policy actions need to be closely studied and appropriate corrective measures need to be taken from time to time. Introduction of annual installation caps, year on year reduction of FiTs, introduction and removal of tax holidays at appropriate times etc. are required for the development of a healthy PV market.

Effectiveness of all these efforts from the government can be measured as it will be reflected on (a) growth in total installed capacity of PV, (b) average cost per installed capacity of PV, and (c) average cost of produced energy and hence gap to grid parity. These values can be used in comparing the policies across different countries and to evaluate the growth of PV sector.

Decentralised planning in Indian energy sector, especially in rural energy projects have faced difficulties in execution levels due to (a) lack of participation from the beneficiaries in planning stage, (b) lack of feed back to the technology development centres as well as the project implementation agencies, and (c) top down planning with no assessment of felt needs and required products and services. These issues need to be addressed while planning for upcoming PV dissemination projects in rural areas.

As per the technology adoption theory proposed by E.M. Rogers, the level of knowledge that the society could imbibe is a key factor since it decides the views and attitudes they develop towards a technology. The views thus developed will then persuade them to make a decision, either to adopt or reject a technology. The more informed and knowledgeable the societies are about a technology, the more will be the probability of adopting that technology. The views thus developed will then persuade them to make a decision, either to adopt or reject a technology. Hence an organised awareness creation and technology familiarisation effort from the side of government is also important for wider adoption of PV technology.

After the detailed discussions on case studies from literature on ‘adoption theory’ and ‘barriers for dissemination of PV’ in this chapter, the next chapter looks into the scope for rooftop PV projects in Kerala. Secondary data from government records and published articles are analysed.

Chapter 3

Scope for Rooftop and Distributed PV Systems in Kerala: Stakeholders and Market Potential

This chapter details out the scope for rooftop PV technology dissemination in Kerala context. The chapter is organised into four sections. The first section details about the current power sector scenario in Kerala. The second section identifies the major players in rooftop PV sector in Kerala. These players being the major stakeholders of the rooftop PV business, are critically analysed in terms of their roles and responsibilities in disseminating PV technology. A review of the data from secondary sources on the market segments and the market potential is done in the third section. Fourth section concluded the findings of analysis from the first three sections

3.1 Scope for PV in the Kerala Context

The ministry of power in Kerala started a mission for 100% electrification of the state in 2009. According to the economic review report 2012, by state planning board, Kerala has achieved full electrification in all villages [32]. Uninterrupted power is available almost all time of the day throughout the year, except during summers. During summer, when the electricity demand is the highest, the utility resort to 30 minutes of scheduled cyclic load shedding on various power feeders in the morning and evening peak hours to manage the excess demand. Generation, transmission and distribution of power in Kerala is done by a single public sector utility, the Kerala State Electricity Board (KSEB) Ltd. Nearly 100% grid extension and the availability of relatively cheap and subsidised electricity without much interruptions make solar PV a less attractive technology for the domestic consumers in Kerala.

As discussed in section 1.2 of this thesis, 78% of the total consumers of KSEB are from residential sector. They consume more than 51% of total annual energy injected to KSEB's grid. Since most of these domestic consumers are paying for their energy usage at subsidised tariffs, the average cost recovery per kWh of energy is Rs. 3.77 from these users. The average cost incurred to KSEB for supplying 1 kWh of energy at the customer' end is Rs. 5.87 [35]. So for more profitability, KSEB would like the domestic sector to consume less or produce more and more of their own power through technologies like PV.

Table 3.1 shows the growth rate of demand and consumption in KSEB grid from 2002 to 2016. The average growth rate in maximum demand for the past 15 years is 3.73% per year and the energy consumption is growing at 6.23% an year. Whereas the capacity addition is growing at less than 1% per year and percentage of the energy demand met by internal generation is going down at 2.5% per annum. KSEB is managing the situation by entering into long term power purchase agreements outside the state from Central Generating Stations (CGS) and from Independent Power Producers (IPPs) [55]. From these stations, power is transmitted to the state through grid infrastructure managed by Power Grid Corporation of India Ltd (PGCIL), which results in Transmission and Distribution (T&D) losses. KSEB also incurs T&D losses in their local grid system within the state. Other than these technical losses, there are losses to KSEB in the form of theft, inefficiency in billing and payment collection etc. All the technical and commercial losses are aggregated into a single indicative value denoted as Aggregate Technical and Commercial (AT&C) losses.

Table 3.1: Power system statistics of KSEB: Demand and supply mismatch [35].

Year	Installed Capacity (MW)	Maximum Demand (MW)	Own Generation (Million kWh)	Power Purchase (CGS, IPPs, Traders) (Million kWh)	PGCIL T&D Losses (Million kWh)	KSEB T&D Losses (Million kWh)	Total Energy Sales in KSEB Grid (Million kWh)	AT&C Losses (%)
2002	2,605	2,333	7,142	5,699	255	4,106	8,480	33
2003	2,608	2,347	5,475	7,330	238	3,877	8,689	32
2004	2,621	2,426	4,488	8,015	174	3,544	8,784	30
2005	2,623	2,420	6,377	6,390	215	3,335	9,217	27
2006	2,650	2,578	7,600	6,700	288	3,348	10,664	23
2007	2,662	2,742	7,745	8,149	370	3,467	12,058	22
2008	2,676	2,745	8,703	8,074	310	3,325	13,142	21
2009	2,744	2,765	6,494	9,628	312	3,191	12,619	21
2010	2,751	2,998	7,240	10,204	357	3,368	13,718	19
2011	2,868	3,119	7,415	10,512	401	3,194	14,331	17
2012	2,877	3,348	8,350	11,263	413	3,371	15,829	17
2013	2,879	3,268	5,389	14,908	364	3,403	16,529	16
2014	2,891	3,588	8,163	14,070	293	3,071	18,868	16
2015	2,835	3,602	7,286	15,031	393	3,142	18,783	15
2016	2,880	3,860	6,739.25	16,448	550	3,267	19,378	15

The hydro plant capacity addition in the past 5 year plan was only 54 MW, as against the target of 248 MW. During past few years, KSEB has been using imported electricity of nearly 71 to 74% of their total supplies within Kerala. All these statistics points towards the need of new sources of power and alternate ways of capacity addition in the state.

Kerala is one of the first states in India to come up with a comprehensive renewable energy policy. The policy which was adopted by the state in the year 2002 states that “Water flowing in stream, wind blowing over the land and waves smashing on the shores, belong to the whole community and not to the ‘owner’ of the land. The Local Self-Governments shall be equipped to develop these resources on behalf of the community” [56]. The same principle can be applicable for the ‘sunshine’ as well. Agency for Non-conventional Energy and Rural Technology (ANERT) was appointed as the state nodal agency for coordinating all activities related to renewable energy projects. The policy document described the ‘eligible producers’ who can generate and supply power to the KSEB grid. It also prescribes the quality of power to be produced and grid connectivity norms. The policy puts no restriction on the legal structure of the ‘power producer’. Companies, co-operative, partnerships, Local Self Governments, registered societies, NGOs, individuals etc. would all be eligible producers. Tariff offered had a ceiling rate of Rs. 2.8 / kWh (for all other energy sources than small hydro plants) and 5% escalation per year for the first five years. Banking of power with KSEB was allowed on a restricted basis. The producers could bank their excess power generated with KSEB during summer months (March to May) and take it back in any other period (June to February). The policy also mentioned about the wheeling charges, settlement procedures for all exchanges of energy, role of KSEB in providing the evacuation arrangement and producer’s financial responsibilities in developing this infrastructure.

The state announced its first solar specific policy – “Kerala Solar Energy Policy 2013” in November 2013 [57]. The policy covers a wide range of topics including legal and regulatory framework for solar procurement obligation, financing the projects, feed in tariffs and net metering, grid interfacing, procurement of power, open access, settlement of energy charges, wheeling charges and banking facility. In short, from a policy perspective, all guidelines are in place for initiating a distributed rooftop PV project with the Local Self Government taking the lead role. The constrains are in actually implementing these guidelines. The policy seeks to ensure bank finance at attractive rates to the consumers to install off-grid systems. But very few banks in Kerala have actually started issuing ‘solar loans’ and that too based on the credibility and bankability of the consumers. Hence at an individual level many of the domestic consumers may have difficulty to access bank loans.

The policy also envisages implementing grid connected rooftop systems on a ll government owned office buildings within the next two years in a Build Own Operate Transfer (BOOT) model. But very few developers have come forward to take up t his opportunity, fearing the irregular annuity payments from the part of the government institutions. As per the policy, consumers who install PV systems up to 1 MW can avail net metering facility and those who are above 1 MW installed capacity can avail a Feed-in-Tariff (FiT) of Rs. 6.86/kWh for the year 2015-2016. The rates were fixed by the Kerala State Electricity Regulatory Commission (KSERC) and will be revised on an annual basis [58]. For availing Renewable Energy Certificates (REC), the installed capacity of the producer should be above 250 kW and should have a metering arrangement. This indicates that at an individual level, domestic users have to mainly resort to the net metering mechanism. A three stage procedure for application and sanction of a grid connected solar PV plant is explained in the notification issued by KSERC in June 2014 [59]. It demands the user to first submit an application form at KSEB for feasibility report and approval for the commencement of work of the power plant. After the installation of the power plant, the user has to aproach the Electrical Inspectorate (the authority for inspection and approval of safety features in the power plants and distributed systems) with all relevant technical details of the plant to obtain an 'energisation certificate'. After relevant safety inspection and issue of the certificate the consumer has to again approach KSEB for the installaion of net meter and signing of net meter agreement. For an average domestic user, these kinds of procedures are difficult to execute, unless the user gets the help from a 'knowledgable facilitating agency (consultant)' to liason with the offices. Otherwise the user needs to blindly trust the system integrators who can do all these procedure on behalf of the user. All these above mentioned factors points to the need and importance of an institutional model or 'solar co-opertive society' of domestic consumers. This institutional model can help in the wider dissemination of PV among domestic consumers, who are the dominant user category in a semi-urban scenario and in a LSG level like a panchayat. Otherwise the panchayat governing body should set up a facilitating agency to help the consumers in going through these procedures and aggregation of installed capacities to avail REC benefits, credit facilities and FiTs.

3.2 Stakeholders in the Rooftop PV Sector in Kerala

3.2.1 The Kerala State Electricity Board Limited (KSEB).

KSEB is the sole generation, transmission and distribution licensee in Kerala. Hence, for implementing rooftop PV projects anywhere in Kerala; KSEB has to be taken into confidence. All grid connected systems has to be commissioned by a KSEB engineer who is in charge of that distribution section. A Power Purchase Agreements (PPAs) has to be executed with KSEB in all such systems. For projects above 1 M W, if open access and wheeling is planned for (utilising KSEB's power transmission infrastructure by private power generation stations on a lease basis), KSEB has to be approached.

Positive aspect for KSEB w.r.t rooftop PV: The immediate advantage for KSEB is that they can meet their Renewable Purchase Obligation (RPO) targets. As per the state policy, generation from all net metered distributed PV systems will be accounted for meeting the RPO of KSEB [60].

Negative aspects for KSEB w.r.t. rooftop PV: The primary issue for KSEB with PV is that the generation from PV is maximum during the mid-days where they do not have much of a demand to manage. Figure 3.1 shows the demand for power on KSEB's grid system at various times of the day [61]. KSEB already has long term PPAs at low prices with NTPC and other base load providing power producers. The time at which KSEB need more power is during early mornings and late evenings, where PV system generates less power. Another issue for KSEB is that if too many distributed power systems get connected to their grid, then the grid management and generation scheduling becomes a big challenge.

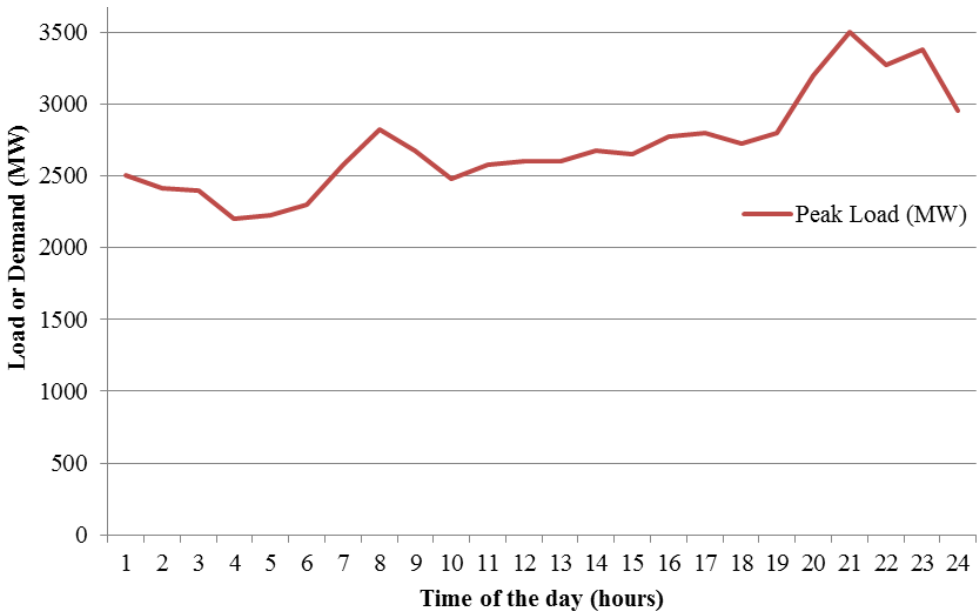


Figure 3.1: Variation of peak load or demand on the KSEB grid system with respect to time of the day [61].

KSEB also have an inhibition towards promoting PV in a big way since more adoption of PV systems in the commercial and industrial consumer sector affects their current cross-subsidy structure. As industries and commercial consumers start using PV power, KSEB will lose their revenue and cannot cross-subsidise the domestic and agriculture sectors, without worsening their already precarious financial situation.

Lack of trained man power and equipments: KSEB has to be the highest competent authority to take the PV sector in Kerala forward. But since PV is a new field, they need to focus on imparting training and developing their human resources throughout the state. For commissioning a grid connected PV system with net metering, final inspection from 'metering and harmonic testing relay teams' has to be done. As of now, there are only two teams all over Kerala to do this testing. This will create unnecessary delays in commissioning the systems, since the teams can't reach all over the state in a short time. Also KSEB should focus on procuring equipments to test the PV systems and make it available in all section offices.

The way forward: KSEB is one of those blessed utilities who have a lot of hydro-based power stations at their disposal. The total installed capacity of hydroelectricity projects in Kerala is 2104.31 MW [35]. Hydro plants can act as peaking stations and the controllability of the power production from such plants are very high. A detailed study by Power System Operation Corporation Limited (POSOCO), India, which is the entity managing the National Load Despatch Centre (NLDC) has come out with the requirement of more ‘flexible’ power systems in India [62]. Till the advent of distributed generation based on renewables, the grid had to manage only time variant demand of the grid using time independent generation stations. Currently both demand and generation are dynamic and control becomes complex. Central Electricity Authority of India (CEA) has given a directive to keep 3% of installed capacity per minute as the ramp handling capacity for coal based thermal plants [2]. For gas fired thermal plants, it should be 4% and for pumped storages (pumped storage is a method in which water is stored in two reservoirs at two different altitudes and water from the higher reservoir to lower reservoir is released through turbines during peak hours for additional generation, and water from lower reservoir is pumped back to the higher reservoir during off-peak hours) it should be 40%. So when an infirm form of power like PV penetrates much into the grid system, KSEB may resort to their hydro stations to control and stabilise the grid. If the generation data from PV is well predictable, and which is going to be possible with advanced weather prediction facilities and live monitoring systems for PV plants, State Load Dispatch Centre (SLDC) may easily put some of their hydro plants under reserve. Since using PV in the day time can save millions of cubic meters of water in the hydro plants (or can be used to pump water back to the reservoir), the existing plants can think of additional generators installed in the same site and use this water in the late evenings to meet the peaking loads. In effect, our dams can act as huge ‘batteries’ which can store energy in the form of potential energy of water.

Kerala’s neighbouring state Tamil Nadu has 40.2% of their total installed capacity based on renewables [63]. This is the highest renewable penetration value among all the states in India, followed by Karnataka with 28.6%. Tamil Nadu has 7179 MW wind power and in total 8062 MW renewable energy based power generators connected to the grid of total 20036 MW capacity. Out of the 2237 MW hydel plants in Tamil Nadu, 912 MW capacity is from reservoirs which are also meant for irrigation purpose and the outflow from them cannot be independently planned based on power system requirements. Hence they built a 400 MW pumped storage project at Kadamparai in Coimbatore district for peak management. They also have 12 coal based power plants of 210 MW each, whose capacity can be varied between 170 to 210 MW. Long term PPAs for another 1000 MW is signed with various IPPs located in the state.

Gujarat with 4058 MW renewable power out of their total capacity of 22537 MW manages the fluctuations in grid through their thermal and hydro generators [63]. They always operate these plants with a margin to accommodate variability from renewables. They have also formed a renewable desk and dedicated engineering team to perform 'weather forecasting', and data analysis to predict the generation from solar and wind, to help the scheduling operations. Rajasthan uses lignite and coal based thermal plants to balance the variability from their huge wind and solar installations. They also have two gas based peaking stations.

Since Kerala is having more of hydropower station within the state, KSEB shall explore the possibility of how to utilise them to handle the deviations in power system, once the share of renewables are increased. Currently Kerala has a base load of 2500 MW. This is mainly met through 1300-1495 MW allocation from central generating stations in the southern region and through 885 MW from five major hydel stations namely Idukki, Sabarigiri, Idamalayar, Sholayar and Pallivasal [34] [64]. Another eight hydel stations are also utilised to meet the variable demands which adds another 662 MW. Kuttiady, Panniar, Lower Periyar, Neriamangalam, Kakkad and Sengulam are the major stations used for this purpose. During peak hours, 166-319 MW is allocated from northern region CGSs. Remaining demand is met through operating some of the sixteen smaller hydel stations with capacities varying from 1.25 MW to 10.5 MW (totalling to 72 MW), KSEB's own two diesel based plants (totalling to 160 MW) and through power purchase.

Table 3.2 shows the statistics about the performance of major hydel power plants of KSEB. Other than the 12 stations listed in the table, most of the plants are performing much below the expected plant load factor (<70% of designed PLF) [35]. Even among the listed power plants in Table 3.2., only four stations (Kuttiyadi, Neriyamangalam, Lower Periyar, and Sengulam) are operated near to their maximum installed capacity. If the generator configurations of various plants are examined, it is clear that, except for Idukki, all the stations are having small and medium capacity generators ranging from 5 to 60 MW. Hence controllability and step wise increase and decrease of generation capacity is conveniently possible. As per Figure 3.1, the additional generation capacity of close to 1000 MW and additional generation of 4.1 million kWh (if you integrate the load curve above the base load of 2500 MW from 6 pm to 10 pm, it is close to 4.1 million kWh) is required to meet the peak loads. Last column in Table 3.2 has the data regarding the water requirement for generating one million kWh from each of the power stations. If the PLF of each of these stations are considered and the overall water requirement per million kWh generation is calculated, it comes to 1.29 million cubic meters. Hence for generating additional 4.5 million units during peak hours, it would require a saving of 5.31 million cubic meters of water. This is only 0.14% of the total effective reservoir capacity of the 12 major reservoirs.

For generating 4.1 million kWh per day, PV capacity close to 1000 MW_p has to be developed within Kerala (1 MW_p grid connected PV system would approximately generate 4100 kWh a day as per simulation [65]). Currently the total installed capacity of all PV projects in Kerala is only 117.74 MW_p [66]. Installed capacity of 1000 MW_p PV would not be yielding 1000 MW throughout the day, since its power production is dependent on the time of the day and associated radiation available. Hence it is not easy to predict that if certain hydel generators could be shut down during day time, with sufficient PV generation available. However studies have proven that the total variability of output power from geographically distributed PV plants is less as compared to the power output from a centralised plant of equal capacity. Murata *et al.* [67] compared the fluctuations in total power generation from a single large solar power plant with spatially distributed smaller power plants, when there were cloud movements. Output from 200 - 250 plants spread across 400 sq. km was compared with the output from a centralized plant. Deviations in the power output of the centralised plant was found to be 40% whereas the deviation in the total power output from the distributed plants was found to be 5 % during cloud movements. Another information to be noted from the available data of KSEB's power system statistics is that, by optimising the operations of existing hydel stations during day time, it can only substitute or complement the falling PV generation capacity during the late evenings, but this is not adding to or augmenting the internal installed capacity of the power system to meet the peak loads. Hence there may be additional generators to be installed to utilise the saved volume of water during day time and to support the peak loads. The costs involved, returns expected and the feasibility of such augmentation works need to be studied by KSEB.

A detailed study on power system dynamics need to be done based on simulations with the data available with SLDC. The storage capacity of the reservoirs, annual water inflow rates and outflow rates, ramping capacity of the hydel plants, variability of power from distributed PV power plants, seasonal variation of demand and supply etc. has to be considered. KSEB is well equipped with their power systems engineering group [68] to take up such a study.

Table 3.2: Performance statistics of KSEB's major hydel power plants: [35].

Hydel Generation Station	Effective Reservoir Capacity (Million Cubic Meters)	Installed Capacity (MW)	Generation Potential at Full Reservoir Level (Million kWh)	Designed PLF (%)	Achieved PLF (%)	Configuration of Generators	Present Max. Load (MW)	Time at which Max. Load Occur (Hours)	(Million Cubic Meter/ Million kWh)
Idukki	1460	780	2398	35	34	6 x 130 MW	506.00	10.00	0.71
Sabarigiri	477	340	1338	51	48	5 x 55 MW + 1 x 60 MW	280.00	5.00	0.62
Idamalayar	1017	75	380	57	50	2 x 35.7 MW	36.00	6.00	4.00
Sholayar	149	54	233	38	49	3 x 18 MW	36.00	6.00	1.50
Pallivasal	63	37	284	86	83	3 x 5 MW + 3 x 7.5 MW	26.60	10.00	0.71/0.79
Kuttiady	234	153	315	40	30	3 x 25 MW + 1 x 50 MW	153.60	18.00	0.71/0.70
Neriamangalam	5	77	295	60	51	3 x 17.5 MW + 1 x 25 MW	76.20	20.00	2.44
Lower Periyar	4	180	493	31	33	3 x 60 MW	176.00	19.00	2.17
Poringalkuthu	30	52	244	61	54	4 x 8 MW + 1 x 16 MW	34.46	7.00	2.83/2.57
Sengulam	1.61	51	182	43	38	4 x 12.8 MW	47.60	20.00	1.27
Kakkad	1.16	50	262	60	54	2 x 25 MW	37.60	11.00	3.25
Kallada	488	15	65	40	33	2 x 7.5 MW	7.60	1.00	9.75

When new hydro based projects are considered, the initial capital expense is a matter of concern. The time delay (and associated escalation in project expenses) and environmental impacts related to the hydro projects are also a m atter of concern. The average pooled purchase cost of electricity for KSEB is Rs. 3.14 during 2014-2015 [69]. The recent tender by SECI for 500 M W rooftop PV installations on various government buildings in different states under RESCO (Renewable Energy Service Company) model has seen tariffs as low as Rs. 3.14 (in Madhya Pradesh, Telangana and Goa) [70]. The lowest bid received for Kerala was Rs. 3.97. This price is the cost of one kWh at consumer premise. KSEB's landing cost per kWh at consumer premise is Rs. 5.87/kWh [35].

The power system statistics from KSEB also has shown that the transmission and distribution losses of KSEB are as high as 16.25%. So generating one unit at the user end using PV is equivalent to generation of 1.2 units at the central generation station.

Encouraging the consumers to generate their own power helps KSEB in reducing their dependency on external sources. If more and more leased rooftop solar systems can be initiated, solar can also become an 'inclusive' technology, where not only the 'credit worthy' people of the society can benefit from this, but also the lower strata of the society can reap the benefits of PV projects. They would find the lease amount as an additional income, from otherwise unused rooftops. So instead of hesitating to accept PV, KSEB should push for more and more PV systems, irrespective of their customer type.

3.2.2 Kerala State Electricity Regulatory Commission

The commission constitutes a chairman and two members. The commission is primarily responsible for the framing and execution of regulatory policies in the power sector in Kerala. It controls the operations of the power sector companies through directives and orders. Determination of tariffs, approval of power purchase costs, wheeling charges etc. comes under the purview of regulatory commission.

The commission has the rights to issue and revoke the licenses of the companies for generation, transmission, distribution and trading of electricity within the state. It also specifies the grid code for the state and acts as a dispute redressal institution for the power sector.

KSERC has issued the first set of regulations for grid connected rooftop PV systems in Kerala on 10th June 2014 [59]. The regulations were timely revised and amended based on the hearings on various complaints from the stakeholders. The commission introduced Generation Based Incentive (GBI) for off grid solar system owners in September 2014 [58]. It also issued orders for waiving off the testing fees proposed by KSEB (Rs. 8000 per site) for site inspection and approval of grid connected rooftop PV systems. The order issued on 1st January 2016 also introduced the provision for increasing the maximum capacity of grid connected PV systems which can be connected to the LT level from 15% of the distribution transformer capacity to 80% of the feeder's average day time load. The order also instructed KSEB to refund 80% of the registration fees (amount remitted at KSEB office at Rs. 1000/kW_p installed) if the customer completes the installation of the project within six months after registration [71]. The commission has the responsibility to see that the orders and regulations are followed by the licensees and the beneficiaries of rooftop PV systems.

3.2.3 Agency for Non-Conventional Energy and Rural Technology (ANERT)

ANERT is the nodal agency for MNRE in Kerala. They implement various schemes in the state initiated by MNRE. All applications for subsidies are directed through ANERT. ANERT also qualifies and empanels system integrator companies and components such as PV modules, inverters, charge controllers etc. which can be used in government departmental projects and for projects seeking subsidies. In general they act as a regulating body for quality of components and integrity of installation companies in Kerala market.

3.2.4 The Government of Kerala (Department of Power, Department of Public Work)

The government policies are in place as early as 2013. But the execution of these policies in the ground level was not effective as expected. The government departments can facilitate the execution of these policy decisions in a time bound and simplified manner.

3.2.5 The Department of Electrical Inspectorate and Electrical Contractors

All grid connected systems below 10 kW can be completed without prior sanction of design from the electrical inspectorate. All systems above 10 kW has to get a sanction from Electrical Inspectorate before the work commences. After the work is completed their officials should visit the site and ensure the safety standards of the system. All liasoning with the inspectorate and KSEB has to be done through an electrical contractor who has 'Class B' or above license from the Public Works Department (PWD), Government of Kerala.

Positive Aspect for Electrical Inspectorate and Contractors w.r.t. Rooftop PV: Licensed electrical contractors have now a new income generation option by getting involved in the inspection and approval of rooftop PV projects. For system sizes from 10 to 25 kW_p, they charge Rs.1000/kW_p. For system sizes between 25 to 50 kW_p, they charge around Rs. 800/kW_p and for systems above 50 kW_p and upto 100 kW_p, the charges are Rs. 600/kW_p [72, 73]. Employees in the Electrical Inspectorate now have a possibility to update their knowledge in the PV field.

Negative Aspect for Electrical Inspectorate and Contractors w.r.t. Rooftop PV: The number of 'Class B' or above contractors who have sufficient knowledge to undertake a PV project is not high. District Electrical Inspectorate offices spread across 14 districts of Kerala have not received proper direction from their higher authorities on the procedure for inspection and how to undertake and complete the inspections in time.

3.2.6 System Integrators and Component Suppliers

There are four government agencies empanelled by MNRE for implementation of rooftop PV projects in Kerala. Other than this, nearly 47 companies are empanelled by ANERT for implementing grid connected rooftop PV projects in Kerala, under its schemes [74].

3.2.7 Domestic Consumers:

Domestic users contribute to the largest number of consumers for KSEB. They are now pampered with low tariff rates and cross subsidies. The typical payback on a PV system for domestic consumer may be around 5 to 10 years, depending on their tariff slab. So the only way for them to feel motivated in investing in a PV system is through provision of low interest solar loans. If they can get 'green-loans' at low interest rates for long duration (say 5%, 10 years etc.), they can pay back the loans through the amount they save from their electricity bill. According to MNRE, benchmark cost per kW_p is Rs. 60,000 for system sizes less than 10 kW_p [75]. Considering that 1 kW_p produces 120 kWh a month, the effective bill saving for a 1 kW_p system owner would be Rs. 405 as per KSEB tariff for the year 2018 [76]. Whereas an EMI payment for Rs. 60,000 at 5% interest and for 10 years tenure would still be Rs.636 [77]. So, only those who are paying above Rs. 5.3/kWh would be able to find it economically attractive to have a PV system bought through EMI (Rs. 5.3 / kWh * 120 kWh/month saving = Rs. 636 saving, which can be used to pay EMI). Table 3.3 shows the average cost per kWh incurred to the domestic consumers of KSEB. This means those consumers who use more than 250 kW h/month would find using solar PV systems economically viable and attractive. If more realistic interest rates of 12%, prevalent in the market for home loans are considered, the EMI value would reach Rs. 861/month (Rs. 7.2/kWh should be the tariff to save this amount from 120 kWh). This means that domestic consumers who use more than 500 kWh/month would find it economically viable to adopt rooftop PV systems.

Table 3.3: KSEB tariff slabs for domestic consumers and average cost incurred per kWh. (Tariff rates in effect from 1-4-2017 to 31-12-2018) [76].

Monthly Energy Consumption (kWh/month)	**Average Cost per kWh (Rs)**
0-50	2.9
50-100	3.06
100-150	3.41
150-200	3.95
200-250	4.56
250-300	5.5
300-350	5.7
350-400	6.1
400-500	6.7
>500	7.5

For those section of domestic consumers who do not have bankability and access to finance, or those who do not want to invest on solar and has good rooftops, some 'rooftop lease' models can be envisaged, where a third party developer can use their roof to develop and sell power to the KSEB. This will also solve their constrain of not having access to 'knowledge centres' about solar technology.

3.2.8 Industrial and Commercial Consumers:

They can easily switch to solar since they can get tax benefits and save considerable amount in their electricity bills. The tariffs are in the range of Rs. 5.5 – 6/kWh for industries and Rs. 6 – 9.3/kWh for commercial consumers. The only constrain is that where to find the initial CAPEX for the project. Even for them, solar loans seem to be a good option. Even if the interest rates are high (~ 12% per annum, no need for green loans), the investment would pay back in less than 5 years. They can also make use of the accelerated depreciation (a company has to pay taxes for the net profit in a financial year at the prevailing income tax rates. The value of the assets such as vehicles, plant and machinery etc. are depreciated at normal rate of 15% per year, and can be shown in the 'expenses' so that 'net profit' is reduced and company makes tax savings. In the case of PV plant, accelerated depreciation rate of as high as 80% was allowed but later replaced with 40% in financial year 2015-16.)

benefit of 40%/year on the investment they make on solar PV projects. This can help them save on their tax returns if they are a profit making entity.

3.2.9 Agriculture and Government Sector:

The agriculture sector also enjoys subsidy and low tariff rates, so a straight forward calculation of PV economics does not seems to be attractive. Whereas from a 'total resource perspective', the agriculture sector is one of the primary sectors who should switch to PV. This can be only through government schemes. The government can afford to do a onetime investment on PV pumps, cold storages etc. which would in the long term save a lot of their subsidy money.

Similarly, those departments under the 'public welfare' and 'public convenience' category, such as drinking water pumping stations, general hospitals, anganwadis (government run child care centres), primary schools, primary health centres etc. should seek for PV solutions under a Build-Own-Operate-Transfer (BOOT) model. Kerala Water Authority is known as the biggest defaulter for not paying the KSEB bills [78]. Since they are into a public service which cannot be interrupted, KSEB cannot refuse them power nor disconnect their supply for making default. In such situations, instead of KSEB supplying power at Rs. 5.87/kWh [35], the government should initiate RESCO model projects at Rs. 3.97/kWh [70] and save KSEB from its burden.

3.2.10 Rooftop PV and Employment Generation:

A study by Natural Resources Defence Council (NRDC) reported that 23,884 full time jobs in India were created till 2014 due to the growth of solar PV industry [79]. IRENA's report on "Renewable Energy and Jobs" indicates that there will be 58,000 direct jobs created in Indian PV sector by 2022 [80]. The total number of direct and indirect jobs created in India through PV sector is reported as 121,000 till 2016 [80]. The nature of jobs are not just installation and commissioning, but also include manufacturing, trading, training and human resource development, different levels of managerial and business development jobs and finance sector jobs. Projects sizing 5 MW_p or below are expected to create more jobs per MW_p [79]. It is estimated that 1 MW_p installed capacity of PV creates 15 full time direct employment for pre-installation to installation time and 4 full time jobs for operation and maintenance activities.

3.3 The PV Market Potential in Kerala

The various consumer categories of KSEB as potential stakeholders have been described in the previous sections. This section carries out a check of facts and figures from their consumer database and power system statistics [35].

3.3.1 Market Segments:

Table 3.4 shows the different tariff categories under Low Tension (LT) consumers of KSEB. The table shows that provided all the investments can claim an Accelerated Depreciation (AD) of 40% in first year and at a CAPEX cost of Rs. 60,000/kW_p for domestic consumers and 55,000 Rs/kW_p for commercial and industrial consumers (as per MNRE, for system sizes from 10 to 100 kW_p), the investments pay back in 3 to 4 years. Other parameters considered are 5% escalation in grid electricity prices, 1.5% of CAPEX as O&M expenses every year (at an escalation of 4% per year due to inflation). 10% duty is levied on the energy usage charges. Hence effective charges (which are 1.1 times the tariff rates) are considered in the calculations. If a financing option and a Debt: Equity ratio of 70:30, with rate of interest 12% for debt is considered, then investments look further attractive with net cash flows becoming positive even from the first year itself. A detailed study of the economic viability of PV systems is discussed in chapter 8.

Table 3.4: LT consumer categories, tariffs and payback on PV systems [76].

KSEB Tariff Code	**Category of Consumer**	**Usage** (kWh/month)	**Tariff** (Rs/ kWh)	**Payback** (years)
LT 1A	Domestic consumers	>500	7.5	5
LT 4A	Industrial (General – manufacturing units, mills, ice factories, workshops, printing press, garment making, food processing etc.)		5.5	5
LT 4B	Industrial (IT and IT enabled)		6	4
LT 6A*	Govt. hospitals, aided education institutions, private hospitals owned by trust, worship centres, libraries	<500	5.5	6
		>500	6.3	5
LT 6B**	Offices of state and central govt., corporations, guest houses, offices of professional such as tax consultants, architects, engineers, advocates,	<500	6.3	4
		>500	7	4
LT 6C**	Offices under income tax, central excise, customs, airport authority of India, motor vehicle dept., offices of all tax/revenue collection departments of state/central govt., banks, ATM counters.	<500	7	3
		>500	8.5	3
LT 6F	Computer training institutes, self-financing educational institutions (including hostels), private coaching centers or tuition centers	<500	7	3
		>500	9	2

LT 6G	Private hospitals and clinics, private clinical laboratories, private X-ray units, private mortuaries, private blood banks, private scanning centers	< 500	5.5	5
		500-1000	6.5	4
		100-2000	7.5	4
		>2000	8.5	3
LT 7A	Shops, other commercial establishments for trading, showrooms, display outlets, business houses, hotels and restaurants (having connected load exceeding 1000 W), private lodges, private hostels, private guest houses, private rest houses, private travelers bungalows, freezing plants, cold storages, milk chilling plants, bakeries (without manufacturing process), petrol/diesel/ LPG /CNG bunks, automobile service stations, computerized wheel alignment centers, marble and granite cutting units, LPG bottling plants, house boats, units carrying out filtering and packing and other associated activities using extracted oil brought from outside, share broking firms, stock broking firms, marketing firms.	<100	6	4
		<200	6.7	3
		<300	7.4	3
		<500	8	3
		>500	9.3	2
LT 7C	Cinema theatres, sports and arts clubs, gymnasiums	<1000	5.9	4
		> 1000	7.3	3
LT 9	Display hoardings		12.5	2

*These are categories of consumers who cannot avail AD benefit since they are either owned by government or fall under 'non-profit' category hence longer payback period.

**Some consumers under this tariff are government offices who cannot get AD benefit, but the ones like banks, professional offices, private hospitals can avail AD.

Table 3.5 consolidates the tariff and payback for HT (High Tension) consumers in Kerala.

Table 3.5: HT Consumer categories, tariffs and payback on PV systems [76].

KSEB Tariff Code	**Consumer Group**	**Usage** (kWh/ month)	**Tariff** (Rs/ kWh)	**Payback** (years)
HT 1A	Industrial (General – all activities listed in LT 4A)		5.5	4
HT 1B	IT and IT enabled industry		5.8	4
HT 2A*	Non-industrial, non-commercial consumers such as public offices run by central/state government, local bodies, technical and educational institutions and hostels run by or affiliated to universities or government departments or government hospitals or government nursing homes, charitable institutions, offices of political parties approved by election commission of India and colonies supplied with energy at HT and HT domestic consumers		5.4	5
HT 2B	Other HT Connections (Activities listed in LT 6C, 6F, 6G)	<30,000	6.2	4
		>30,000	7.2	3
HT 4	Commercial establishment: airports, hotels/restaurants, lodges, hostels, guest houses, cold storage, freezing units , cinema theatres, milk chilling plants, offices/ telephone exchanges of telecom companies, television channels, LPG bottling plants, showrooms, display and service stations of automobiles	<30,000	6.3	4
		>30,000	7.3	3

*These are categories of consumers who cannot avail AD benefit since they are either owned by government or fall under 'non-profit' category hence longer payback period. Still the payback period look attractive.

3.3.2 Market Size:

Here the potential market size is calculated in terms of MW_p installations, considering the fact that KSEB has to meet the Solar Procurement Obligation (SPO) as per the guidelines from the Ministry of Power (MoP), Government of India [81]. Table 3.6 shows the annual expected SPO to be complied by KSEB. Total energy consumption by KSEB's consumers for the year 2015-2016 was 2,47,69 million kWh. Hence a 0.25% SPO implies at least 0.25% of this energy (62 million kWh) shall be produced from solar PV plants within the state. MoP has considered 20% CUF for PV plants in Kerala (which means 1 kW_p would generate 1752 kWh/year or approximately on an average 4.8 kWh/day) and had assigned a target of 35.33 MW to be installed in Kerala.

Table 3.6: SPO obligation trajectory of KSEB [66, 81].

	Year			
	2015-2016	**2016-2017**	**2017-2018**	**2018-2019**
SPO Target (%)	0.25	2.75	4.75	6.75
Target Installation Capacity (MW_p)	35.33	264.88	671.53	954.28
Achieved Installation Capacity (MW_p)	13.05	15.86	117.74	NA
SPO Compliance (%)	36.93	5.98	17.53	NA
Deficit Installation Capacity (MW_p)	22.28	249.02	553.79	NA

Kerala Solar Energy Policy 2013 di rects that the SPO of the utility has to be transferred to the consumers [60]. As a first step, all commercial consumers with connected load more than 20 kVA, industrial consumers with connected load more than 50 kVA and all HT and EHT consumers were expected to meet a SPO of 0.25% by March 2015. A 10% year on year escalation of this SPO was also proposed in the policy. Under this regulatory scenario, at least 950 MW is the expected solar installation business potential in Kerala. Even though all of this capacity may not be realised as rooftop systems, even a 10% share would mean 95 MW_p.

Let us assume the market picks up by itself by convincing the consumers and at least 1% of the consumer categories who find PV viable (pay back less than 5 years) adopt PV. Minimum system size is calculated based on the annual energy consumption of each category and expected annual specific yield from PV system at 16.5% CUF (1450 kWh/kW_p/year). ANERT has a program where the domestic consumers are offered capital subsidy for system sizes starting from 2 kW_p and above. Hence the minimum system size is considered as 2 kW_p for domestic consumers, even though the consumption indicates 1 kW_p requirement. Similarly, the average usage of commercial consumers as per statistics report is very less, but here the assumption is that those consumers above 500 kWh per month would be interested to install rooftop PV and hence minimum value of 5 kW_p is considered for LT 6 and 7 categories. For industries with at least 50 kVA connected load (and having SPO) and considering the average consumption value of 8071 kWh/year from LT 4A and 4B categories (refer Table 3.7), 10 kW_p as the expected minimum system size is assumed. This scenario projects a market size of 317 MW_p.

Table 3.7: Expected market size assuming 1% consumers in each sector adopts solar power [35].

KSEB Tariff Code	Consumer Category	No. of Consumers	Average Sale of Electricity per Consumer (kWh/ year)	Minimum Size of PV System Expected to be Installed per Consumer (kW_p)	Expected PV Capacity to be Installed (MW_p)
LT 1A	Domestic	91,24,747	1090	2	182.49
LT 4A and 4B	Industrial	1,36,693	8,071	10	13.67
LT 6 and 7	Commercial and Offices	19,23,402	1,422	5	96.17
HT and EHT	Industrial and Commercial	5,005	8,20,380	500	25.03
Total					**317.36**

3.4 Conclusions

Secondary data analysis clearly shows good potential for rooftop PV power plants in Kerala. The power sector infrastructure in Kerala is well equipped to adapt to the increase in PV penetration. Department of Power, KSEB, Electrical Inspectorate, ANERT, System Integrators, Public at Large (Domestic, Industrial and Commercial, Agricultural consumers) are the stakeholders in this arena. Theoretically, there is a minimum ‘demand’ to install 317 MW_p PV plants across various customer categories of KSEB. But we need to analyse the ‘supply’ side of this aspect, which is the availability of rooftops. The next chapters therefore concentrate on finding out actual solar PV potential in Kerala utilising primary data about rooftop availability from sample surveys.

Chapter 4

Resource Assessment and Participatory Planning for Dissemination of Rooftop PV Systems: Case Studies from Rural and Urban Contexts in Kerala

After exploring the potential for rooftop PV systems in Kerala through secondary data analysis, assumptions and estimations in the previous chapter, this chapter elaborates the findings from primary data on rooftop potential in a rural and urban contexts of Kerala. A novel methodology of crowd sourcing the site survey at various buildings to school students was tried out in this study. This chapter covers two independent studies which were carried out to estimate the rooftop PV adoption potential in Kerala. The first study was initiated by a semi-government organisation in Kerala called Centre for Development of Imaging Technology (C-DIT). Technical expertise and assistance for this study was provided by NCPRE, IIT Bombay and I was a member of the team which planned and executed the survey. The study envisaged 'Gram Panchayats' (local self-governments) as appropriate 'scale' of administrative unit for decentralised planning and execution of decentralised energy projects like rooftop PV. The second study was done in an urban context, in the city of Trivandrum. Site surveys of select customers and estimation of available roof area was performed. The survey also collected information about the existing electrical appliances at the consumer premises and later used this data to conceive a new solar PV dissemination strategy clubbing with energy efficient equipments and bank loans.

'Gram Panchayats' are a system for local administration for villages mainly seen in South Asian countries. The geographical size, population and energy demand in a typical panchayat are of the scales suitable for planning and implementing distributed power generation systems. The scope for promoting solar PV technology through such local self-governments was investigated in Chendamangalam Gram Panchayat, Kerala. An energy demand and rooftop PV potential assessment was carried out on more than 6500 buildings in this LSG unit. It was concluded that there is scope for installing nearly 11.3 MW rooftop PV systems in this panchayat, whereas the total demand of the panchayat is only 7 MW. The energy generation predictions using simulation software (PVSyst) show that the annual yield from the 11.3 MW, if installed will be 12 million kWh whereas the annual consumption from all the buildings in the LSG unit is only 7.2 million kWh. The next section of the report discusses different stages of planning, system designs for different types of buildings and implementation models suitable for distributed rooftop PV systems in a panchayat.

4.1 'Solar Panchayat': Concept and Approach

'Solar Panchayat' is a concept in which a gram panchayat moves towards energy security by meeting most of its daily electricity requirement by distributed solar PV solutions. There should be an optimum level of offsetting grid power with PV, by integrating 'custom made' solutions to different categories of consumers. These 'custom solutions' can be in terms of engineering designs, institutional models, financial model innovations, or a combination of these. In order to design such solutions, a number of parameters need to be considered such as the needs and demands, load patterns, spread and distribution of loads, reliability of supply required and financial capability of the consumers. Finally, the operation and maintenance of the distributed power generation systems could also be undertaken by the local authorities through the formation of a 'local institution' ('solar co-operative' or 'maintenance committee'), which can then generate a pool of local jobs. In short, a gram panchayat should be empowered to assess its energy demand, identify its potential for PV generation, design and implement small scale rooftop PV systems, identify sources of finance, design financial packages and institutionalize the operation and maintenance of the PV systems within its administrative boundaries.

The above mentioned objectives can be attained through a sequence of panchayat level activities. The activities should start with wide awareness creation among the public about the need and potential of renewable energy and PV in the current power sector scenario. Later an energy survey to identify the energy demand (equipment usage, load patterns etc.) and supply potential of PV (availability of shade free rooftops) should be carried out at the premises of different types of consumers. Based on the analysis of the survey data, custom made 'techno-financial' solutions should be offered to each type of consumers in the panchayat- domestic consumers, public buildings, office spaces, commercial spaces, schools and other categories. The proposed set of activities is summarized in Figure 4.1.

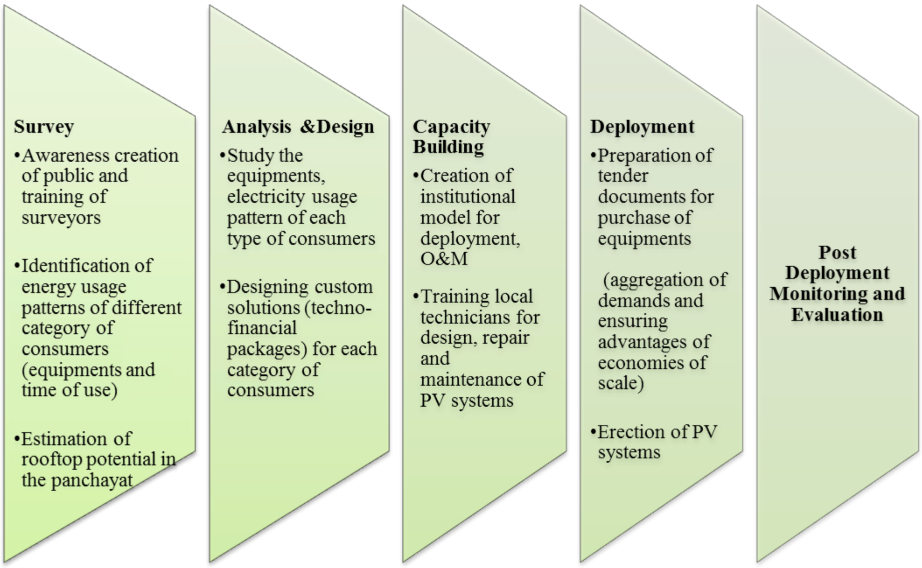


Figure 4.1: Action plan of a solar panchayat project.

4.1.1 Participatory Survey with Educational Institutions in the Panchayat: Awareness Creation and Data Collection Approach

A participatory energy survey by the high school students of 4 schools in the panchayat was conducted to collect information regarding the ownership of appliances, equipment usage patterns (behavioural aspects), and available shade free rooftop area from various buildings. More than 2500 students were trained as enumerators. They were given class room level orientation sessions, where they were taught how to ask questions, collect information, and fill up the survey questionnaires with reliable data. The questionnaire contained mainly 4 sections (see Annexure I).

1) Questions regarding ownership, use, type of construction and other features of the building.
2) Table to be filled with data from previous utility bills (kWh consumed per month, connected load (demand), tariff and average bill amount).
3) Tables to be filled based on the information about the appliances used by the consumer, time of the day when they are operated, duration of operation, equipment which the consumers think are very necessary and critical, and other necessary details regarding equipment ownership and usage.
4) Questions regarding the type of rooftop, proximity of shading objects and approximate shade free rooftop area available for installing PV modules.

The survey was organized as a one day event on 12th January 2013. More than 6500 buildings were surveyed. Trained students were grouped into teams of two, and each team were allotted 10 to 12 houses in the vicinity of their school, where they executed the survey. These students were assisted by 250 volunteers from women self-help groups (SHGs) in the panchayat. They helped the students in identifying the houses and other target entities. They also ensured the safety of the students in the field. The survey of non-residential buildings (mainly commercial and office spaces) was done by students from two engineering colleges, located in the nearby towns. Awareness campaigns were also organized for general public about the survey, in order to ensure the success of the event. Every decision regarding allocation of survey areas for different schools, logistics for student enumerators, involvement of SHGs in the survey, etc. were done in consultation with the elected representatives of the panchayat and parent - teacher associations of the schools, thereby making the survey really a participatory process. In short, the survey helped in achieving the twin goals of data collection and large scale awareness creation about PV technology and energy conservation.

4.1.2 Data Entry and Data Quality Checks

Several errors were found in the data collected. To improve the accuracy of data, cleaning was done. There were number of possibilities how errors had occurred in the collected data such as

1. Erroneous entry of data from survey forms to electronic data bases.
2. Erroneous data noted down by students during the survey.
3. Erroneous data provided by people.

Case 1 was verified first by checking the data available in the soft copy with the hard copy of survey form. It was found that there have been hardly any errors in entry of data. This leaves with only cases 2 & 3, i.e. primary data (data collected in this survey) being wrong.

To improve the accuracy of data, data correction and deletion was done before analysis. Data correction was done in the following ways

1) Manual correction of forms from the secondary data available online. All KSEB bills under an electrical section are available online. This bill has the information that feed into page 1 of questionnaire such as connected load, energy consumed, amount paid and average consumption. Those forms in which any of this value was very high or very low were cross-checked with online bill data by entering the consumer number which was in the questionnaire form.
2) Manual correction of forms in which data have been interchanged by mistake was also done. Wattage of each equipment, number of hours of use and number of equipment getting interchanged (in the table of page 2 of questionnaire) was one of the common errors found in the filled forms. For e.g. the value '40' was written in place of number of equipment and the value '2' was written in the field meant for the wattage of equipment.. As no lighting equipment come with 2 W (LED lamps are not yet popular in the Panchayat), it was corrected to 2 incandescent lights of 40 W each used in the home.
3) Limits for each field were also used at the next stage for data correction. For domestic users, the counts of certain equipment were rounded off to an upper limit in some cases. *e.g.* if the response in a questionnaire states that there are more than 2 television sets in a house or there are more than 10 incandescent lamps/ fans etc., the counts were limited to a maximum number (2 for T.V, 10 for incandescent lamps, fans and other lighting sources). Similarly the lower limit for connected load was set as 50 W. The limits were

based on the assumption that, even if there are more number of equipments in a household than these limits, they might not be operated in normal day to day usage.

4) In order to check that the kWh and amount stated in the bills were realistic, (i. e. primary tariff) the average cost per kWh was calculated from their bill amount and kWh consumed. It was verified whether it falls between Rs. 1/kWh to Rs. 6.75/kWh. Those forms which had values beyond these limits were not considered for analysis. This 'primary tariffs' calculation was done using 1 to 3 previous bills issued before Jan 2013.
5) The shade free rooftop areas listed were checked against the total rooftop area (if they are less than or equal to the total rooftop area).

After all these filtering and validation procedures, 4416 entries were available for detailed analysis on which the data analysis was carried out. In the following discussions all percentages are with reference to these 4416 entries unless otherwise stated.

4.1.3 Statistics of Power Demand, Equipment Ownership and Usage Patterns

The survey could cover only 67% of the 9644 odd buildings in the panchayat. Out of the 6488 buildings covered in the survey, 6131 were domestic consumers and they are the dominating category of the consumers. The distribution of buildings covered in the survey based on the usage categories and their energy consumption data is given in Table 4.1.

Table 4.1: Distribution of buildings covered in the survey and their electricity demand.

Building Category	Number of Buildings	Total Connected Load (kW)	Total Bimonthly Energy Consumption (kWh)
Households	6131	5152	7,43,984
Shops	190	139	21,656
Schools/ pre-schools/ Academic institutions	35	87	10,757
Religious institutions	34	63	14,209
Office spaces	56	100	16,502
Commercial and small industrial buildings	34	48	8,397
Others	8	27	4,864

When the numbers were extrapolated to the entire population of the village, the total connected load was found to be approximately 7 MW and the annual energy consumption was found to be nearly 7.2 million kWh. During the time period of the survey, KSEB charged the domestic consumers in a slab based tariff system, depending up on their 'bimonthly consumption' of energy. The slab system as well as the energy charges in each slab is revised from time to time. The tariff slabs which existed during the time of survey can be understood from the x- axis of the graph in Figure 4.2. Domestic consumers using 0-80 kWh in two months were charged at a rate of 1.5 Rs/kWh and those who used 80-160 kWh per two months were billed at 2.2 Rs/kWh for consumption above 80 kWh and so on. Figure 4.2 show the cumulative connected load and the bimonthly energy consumption from the domestic consumers in different energy consumption slabs.

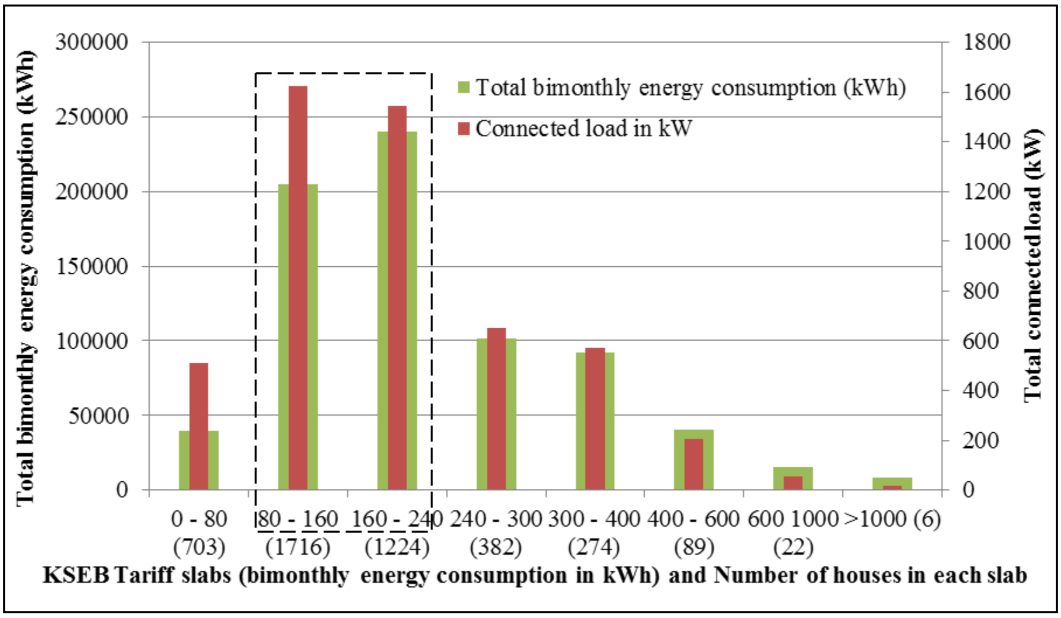


Figure 4.2: Number of houses under different consumption slabs and their cumulative connected loads and energy use.

Figure 4.2 presents the distribution of domestic consumers covered in the survey w.r.t. their connected loads and energy usage. A detailed analysis revealed that majority of the domestic consumers in the panchayat (67%) consumes between 80 to 240 kWh bimonthly, i.e. approximately between 1 to 4 kWh a day. Similarly, it was found that the cumulative connected load from these slabs contributes to 61% of the panchayat's total connected load (refer Figure. 4.2). The total energy consumption from these consumers was found to be 60% of the whole panchayat's consumption.

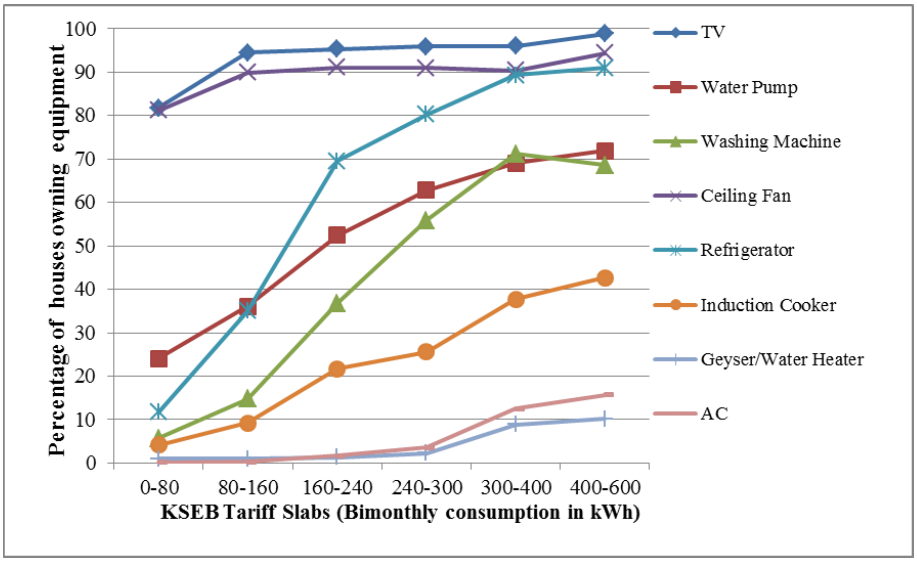
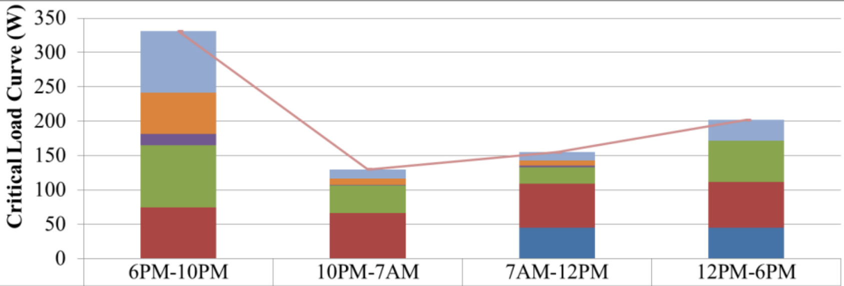


Figure 4.3: Percentage of households owning different equipments (tariff slab wise).

Figure 4.3 shows that appliances like televisions, water pumps, washing machines, ceiling fans, refrigerators, etc. has penetrated well in this area. This has in a way increased the day time demand for power in the households. Inverter based power back up systems were found in 8% of the households. The number of fluorescent tube lights in each home across different slabs varied from 1 to 3 and the number of CFL lights varied from 2 to 4 per home. Number of ceiling fans varied from 2 to 5 per home. New and high power rated equipments like induction cookers, air conditioners, water heaters, etc. are also being used by some of the consumers, especially the ones in the higher tariff slabs.

Based on their equipment ownership and usage pattern, typical load curves were developed for each slab of domestic users. The load curve for domestic users in 240-400 slabs is as in Figure 4.4. A detailed analysis of the equipment ownership patterns and load patterns of other category of consumers is present in the report released by NCPRE, IIT Bombay [82].

(http://ncpre.iitb.ac.in/research/reports.html)



	6PM-10PM	10PM-7AM	7AM-12PM	12PM-6PM
TV	90	13.3	12	30
Flour.tube	60	8.9	8	0
Inc.Lamp	0	0	0	0
CFL	16.5	1.2	2.2	0
Fan	90	40	24	60
Refrigerator	75	66.7	64	66.7
Washing Machine	0	0	45	45
Total	331	130	155	201.7

Contribution to the load from each equipment at different times of the day (W)

Figure 4.4: Typical load curve of consumers in the energy consumption category 240 - 400 kWh bimonthly.

4.1.4 Shade Free Rooftop Available with Different Types of Buildings in the Panchayat: Can PV Meet the Demand?

PVsyst simulations shows that a 1kW PV installation in Chendamangalam using 10% efficient panels can generate on an average 3.75 kWh per day and the area required is 11.8 sq. m. If 15% efficient panels are used then area required is 7.8 sq. m. per kW. Efficiencies of commercial crystalline silicon modules, which is a leading technology for rooftop installations, vary from 13 – 20%. Assuming an inter-panel spacing of 25% of the active area, the typical area required for installation of solar panels with efficiency of 15% will be maximum 15 sq. m. per kW. Hence in this case study, 15% PV module efficiency and 15 sq. m. per kW_p is considered for calculation of the rooftop potential of various buildings in the panchayat. Heavily shaded, structurally weak, and difficult to access rooftops and buildings were neglected in calculating the rooftop potential (considered as 'without potential').

Domestic Consumers

From the rooftop potential perspective, it was found that almost 80% of the households have an open concrete and flat rooftop, suitable for PV installation. They contribute 1,68,610 sq. m shade free area, which is 8 times more than the total shade free area in tiled roof houses (20,966 sq. m). It is important to note that the houses which contribute to the maximum power consumption in the panchayat (80 - 240 kWh bimonthly slab) has a good amount of shade free rooftop (1,07,696 sq. m). Based on their bimonthly energy consumption and available shade free rooftop, the domestic users were categorized into three – 1) Houses which can produce enough or more than enough energy for their daily needs through rooftop PV (shown as cells in green colour, Table 4.2), 2) Houses which have rooftop potential to partially support their daily electricity needs through PV (cells in yellow, Table 4.2), and 3) Houses which do not have enough shade free rooftop area to install at least 1 kW of PV modules. It was found that nearly 60% houses fall under category 1.

Table 4.2: Distribution of residential buildings covered in the survey and their rooftop PV potential.

KSEB Tariff Slab (kWh /month)	Number of Households	Shade-free Rooftop area (sq. m.)	Number of Households with rooftop potential to install PV modules					
			1-2 kW_p (>15 sq. m.)	2-3 kW_p (>30 sq. m.)	3-4 kW_p (>45 sq. m.)	4-5 kW_p (>60 sq. m.)	> 5 kW_p (>75 sq. m.)	Without Potential (Highly shaded)
0-80	703	19,630	97	125	57	48	36	340
81-160	1716	55,475	195	285	203	145	186	897
161-240	1224	50,016	112	167	131	117	264	433
241-300	382	19,803	30	23	20	12	32	157
301-400	274	15,148	23	35	23	17	97	79
401-600	89	5,575	7	9	9	11	32	21
601-1000	22	965	0	2	3	2	5	10

Shops

69% of the shops consume less than 100 kWh bimonthly. Another 20% use between 100 - 200 kWh bimonthly. Most of these shops are located in and around 7 major commercial centers in the panchayat. Hence the rooftop potential for PV based energy generation for the shops was estimated based on their collective rooftop area at each commercial center. The collective shade free rooftop area of the cluster of shops was found to be ideal for implementing grid connected PV systems ranging from 5 to 30 kW. In 5 out of 7 locations, calculations show that, such systems can generate more electricity than that is required for the cluster of shops.

Educational Institutions

There are 18 Anganwadis (government undertaking child care centers/ pre-schools) and 4 small schools found in the survey, whose connected load falls below 300 W and consumes less than 1 kWh a day. Off grid PV packages with 250 W (or more) modules, CFL lamps and ceiling fans can be suitable for Anganwadis and small schools. Another 10 schools with comparatively large buildings and campus were found in the panchayat. Their connected loads ranged between 1 to 5 kW. Their energy consumption ranges from 4 to 8 kWh per day. Out of these 10 schools, 7 of them have a rooftop potential of installing more than 5 kW PV systems. It shall be also noted that these schools work from 10 a.m. to 4 p.m. during week days. PV power availability shall me more during the working hours.

Government Offices

There are 5 government institutions working in this panchayat for the administration and service of the public. All these offices have working hours between 10 am to 5 pm, 6 days a week with Sunday holiday. Some of the government offices like the panchayat administration office, the village office (for collection of land taxes), sub registrar office, etc. were found to have the rooftop potential for supporting their day time electricity needs through PV systems sizing as high as 20 kW_p.

Convention Centers and Community Halls

There are 6 auditoriums or convention centers in the panchayat. All of them have immense rooftop potential for installing PV systems (ranging from 12 to 40 kW). Some of them have very high consumption of electricity (34 kWh a day) whereas some others use only 5 kWh a day. Utilizing entire rooftop potential of such auditoriums for PV power plants becomes viable only when the utility is ready to buy the excess power produced.

4.1.5 Optimal Utilization of the Rooftop Potential and the Way Forward

In order to realize maximum utilization of the available rooftops, it needs a well-planned implementation strategy for rooftop PV systems. This includes technical design of systems for each category of consumers and building types, identification of funding agencies and financial models, constitution of a village level co-operative society for planning, implementation and post implementation operation and maintenance of PV systems and co-ordination of activities between different stakeholders.

There are also a few limitations in terms of the data available through this survey, e.g. the total shade free rooftop available in the panchayat is estimated irrespective of the alternate use of rooftops by households like for drying clothes and food items, rainwater harvesting and other similar activities. Some other social aspects, like the willingness of the rooftop owners to participate in a community level or collective rooftop implementation model was also not considered.

Module efficiency of 15% was considered in the calculations mentioned above. Modules with 20% efficiency (without concentration etc.) are already available in the market. If this possibility is considered, the total installation potential in the panchayat can be revised upwards by 33%. In summary the actual rooftop PV potential of the panchayat can deviate from the estimate of 11.3 MW_p depending on the PV technology choice and other choices of the potential PV system owners. Based on the survey results and existing energy tariffs, different implementation models and concepts possible in the panchayat are discussed in the further sub sections.

Sites with Feasibility for Immediate PV Installation

As discussed in the previous section, the educational institutions and a few of the government offices can be immediately recommended for the installation of rooftop PV power plants ranging from 1 – 5 kW_p or more, depending on their capacity and need. It has been identified during the survey that some of the Anganwadis were not electrified and their requirement can be easily met by small off-grid PV systems.

The systems on public buildings can be designed in a grid-tied mode with net metering. Grid can act as a backup option when the generation from the PV plant is insufficient to meet the load. The power availability factor is improved or kept unaffected compared to ‘grid only’ supply. In this scenario battery backup is not desired, reducing the system cost and maintenance significantly. The advantages of beginning the rooftop PV campaign through installations in government owned buildings can be;

- Such systems can act as demonstration sites of grid connected roof top solar power plants which facilitate reduction in dependency on grid power.
- Performance of the pilot plants can be compared with the expected results from PVSyst simulation and also monitored continuously to generate data on reliability of PV systems at the location and climate. Such a study is essential before rolling out large scale implementations.
- Since these systems are becoming an asset to the government institutions, fund raising may be easier.

- Demonstration of such systems in educational institutions can be used for teaching (local technician training) purpose and also create an awareness and familiarity towards PV technology among the upcoming generation

Conversion of Existing Inverter - Battery Systems in the Panchayat to Solar-Inverters

Almost 8% of the domestic users in the panchayat own inverters and battery backup system to have uninterrupted power during load shedding hours. These systems do not have any control of the time at which their batteries are recharged and most of them recharge the batteries from grid during peak load hours (6 p.m. to 10 p.m.). The usage of such inverters in effect nullifies the purpose of load shedding. So it is also a necessity for the utility to convert them into solar inverters, i.e. they charge batteries from PV panels during day time. A simple modification in the circuit and charging logic of the existing inverters or additional hardware to change the control logic of charging and discharging can solve this issue.

Need Based Design

The number and types of loads required for a class of consumer shall be decided as per the primary survey information. The sizing of PV modules shall be based on their average daily consumption from grid, i.e. based on the tariff slab they belong to. Here, the major assumption is *that 50% of the daily energy consumption is offset by PV packages*. i.e. a consumer who uses to 30 kWh per month must offset at least 0.5 kWh daily using PV.

The sizing of the inverter shall be based on the ownership percentage of a particular equipment in a slab. If more than 50% of consumers in a slab own a particular appliance, then its power rating can be included in designing the power rating of the inverter.

E.g., more than 70% of consumers in the slab 160 – 240 kWh bimonthly energy consumption own refrigerators. Hence it was decided to include the power rating of refrigerator (typically 250 – 300 VA) into the peak power rating of the inverter recommended for this category of consumers. If the consumers are able to schedule the use of their equipments, i.e. either a refrigerator or a washing machine at a time, the 1200 VA inverter (as suggested in the Table 4.3) may still support the requirements. Based on this assumption of scheduling, three equipments with high power rating (refrigerator, washing machine, mixer, water pump) have been included in the package of higher slabs.

Battery bank designed is slightly undersized in some packages based on the assumption that some part of the PV energy produced (in the 50% grid offset energy) is directly utilised during day time (using smart charge controllers). Hence decreasing the need for storage and avoids some efficiency losses.

The prices are indicative and based on the primary data collected from open market.

Note: The packages can be designed by using different standard module sizes and batteries. This set of packages is one set of example for each category of consumers. Similarly the percentage of daily energy needs supported through PV can be varied (not necessarily 50%), based on the user needs. It can be optimised based on the actual expected daily energy need, actual monthly energy consumption, number of kWh to be saved to jump to the next lower consumption slab (thereby having additional benefit of lower tariff, on top of bill saving on offset kWh), user's investment capacity and economic feasibility.

Table 4.3: Need and 'equipment ownership' based solar packages designed for different categories of domestic consumers.

Bi-monthly Consumption Slab	List of Equipment to be Run on Solar Inverter			Solar Pack			Other Specification	Approx. Cost (INR)	Approx. kWhs Offset from Grid per Day
0-80	Equipment	Quantity	Typical Power	Equipment	Quantity	Specification			0.375 - 0.5
	Fan	1	40-60W	PV module	100 W	Mono/Multi crystalline	10 years product warranty and 25 years performance warranty	6000	
	TV	1	80-120W	Inverter/ Power Conditioning Unit	300 VA	Minimum Efficiency of 90%, Pure Sine wave	Automatic load management system	5000	
	Fluorescent light (4 ft)	1	40 W	Battery Bank	100Ah, 12V (1200 Wh)	Tubular Valve Regulated Lead Acid		12000	
	CFL	2	12W	Other BOS and installation Charges				3000	
Total								**26,000**	

80-160	Equipment	Quantity	Typical Power	Equipment	Quantity	Specification			0.75 - 1
	Fan	2	40-60W	PV module	200 W	Mono/Multi crystalline	10 years product warranty and 25 years performance warranty	12000	
	TV	1	80-120W	Inverter/ Power Conditioning Unit	500 VA	Minimum Efficiency of 90%	Automatic load management system	5000	
	Fluorescent light (4 ft)	2	40 W	Battery Bank	100Ah, 12V (1200 Wh)	Tubular Valve Regulated Lead Acid		12000	
	CFL	3	12W	Other BOS and installation Charges				8000	
Total								**37,000**	
160-240	Equipment	Quantity	Typical Power	Equipment	Quantity	Specification			
	Fan	3	40-60W	PV module	500 W	Mono/Multi crystalline	10 years product warranty and 25 years performance warranty	30000	

	TV	1	80-120W	Inverter/ Power Conditioning Unit	1200 VA	Minimum Efficiency of 90%	Automatic load management system	10000	1.8-2
	Fluorescent light (4 ft)	2	40 W	Battery Bank	150Ah,12V (2 Nos) (3600 Wh)	Tubular Valve Regulated Lead Acid		32000	
	CFL	3	12W	Other BOS and installation Charges				22000	
	Refrigerator/Washing* Machine/Water Pump	1	200 - 300W						
Total								**94,000**	
240 – 400 and above	Equipment	Quantity	Typical Power	Equipment	Quantity	Specification			
	Fan	3	40-60W	PV module	1000 W	Mono/Multi crystalline	10 years product warranty and 25 years performance warranty	60000	3.75- 4
	TV	1	80-120W	Inverter/ Power	1500 VA	Minimum Efficiency of	Automatic load management	15000	

				Conditioning Unit		90%	system		
	Fluorescent light (4 ft)	3	40 W	Battery Bank	150Ah,12V (4 Nos) (7200 Wh)	Tubular Valve Regulated Lead Acid		64000	
	CFL	3	12W	Other BOS and installation Charges				40000	
	Refrigerator*	1	200 - 300W						
	Washing Machine*	1	500-700W						
	Mixer*	1	200-300W						
	Water Pump (0.5 HP)*	1	373 W						
Total								**1,79,000**	

*Heavy loads with initial surge currents may have to be scheduled (used one at a time/two at a time) based on inverter capacity

Long Term Implementation Models for Domestic Users: Community Level Implementation Strategies

Data shows that even though the total availability of rooftop among domestic users seems to be promising, there are quite a number of houses without shade free rooftops. Similarly there are houses with rooftop potential to produce more energy than they need. Through collective rooftop programs or community level implementation strategies, this excess-deficit issue of rooftop area can be balanced out. A clear advantage of such strategies would be a larger pool of stakeholders who would distribute the installation and maintenance costs, and possibilities to institutionalize operation and maintenance at a grassroot levels. A collective program would allow the scaling up of inverters and other “balance of system” (BOS). Scaling up a lso makes it possible to connect to the grid at a higher voltage level (which is more acceptable to the utility). A common storage and larger PV plant can be more cost effective and better maintainable by virtue of their size and through institutionalization of operations. Another attractiveness of the community PV model is the inclusiveness. Lower end users can also become a part of such collective programs.

- ***Disadvantages:*** Identification of user groups with optimized collective rooftop potential – electricity demand and spatial distribution is a challenging task. Some sort of social engineering will be required to overcome the inhibitions of certain users to bring them into a community model. Proper guidelines should be devised to share the incentives. For example, what additional benefit will be given for those who lease out additional rooftop area to community solar systems? What should be the charges on those who do not contribute their rooftops?
- ***Identification of cluster of houses based on distribution transformers:*** There are 58 step-down distribution transformers in the panchayat which gives electricity connections to the low tension (LT) domestic users from the power feeder lines. One method of pooling domestic consumers can be based on t he transformer from which they have availed connection.

4.2 Integrating Rooftop PV with Demand Side Management (DSM) and Super-Efficient Equipment Programs (SEEP): Findings from the "Sun Shift" Project of the Kerala State Electricity Board (KSEB)

Rooftop PV potential assessment in a rural context of Kerala, the methodology used and the results were discussed the previous section. In this part of the thesis, a similar assessment exercise carried out in an urban context of Kerala is elaborated. This activity was conducted in association with KSEB, as a part of their initiative to disseminate 'smart inverters' which can help them in managing demand from domestic consumers during peak hours.

It was estimated through Chendamangalam survey that around 8% of the domestic users have battery based power backup and inverters at their homes for uninterrupted power. According to the census data, there are 1,00,28,709 occupied houses in Kerala [37]. This means, around 8 lakh inverters are installed in the residential buildings all over Kerala. If these numbers are extrapolated to the shops and other establishments which comes to around 20,60095 numbers [35], there are around 10 to 12 lakh inverter and battery based power back up systems present in the distribution system of KSEB. Majority of them are installed by the domestic consumers. During the period of load shedding, the above mentioned inverters supply the essential loads of the consumers and once the feeders are energised after load shedding, these large numbers of systems start charging their batteries from grid and create a spike on the already existing peak of the load curve, thereby defeating the purpose of load shedding. If charging of the batteries can be postponed to a time period after the peak hours (6 p.m. to 10 p.m.), or if the charging of batteries can be done from an alternative source like a solar PV system, KSEB can make savings in the purchase of power during peak load. So if a 'smart inverter' can be designed or any such power electronic device which can prevent the charging of batteries from grid during peak hours could be introduced, then it can be promoted among the domestic consumers with active participation from KSEB. To further maximise the benefits to KSEB from such a device, the system can be so designed that the batteries are charged during the day time from PV modules and during peak hours, (assuming that there is an excess charge in the batteries, more than enough to support the loads during scheduled load shedding), the loads in a house can be intentionally islanded from the grid and can be run on t he stored energy in the batteries. If large numbers of such devices are disseminated among the domestic users, then the 'effective load' on the grid can be reduced during peak time.

With these ideas in the background, KSEB initiated the 'Sun Shift' program in October 2013. A special technical committee was constituted with an objective to design and disseminate smart inverters which can help in 'shifting' the peak load time using stored energy from the 'sun'. The committee was chaired by eminent scientist Dr. R.V.G Menon (Ex-Director, Agency for Non-conventional Energy and Rural Technology, Government of Kerala) and through a series of sittings, the technical and functional specifications of the 'smart solar inverter' was finalised. I was introduced in the committee as an expert member and representative from NCPRE, IIT Bombay and had attended the fifth and sixth sittings of the committee on 20-1-2014 and 11-3-2014 respectively. During these meetings, I was assigned by the committee to undertake a rooftop potential assessment and market potential study for 'smart inverters' through sample surveys within the city of Thiruvananthapuram. A package including a 650 VA 'smart inverter', 150 Ah, 12 V battery and a 250 W_p PV module was suggested and its estimated cost was around Rs. 30,000 to 40,000. The package was also called as 'Peak Load Shifter' and the scheme was named as 'Sun Shift' program. It was decided that KSEB should also interact with financial institutions and provide the consumers a flexible payment option for these inverters. A down payment option of Rs. 15,000/- with the remaining amount paid as EMIs (Equated Monthly Instalments), along with the electricity bills can be attractive.

The above mentioned product was also proposed to be pilot tested in Cantonment distribution section of KSEB, Thiruvananthapuram. The result of implementation of this product on peak load and the stability of power system can be studied at this small scale and could provide valuable insights into the potential for wider deployment. During the second sitting of the technical committee, it was decided that a survey of domestic consumers in the Cantonment section was necessary to understand the day time usage and load profiling. Later in the fifth meeting, it w as also decided that the Energy Saving and Co-ordination Team (ESCOT), KSEB will facilitate this survey along with the Innovation group of KSEB. I was given the responsibility of finding a partner educational institution and training their students as enumerators and execution of the survey in Cantonment distribution section of KSEB, Thiruvananthapuram. The students from *John Cox Memorial CSI Institute of Technology*, Thiruvananthapuram were trained as enumerators and a sample survey was implemented in Cantonment section during the first three weeks of March 2014. The details about the planning, execution and data analysis of the survey is given in sections 4.2.1 to 4.2.8. A detailed report on the survey and its findings is published in NCPRE website [83].

(http://ncpre.iitb.ac.in/research/reports.html)

4.2.1 Planning and Execution of Energy Survey at Cantonment Section

The Energy survey at Cantonment was planned and executed in similar lines as that of the Chendamangalam Energy Survey [82]. A detailed questionnaire was designed which had questions regarding the equipments owned by domestic consumers, their usage pattern and availability of shade free area for rooftop PV installation. Explicit questions regarding the following information were included in the questionnaire. The complete questionnaire is available in Annexure II.

1) The star rating of the appliances in use, if applicable.
2) The age of the equipments in use and willingness of the user to replace the same.
3) The availability of segregated domestic wiring for high power appliances (which will help in easy integration of smart solar inverters into the system).
4) Time-of-the-day during which different equipments are operated.
5) Details of inverter systems in use by consumers, if any and willingness to buy a smart solar inverter provided through the sun shift project.
6) Ownership of solar water heater.
7) Possibility of replacing resistive speed regulators for ceiling fans with electronic regulators.

A review of literature, mainly the report on promoting super-efficient equipments in India through SEEP (Super-Efficient Equipments Program) by Prayas Energy Group, Pune [84] prompted in including questions regarding standby mode losses in TV, DVD players, set top boxes and computers. The questionnaire also adopted a few questions from the standard questionnaire used by the U. S. Department of Energy Information Administration [85].

Sampling Criteria

The appliance ownership and the usage pattern were found to be closely related to the socio economic status of the consumer as per the study by Prayas Energy Group, Pune [84]. Even the size of the houses and the associated roof area can also be linked with the economic status of a consumer. The number of units (kWh) of electricity consumed per month can be a good proxy for the economic status of a consumer. Hence a sampling criteria based on the monthly energy consumption of the domestic consumers was followed. The other parameters considered while sampling were the location and the distribution transformers from which the connection was made. A sample size of 10% was fixed arbitrarily. The sampling method adopted in this study was 'Stratified Random Sampling' [86]. First the entire population was divided into disjoint subgroups (based on geographical location and monthly electricity consumption) and later the 10% samples were randomly picked from subgroups through a lottery system. This ensured fair representation of samples from all 'strata' or subgroups and avoids sampling errors and outliers. Based on these criteria, 775 sample households were surveyed out of the 7042 domestic consumers in Cantonment section.

A meter reader typically covers the billing of 80 to 120 houses in a day based on the density of houses in an area. The area which is covered by a meter reader in a day is called as a sub area and denoted by "Area code/Day code" (e.g. A1/5 denotes the area (or the group of houses) covered by a meter reader in his billing cycle on the fifth day in the geographically demarcated area A1).

Table 4.4 shows how the numbers of sample houses to be surveyed were decided based on the number of consumers in each tariff slab in that region. The details about the customers and their tariff slabs were obtained from KSEB's Cantonment section office, through their internal web application called ORUMA (Open Resource Utility Management Application) [87]. Figure 4.5 shows the part of the city which was considered for the sample survey.

Table 4.4: Distribution of samples from different tariff slabs into different billing sub- areas.

Tariff Slabs (kWh consumed per month) (Area A2/1)	Number of Consumers	Target Samples to be Surveyed
0 - 40	21	3
41 - 80	6	1
81 - 120	9	1
121 - 150	6	1
151 - 200	18	3
201 - 300	15	2
301 - 350	2	1
351 - 400	3	1
401 - 500	0	0
> 500	3	1
Total	83	14

Figure 4.5: Image of Cantonment section (5 sq. km) from Google Earth and the demarcation of billing areas (approximate scale 1cm: 200 m).

Training of Students

The students from 4^{th}, 6^{th}, and 8^{th} semester classes in various departments of *John Cox Memorial CSI Institute of Technology*, Thiruvananthapuram took part in the survey. A general orientation session was conducted for all the classes, and they were informed about the nature of the survey and the duties the enumerators have to undertake during the survey.

Nearly 200 students voluntarily agreed to become enumerators. Those students who were interested to join the survey were grouped into teams of two and were allotted a survey area. They were given a detailed class on how to ask questions, make observations and to fill the questionnaire. The teams were given hand-outs containing the Google map image of their allocated survey area and the walking path which they have to follow in the field was marked on it. They were also given a complete list of consumers present in that area, along with their consumer numbers, billing codes, distribution transformer and the distribution post number from which they took connection. The required number of houses to be surveyed based on tariff slabs was also given to them (as given in Table 4.4). A detailed class regarding how to use the map and the hand-outs in locating a consumer was given to them.

4.2.2 Analysis of the Load Data from the Survey

The connected load and the energy consumption from the samples covered was studied and compared with the actual data available from KSEB. This helped in understanding whether the sample which was covered in the field was a true representation of the whole population. This exercise would help us to assess the accuracy of projecting the findings of the survey to the entire population. The deviation of the actual value from the predicted value was within ± 8% in most of the tariff slabs. Through this study, it is concluded that the total connected load of the Cantonment distribution section is around 15 MW. The study also shows that the total energy consumption from the domestic connections of Cantonment section comes around 1 GWh a month.

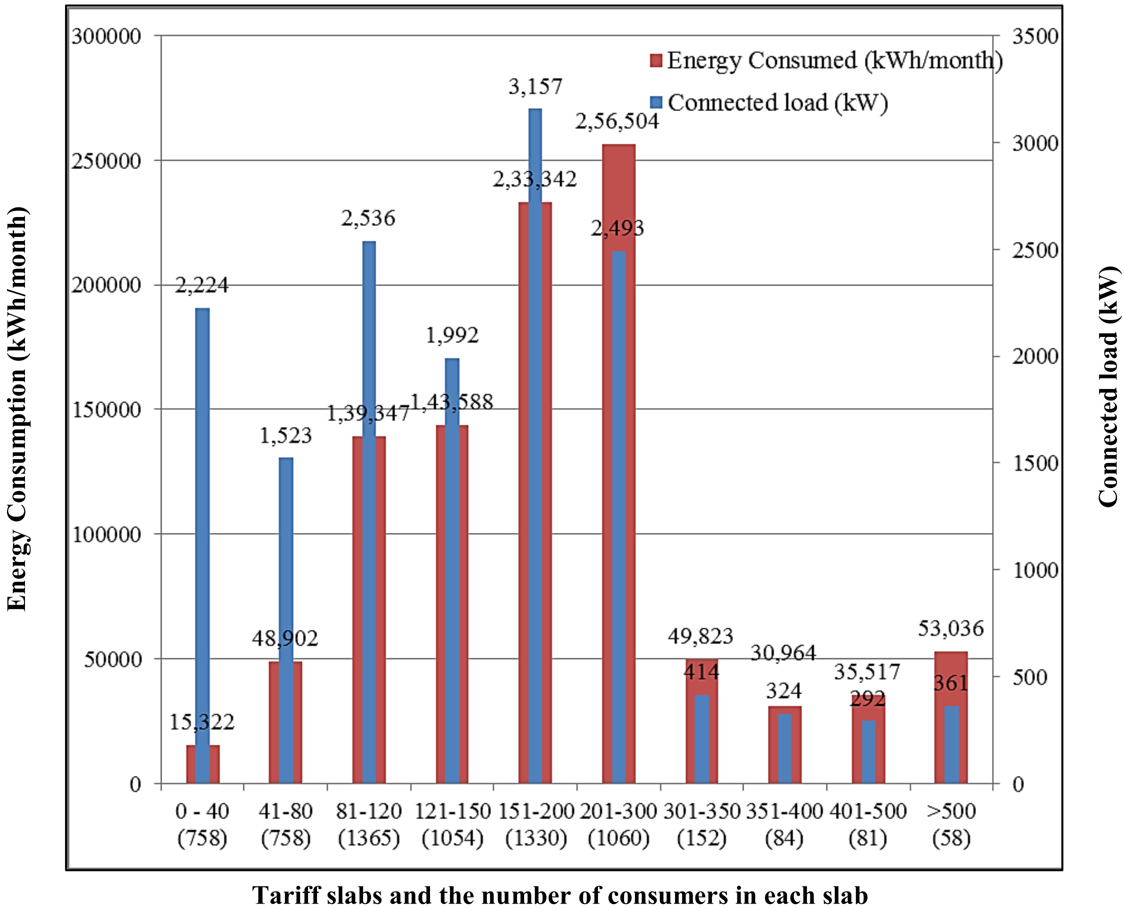


Figure 4.6: Connected load and energy consumption per month of domestic users in Cantonment section.

Figure 4.6 portrays the distribution of samples (number of residential customers in Cantonment section) as per their monthly energy consumption and connected load. The power and energy requirement of Cantonment section is mainly governed by the usage pattern of 70% of the consumers who belongs to the mid-slabs (who consumes 81 – 300 kWh/month). They contribute 66.5% of power demand and consume 76.7% of energy. Hence, if someone wants to implement any energy conservation or demand management program, they should be targeted to this class of consumers. The higher slabs users constitute only 6% of the total users but they contribute to 9% of load and 16.9% of energy use.

Scope for Energy Saving and Demand Management through Introduction of Energy-Efficient Equipments

Television: 61% of the consumers in the Cantonment section uses Cathode Ray Tube (CRT) televisions. This consumes at least 50% more energy when compared to Liquid Crystal Display (LCD) or Light Emitting Diode (LED) based televisions [84], [88, 89]. Average age of CRT television was found to be 7 years and if at least 10% of these old CRT television owners replace their televisions with an LED display, then there can be a reduction of 25 kW in the connected load and roughly 50 MWh of energy saving per year (assuming a usage of 5 hours per day per equipment). In more than 44% houses in the Cantonment section, people are using set top box or Direct to Home (DTH) receivers along with the TVs for better quality of reception. This equipment will also contribute to around 8 to 25 W consumption while they are switched on [90]. Again, a minor amount of load and energy consumption also happens when the TV sets are put in standby mode (5 to 20 W) [84] [90, 91]. As per the survey, just properly switching off the DTH receiver could save 56 MWh, which is almost equal to the actual consumption for four months by the people of the lowermost tariff slab.

Refrigerators: More than 75% households in Cantonment area use refrigerators of capacity 150 – 250 litres. It was seen that 24% of the refrigerators were more than 10 years old. A refrigerator which is more than 10 years old will end up using 50% more energy than a new energy efficient model [92]. If all of these old refrigerators can be replaced by new energy efficient models (at least 3 star units), it can result in as high as 250 MWh energy saving in a year.

Air conditioners: Nearly 15% of the domestic consumers in Cantonment have split Air Conditioners (ACs) installed in their houses. The ACs are used on an average 130 days in a year. Average hours of use per day were 5. The most popular models are between 1 and 1.5 ton capacity (88% of the total equipments). If 10% AC owners adopt to replace their existing ones with five star rated models, then it can result in a reduction of peak load by 34 kW and an annual energy saving of 22 MWh. But only 2% of the split AC users were positive towards exchanging their equipments with higher star rated ones.

Water Heaters: 20% of the consumers in Cantonment use electric water heaters. As reported in Prayas Energy Group's study [84], people should shift to more efficient water heating methods like solar and gas based systems. If around 35% of the water heaters could be replaced, the reduction in energy and peak load in Cantonment is 108 MWh and 280 kW respectively.

Ceiling Fans: The power rating of ordinary fans varied from 50 W (most efficient ones) to 100 W. Assuming that the fans are operated for at least 300 days in a year and 10 hours a day, and if at least 20% of the existing fans are replaced with energy efficient models, then there can be a load reduction of 1541 kW and an annual energy saving of 250 MWh.

Fluorescent Tube Lamps: Fluorescent lamps are owned by 65% of the houses in Cantonment. The number of fluorescent lamps present in a house varied from 1 to 15. The most popular models were the 40 W, T12 (number 12 denotes the diameter of the lamp is 12 times 1/8th of an inch, which means 1.5 inch or 37.5 mm) and 36W, T8 lamps (1200 mm length). 1200 mm T5 model fluorescent lamps give an opportunity of huge energy and power saving through the replacement of existing 1200 mm T12 and T8 lamps. A T5 lamp would consume only 28 W instead of 40 W of a T12 (36 W for a T8) lamp. Further, 1200 mm long ***18W, T8 and 16W, T5 LED tube lights*** are also available in the market [93]. The potential savings in connected load and energy by replacing T12 fluorescent tube lamp by a T5 LED lamp is as high as 160 kW and 337 MWh (annually).

Compact Fluorescent Lamps (CFLs): The number of CFLs present in a house varied from 1 to 15. The most popular were the 11, 15 and 22 W models. Scope for energy and power saving through the replacement of 20% of each 11 W, 15 W and 22 W CFLs with 8 W, 10 W and 16 W LED lamps is 35 MWh and 17 kW respectively.

Rooftop Potential of Houses in Cantonment for PV Installations

The type (slanted or flat), material (tiled, tin sheet, concrete), area, and availability of shade free space on the rooftop of houses were studied in this survey. The analysis was carried out on a sub area basis. The entire Cantonment section is divided into four sub areas namely A1, A2, B1, B2 based on the order in which the meter readers visit these areas for monthly billing of energy usage. Figure 4.5 shows the satellite image of the Cantonment area and the demarcation of sub areas. Table 4.5 compare the available number of eligible houses, total rooftop area available for PV installation, number of potential buyers for 'smart solar inverters' and the potential PV installation capacity across different areas. The total PV installation capacity from the entire Cantonment section comes around 17.1 MW, with an assumption that 15 sq. m. is required to install 1 kW_p of solar PV modules. Based on PVSyst simulations, the energy generated per month from the Cantonment section under the assumption of full utilization of PV installation potential is 2.04 GWh. This is almost double the value of the present energy use in this section per month (from domestic users).

Table 4.5: Distribution of samples from different tariff slabs into different billing sub- areas.

Sub Area	A1	A2	B1	B2	Total
Total Number of Houses	1,944	1,860	1,688	1,503	6,995
Houses Suitable for Rooftop PV Installations	1,139	996	1,006	951	4,092
Percentage of Houses Suitable for PV Installation	59	54	60	63	58
Rooftop Area from Suitable Houses (sq. m.)	85,865	63,043	56,657	50,923	2,56,488
Total Shade Free Rooftop Area from All Houses (sq. m.)	1,31,176	1,45,148	98,493	15,13,396	52,61,559
Conservative Estimate of PV Installation Potential of Shade Free Rooftops (MW_p)	5.7	4.2	3.8	3.4	17.1
Potential Buyers for Peak Load Minimizer	215	232	281	459	1,187

4.2.3 Understanding "How Much Can You Save on Your Electricity Bills?"

As per the tariffs which were in existence during the survey activity, the domestic consumers had to pay Rs. 1.5 to 7.5 per kWh, depending on the tariff slabs as specified in the government order [94]. The tariff structure is given in Table 4.6.

Table 4.6: Tariff structure for domestic consumers in Kerala during 16-8-2014 to 30-9-2015 [36].

Monthly Consumption Slabs (kWh)	Pre Revised Tariff (paise per kWh)	Monthly Consumption Slabs (kWh)	Revised Tariff (paise per kWh)	Remarks
0-40	150	0-40	150	This rate is applicable to consumers who belongs to BPL (Below Poverty Line - annual family income of less than Rs. 27,000)
0-80	220	0-50	280	Telescopic Charges. E.g. if the monthly consumption is 120 units, first 50 units will be charged at 280 paise, next 50 units at 320 paise and remaining 20 units at 420 paise.
81-120	300	51-100	320	
121-150	380	101-150	420	
151-200	530	151-200	580	
201-300	650	201-250	700	
0-350	500	0-300	500	Non Telescopic Charges. E.g. if the monthly consumption is 275 units, then the entire 275 units are charged at 500 paise
0-400	550	0-350	570	
0-500	600	0-400	610	
Above 500	700	0-500	670	
		Above 500	750	

As the 'per kWh cost' of energy varies with the slab in which they belongs, it is obvious that the users from the higher energy slabs gain more monetary benefit for each kWh of electricity they save. However, due to the telescopic nature of the tariff slabs at the lower energy consumption levels, the relation between cash savings for each kWh saving in energy is not linear. Figure 4.7. shows the variation of the 'Rs saved per kWh saved' for the users belonging to different tariff slabs. For the ease of calculations, the mid values of each tariff slabs are used for generating these graphs. The reason for sudden jumps in 'Rs saved per kWh saved' in some curves is due to the shift to a lower tariff slab for the users due to energy saving. If a user who currently uses 125 kWh per month saves 5 kWh a month, then he shifts himself to the group of consumers eligible for 'energy charge subsidy' (whoever consumes less than 120 kWh). Hence there is a jump in savings from Rs. 4.2 per unit saved to Rs. 15 per unit saved. Similarly at higher slabs, a suitable number of units saved will help the users to shift themselves from higher 'non-telescopic' slabs to lower telescopic slabs and causes considerable bill savings.

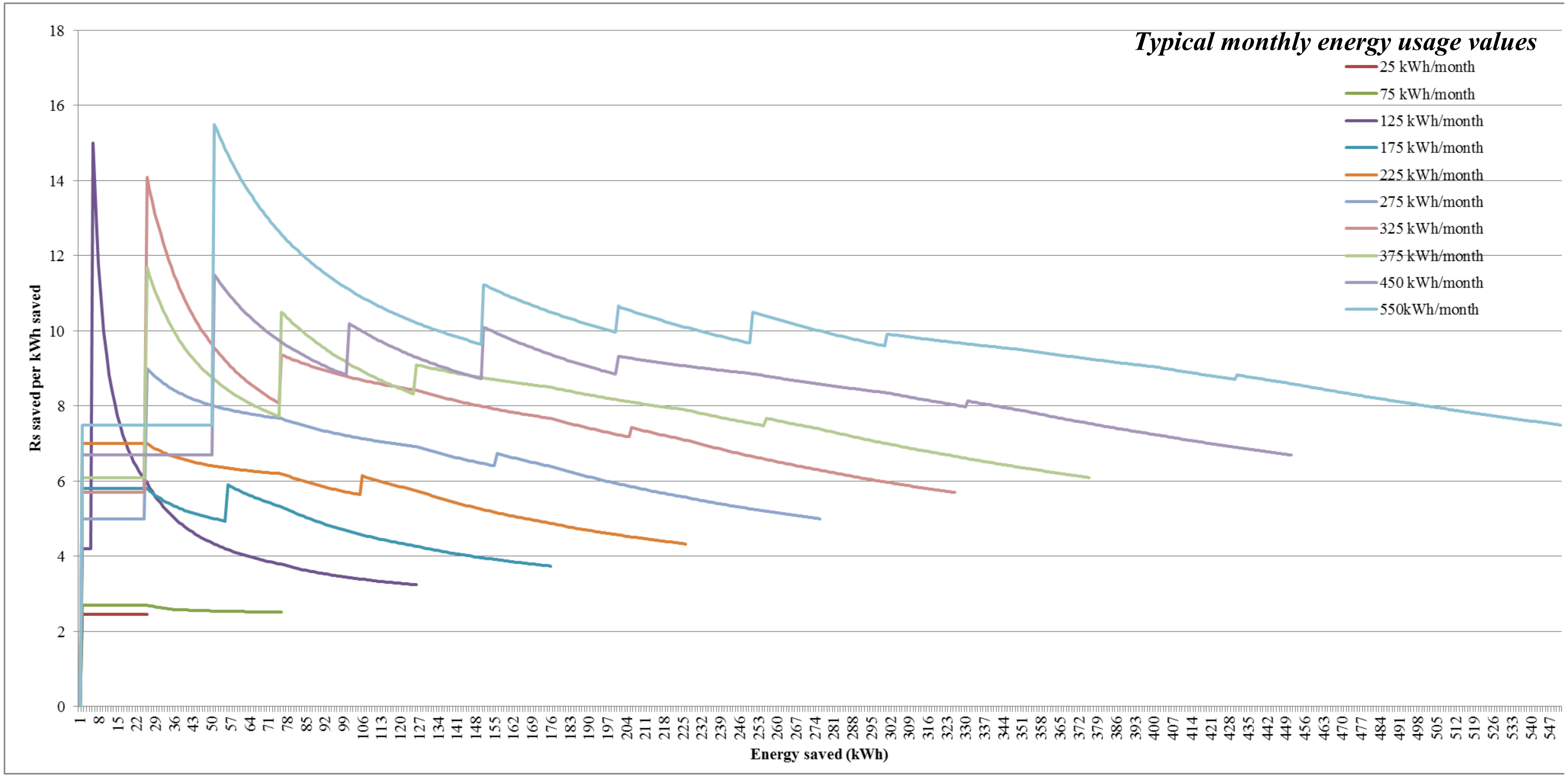


Figure 4.7: Trend of cash savings 'per kWh energy saved' for typical monthly energy consumptions.

Table 4.7 shows the minimum number of kWhs to be saved for different monthly consumption values to reach the peak of the 'per unit saving' trend lines. It also has the corresponding value of cash saved per kWh saved at the particular peak point.

Table 4.7: Minimum kWh to be saved to maximise Rs. per kWh for different ranges of current monthly consumption.

Current Monthly consumption (kWh)	Minimum kWh to be saved to maximise Rs per kWh saved	Maximum value of Rs saved/ kWh saved	Average value of Rs saved/kWh saved
1-40	1	2.45	2.45
41-50	41-50	2.0	2.397
51-100	1	2.70	2.596
101-120	1	3.7	2.963
121 - 200	1-80	58.2 - 5.875	4.704
201-250	1	7.00	5.692
251 - 300	1-50	105 - 7	6.608
301 - 350	1-50	215.7 - 9.9	7.831
351 - 400	1 - 100	146.10 - 9.4	8.01
401-500	1-200	246.7 - 9.25	8.566
x > 500	1 to (x-500)	407.1 - 10.14	9.766

Table 4.7 shows that we will have to identify equipment replacement methods or resort to 'alternative energy generation methods like PV' to realise energy savings from 1 to 200 kWh per month for different slabs of users to maximise their return on investment on 'bill saving' initiatives. To understand the scope of energy saving through equipment replacements, we need to study four aspects; (i) the typical set of equipments in the households within a particular slab, (ii) duration of operation of these equipments, and (iii) the energy saving potential associated with each equipment through replacement, redesign or change in usage pattern and (iv) the cost involved in the replacement or redesign of equipments. Information regarding the first two aspects was collected during the survey and the third one was calculated from the first two values, along with the cost information (fourth value) collected independently from various sources.

With the above mentioned information, payback period calculations were made for each equipment replacement activity with three different perspectives for various slabs of users. First one is from a user's perspective. The savings in bill was calculated at the slab's average saving rate (Rs saved / kWh saved). The current consumption was varied from the beginning to the end of the slab and the number of units saved was also varied from 0 to end value of slab. Saving was calculated at each point and the average value (Rs saved / kWh saved) of the entire matrix was calculated. Simple payback period of the equipment replacement was calculated using this value. Very few replacement options seem to be attractive with this pay back calculation at lower slabs. A payback period of anything less than or equal to 5 years was considered attractive and practical.

Pay back at marginal cost of electricity was also calculated. The rate at which KSEB buys power at peak load time is normally around Rs. 12 per kWh. Supposing the entire energy saving has happened during the peak hours, and then it might be helping KSEB to avoid the costly power purchase. A value of Rs. 12 per kWh was used in this calculation [95]. This calculation shows that most of the replacement options are economically viable at the marginal cost. If there can be some cost-sharing mechanism between the user and the utility on the initial investment of equipment replacement, then such replacements can be easily realised.

Pay back was also calculated based just on the losses incurred to KSEB through the sales of electricity to domestic users at lower prices than their purchase price. Again the purchase price considered was that of the maximum value at peak load time. In this case, even if the user is not sharing the cost of replacement, instead the utility itself is investing the whole replacement cost, even then the saving of 'losses' alone will make this investment from the utility economically viable for them. The only condition is that the users who are beneficiaries of the exchange program should be charged at the same tariff level currently they belonged to, prior to the exchange. Otherwise, they will get undue advantage of lower tariff rates at the new consumption levels, at the expense of utility's investment.

Table 4.8 shows the various equipment replacement options, the associated energy saving and bill savings, costs associated with replacements and the payback period calculations with three different perspectives as mentioned above. The calculations are made for a typical household with monthly energy consumption between 201-300 kWh. The equipment ownership and usage data for this category of consumers are taken from the survey data. All those replacements which are paying back in less than 5 years are highlighted in green background colour in the table. Similar tables were calculated for all other tariff.

Table 4.8: Power, energy, bill savings and pay back periods for different equipment replacement options for tariff slab 201-300 kWh/month.

Equipments owned by a consumer in the slab 201-300 kWh/month use	**Replacement / Renewable energy generation option**	**Replacement cost* (Rs)**	**Power saving per equipment replacement (W)**	**Energy saving (kWh/ month)**	**Monthly bill saving @Rs. 6.20 /kWh**	**Simple payback period (years)**	**Payback period at marginal cost @Rs. 12/kWh (years)**	**Payback period at KSEB's saving in revenue loss (12- 4.66** = 7.34 Rs/kWh)**
TV	CRT TV (120 W) replaced with LED TV (35 W)	15,000	85	13	80.55	16	8	13
Ceiling Fan	Current model (60 W) replaced with super-efficient model (35 W)	2,700	25	8	49.57	5	2	4
Resistive Regulator	Current model replaced with electronic regulator (27% saving)	200	18	6	37.18	0	0	0
T8 fluorescent Tube light	Current model (36 W) replaced with T5 LED light (16W) lamp	1,750	20	4	24.78	6	3	5
T12 fluorescent Tube light	Current model (40 W) replaced with T5 LED light (16W) lamp	1,750	24	4	24.78	6	3	5
15 W CFL	Current (15 W) model replaced with 8 W LED lamp	350	7	1	6.2	5	2	4

22 W CFL	Current (22 W) model replaced with 12W LED lamp	700	10	2	12.39	5	2	4
Refrigerator	Current model replaced with next level in BEE star rating (ensures min.100 units a year saving as per BEE) [96]	15,000	NA	8.5	52.67	24	12	20
Smart solar inverter***	Install a smart solar inverter with 250 W PV module to produce at least 30 units per month	35,000	300	30	185.88	16	8	13
Smart solar inverter + 30% capital subsidy	Install a smart solar inverter with 250 W PV module to produce at least 30 units per month	24,500	300	30	185.88	11	5	9

* Replacement cost of various equipments was compiled from various internet sources and publications [89] [97-102]

** 4.66 is the average price at which electricity is sold to the consumers in this particular slab [36].

*** By purchasing a solar inverter, the consumer can reduce his/her consumption from KSEB as well as get the comfort of uninterrupted power.

4.2.4 Technical and Functional Requirements of a ‘Peak Load Shifter’

As explained in section 4.2, it is estimated that there are around 10-12 lakh inverter and battery based installations present in the distribution system of KSEB. During the period of load shedding, the above mentioned inverters supply the essential loads of the consumers and once the feeders are charged after load shedding, the large number of inverters in the circuit turns to heavy charging mode thereby defeating the purpose of load shedding. If the charging of the batteries can be postponed to a time period after the peak hours (6 p.m. to 10 p.m.), KSEB can make sufficient savings in the purchase of power during peak load. The functional and technical requirements were discussed and finalised by the technical committee, based on the feedback from the energy survey.

Basic functional requirement of the peak load shifter

1. Under normal conditions and by default the battery shall be charged from the solar source.
2. The inverter with peak load shifter should meet the load whenever there is a power failure. If there is excess charge (say above 50 %) at a pre-set time during peak load, the excess charge is used to meet a portion of the load during peak hours till the charge drops to 50 %. The balance charge is retained to meet the load during power failure.
3. The batteries should not be charged from the grid during peak hours at any cost.

The technical specification of the inverters:

Power Conditioning Unit

a. Rating – 650 VA.
b. Type – IGBT/MOSFET based.
c. Input AC – 230V ± 5%.
d. DC Voltage - 12/24V.
e. Output Voltage – 230 V AC ± 2%.
f. Efficiency - 85 % or above.
g. Output Waveform: Sine wave.
h. Total Harmonic Distortion: Less than (<) 3%.
i. Operable Ambient Temperature: 0 to 50°C.
j. Noise Level shall be less than 45db.

k. Cooling: Air cooled.

Protections:

a. Short circuit (circuit breaker & electronic protection against sustained fault).
b. Over-load protection.
c. Under voltage of Battery (automatic shutdown).
d. Auto/ Manual re-connect provision.
e. Reverse polarity protection both for the PV array and Battery (DC).
f. Surge Protection: 150% of the rated capacity for a period of 10 seconds.
g. Indicators / Displays / Alarms :
    i. Digital Display(s) of input DC SPV voltage & current, AC output voltage, frequency, power and current.
    ii. Separate indication for SPV charging.
    iii. Battery Low indicator and Alarm / cut off.
    iv. Overload Alarm / cut off.
    v. System Cut off Indicator.
    vi. System reset button.

Battery:

a. 12V, 150 Ah, C10, Tubular (Deep Discharge)

Operational Modes of the Solar Inverter with Peak Load Shifter

The system should have basically 5 operational modes

1) **Normal Inverter Mode:** Whenever grid fails (**irrespective of the real time**) the inverter supplies power to the load by drawing energy from the battery. This process will continue until the battery terminal voltage drops below a threshold value. Normally, for solar inverters, deep discharge batteries are used and their Depth of Discharge (DoD) is set as 75%.
2) **Evening Peak Load Shaving Mode:** During this period **(6 p.m. to 10 p.m)**, the charging circuit from grid to the batteries is disconnected. This will avoid unnecessary phantom loads on the mains due to no-load losses of the battery charging circuit of the inverter. If the battery charge levels of the inverter system is above a threshold value, say 50% (should be a programmable value and can be termed as '**EP**') the loads are connected to the inverter output. Thus the inverter enters into Peak load shaving

mode. The loads are transferred back to the grid once the battery levels drops below 'EP'.

3) **Morning Peak Load Shaving Mode:** During this period **(6 a.m. to 9 a.m.)**, the charging circuit from grid to the batteries is disconnected. This will avoid unnecessary phantom loads on the mains due to no load losses of the battery charging circuit of the inverter. If the battery charge levels of the inverter system is above a threshold value, say 50% (should be a programmable value and can be termed as '**MP**') the loads are connected to the inverter output. Thus the inverter enters into Peak load shaving mode. The loads are transferred back to the grid once the battery levels drops below 'MP'.
4) **PV Energy Optimisation Mode:** During day time, i.e. solar power is available and if the batteries are almost near full charge, say 97% (should be a programmable value and can be termed as '**EOS**'), the loads are transferred to the inverter. This will prevent the batteries from over charging since the *day time loads* will consume the incoming solar power. This process will continue till the battery charge level drops to 93% (**EOE**). If there are no day time loads, the battery may get charged up to 100 % by solar power. Then the solar charging circuit should be cut off to prevent overcharging of the batteries at 100%.
5) **Off Peak Hours Grid Charging mode:** If the battery charge dips below a critical value, say 50% (should be programmable and can be termed as **'C'**), then the charging circuit from the grid can be reconnected during off peak hours (9 a.m. to 6 p.m. and, 10 p.m. to 6 a.m.). Hence hybrid charging can be allowed till the battery charge level reaches a critical value 'C' during day time. This will increase the reliability of the power back up.

The inverter has 6 programmable control variables: DoD, EP, MP, EOS, EOE, C

In addition to the above variables, the time durations for entering into various modes shall also be programmable by a super user (KSEB staff, system integrator technician).

The batteries shall be charged through solar power, a charge controller should be present in the inverter. It is preferable to have an MPPT (Maximum Power Point Tracking) algorithm inbuilt in the charge controller.

14 companies, who are manufacturers of power electronics equipments were successful in realising this product and were empanelled as vendors with KSEB. The empanelment was done after rigorous testing of a sample products supplied by them at the testing labs of College of Engineering Thiruvananthapuram.

Figure 4.8 shows the control logic flow of the inverter used in peak load shifter package.

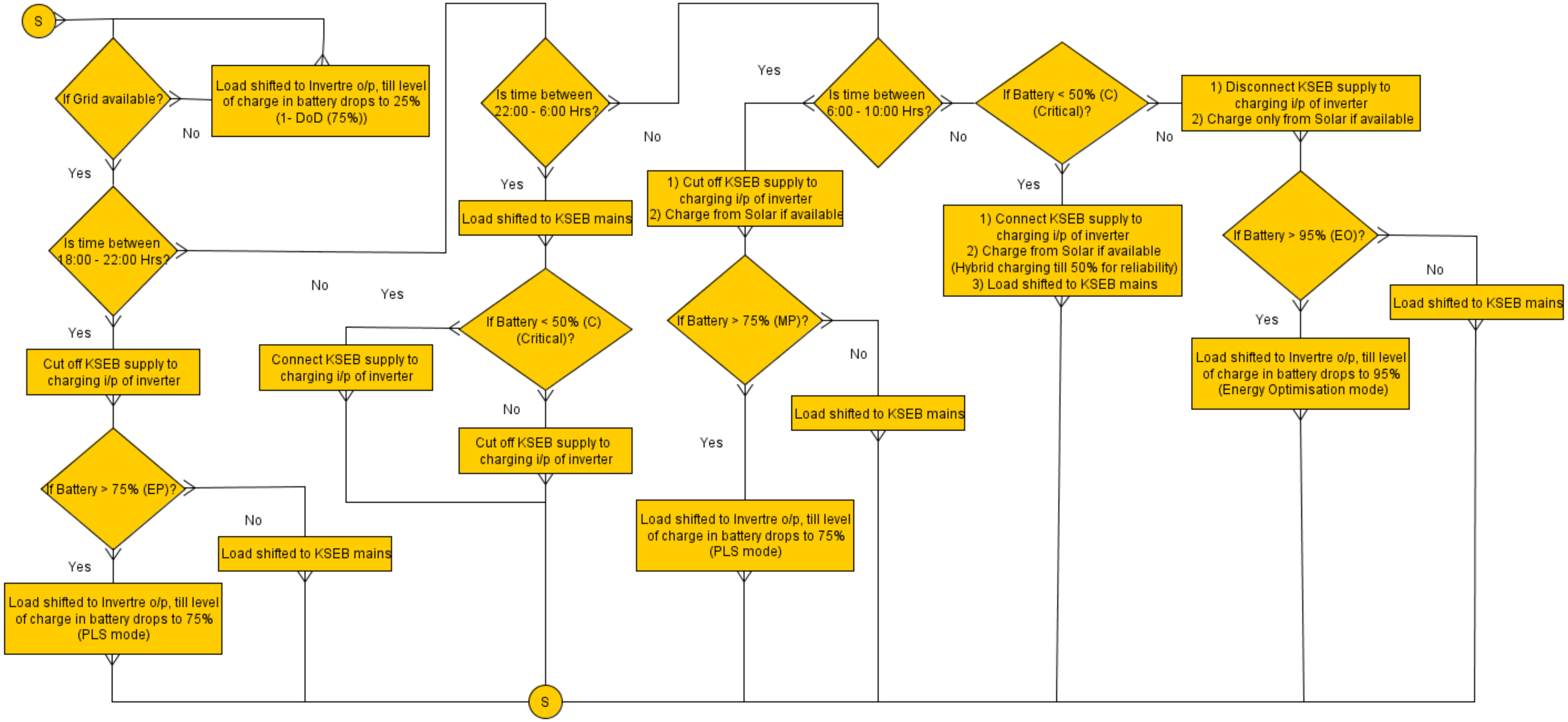


Figure 4.8: Control algorithm for the operations of 'Peak Load Shifter'.

4.2.5 Need for Alternate Control Logic for Peak Load Shifters – Staggered Triggering of Inverters During Peak Load

One major concern with the PLS logic is regarding the triggering time. As per its default logic, the inverter is switched on based on a real time clock at 6 PM. The basic package is providing only a 12 V, 150 Ah battery. This is not adequate to support the loads in a house for the entire 4 hours of peak load. Depending on the variation of the loads from different houses, the battery discharge time will vary from house to house. Based on the equipment ownership the base load on the inverter from customers from different tariff slabs is calculated. Since the PLS logic allows only 50% of the battery to be discharged for peak load shifting operation, we have only 75 Ah to discharge during peak load. Based on these two values and assuming 80% efficiency of inverters, the discharge time for various households are calculated as shown in Table 4.9.

Table 4.9: Base load, discharge current and the discharge time for batteries in a PLS inverter for different tariff slabs.

Tariff Slab (kWh Consumed/Month)	Base Load (W)	Discharge Current from Battery (A)	Discharge Time (Hours)
0 - 40	385	40	1.88
41-80	451	47	1.6
81-120	488	51	1.47
121-150	495	52	1.44
151-200	571	59	1.27
201-300	565	59	1.27
301-350	650	68	1.1
351-400	650	68	1.1
401-500	650	68	1.1
>500	650	68	1.1

The table shows that none of these inverters can stand more than 2 hours. But the actual peak load happens at 8 PM. By the time it becomes 8 PM, all the inverters will stop shifting the load off from the grid. Also, the entire load shifts back to the grid within the span of less than 1 hour (depending on the stopping time of the inverter). The grid faces a huge ramping up of load (in fact a steeper ramp than that existed before) which is difficult to forecast and handle. In fact the PLS has created more problem than that existed before. It is not shifting the peak, at the same time creating a steeper ramp. A case study was done based on the consumer data available for the distribution transformer at 'Brigadier Lane'. There were 450 connections under this transformer and out of which 418 are domestic consumer (LT 1A). The capacity of the transformer was 250 KVA. The peak load was around 225 KVA at around 8 PM.

The total number of consumers in each tariff slab and the probability of consumers from each tariff slab participating in the PLS program was assumed as shown in Table 4.10. The analysis shows that a maximum of 90 KVA can be shifted down during the peak if all the inverters are working at 8 PM. But as per the current triggering logic, the new load curve will be as shown in Figure 4.9. The different inverter triggering scenarios are discussed below.

Table 4.10: Reduction in load by domestic consumers from different tariff slabs under the distribution transformer at "Brigadier Lane" due to adoption of PLS.

Tariff Slab (kWh)	**No. of Consumers**	**Probability of Consumers Participating in PLS Program (Percentage)**	**No. of PLS Used in Each Slab**	**Load Shifted by Each Inverter**	**Total Load Offset (W)**
0 - 40	23	0	0	385	0
41-80	51	15	8	451	3,608
81-120	111	30	33	488	16,104
121-150	90	45	41	495	20,295
151-200	81	50	41	571	23,411
201-300	49	70	34	565	19,210
301-350	8	90	7	650	4,550
351-400	2	100	2	650	1,300
401-500	0	0	0	650	0
> 500	3	100	3	650	1,950
Total			169		90,710

Different triggering scenarios

a. All inverters trigger at 6 PM (assuming all of them offsets 450 – 650 VA as per their tariff slab)

In this scenario, the inverters were assumed to bear their actual load (load was calculated based on their tariff slabs) and hence, each of the inverter will run for variable time as shown in Table 4.9. Hence the off time of inverters varies and almost all linverters are switched off between 7:06 p.m to 7:36 p.m. The equivalent variation in the load curve is as shown in Figure 4.9. It is obvious that the peak load remains unchanged and the purpose of PLS program is not met.

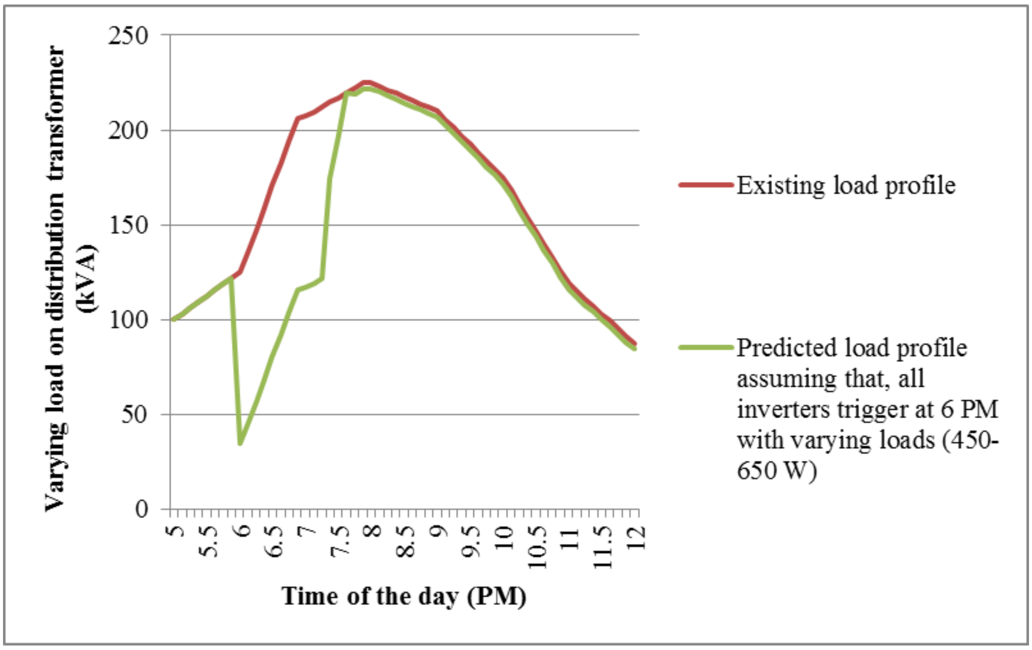


Figure 4.9: Existing and predicted load line of distribution transformer at Brigadier Lane due to PLS implementation (inverters offset 450 – 650 W for 1.1 to 1.6 hours).

b. Staggered triggering of inverters based on total number of inverters and their base loads (assuming all of them offset 450 – 650 VA as per their tariff slab)

Here a certain number of inverters are scheduled to trigger serially at an interval of 15 minutes, starting from 6:30 p.m. Lesser number of inverters are triggered at 6 p.m., more at 6.15 p.m., even more number at 6.30 p.m. and so on. Some of them may be triggered even after 8 p.m. This will ensure that the total number of inverters running at a given time is optimised to give a final flat load curve. The expected result is as shown in Figure 4.10. This curve was obtained by triggering the inverters as shown in Table 4.11.

Table 4.11: Inverter triggering schedule for optimising the peak load shaving.

No. of PLS Used in Each Slab	Load Shifted by Each Inverter	Time Slots in which Inverters are Triggered (PM) and Number of Inverters Triggered in Each Time Slot								
		6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30
8	451					2	4	2		
33	488				1	8	16	8		
41	495	1	4	3	5	5	10	5	5	3
41	571		2	3	5	7	10	7	5	2
34	565	3	4	5	5	5	7	2	1	2
12	650		1	1	2	5	2	1		
Total Load Offset (W)		1,695	5,747	10,935	17,915	34,366	58,198	67,444	66,247	62,681

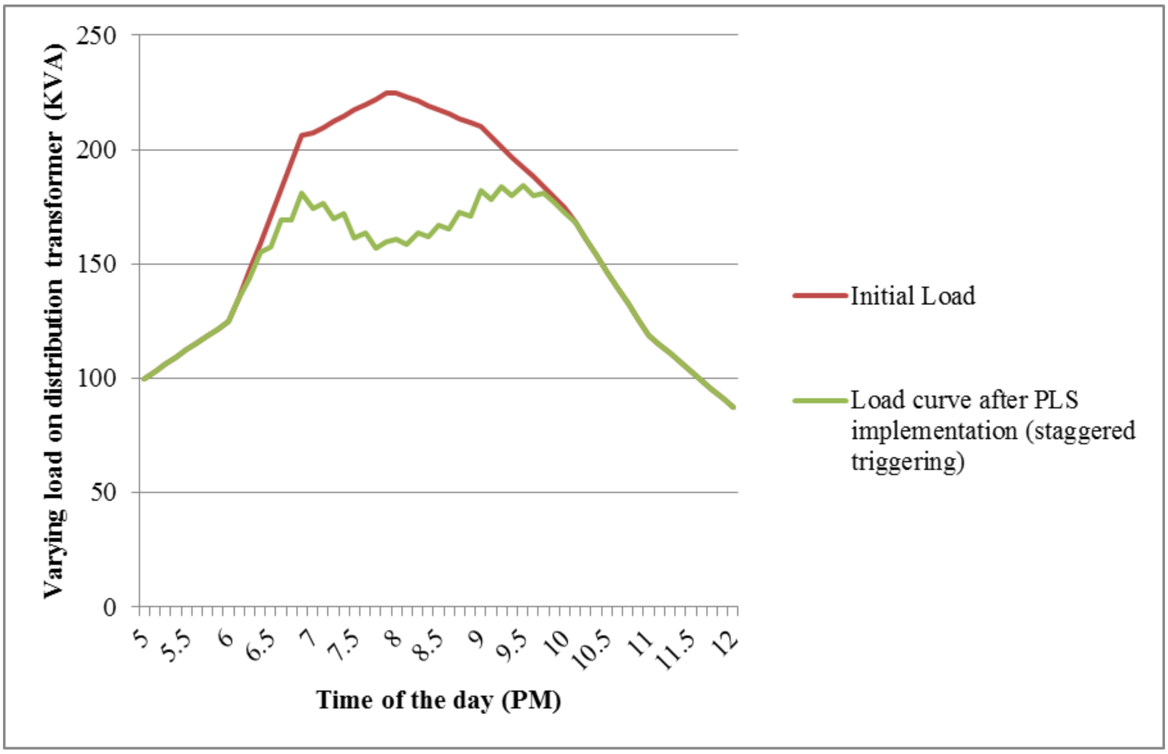


Figure 4.10: Existing and predicted load line of distribution transformer at Brigadier Lane due to PLS implementation (all are triggered at different times and each inverter offset 450 – 650 W for 1.1 to 1.6 hours).

Out of the two options of triggering available, the staggered triggering option seems to be better for the optimal shaving of peak load. But the optimising function is quite complex. It needs various inputs such as total number of inverters under that transformer, expected base load of each inverter, peak load and time at which peak load happens. All these numbers keep on changing. New users can buy PLS and the total number varies. Even the peak load also varies and the time at which it occurs varies from time to time. Hence it is impractical to optimise the load curve as discussed in scenario ‘b’. Another drawback of the above simulation is that, the load curve of the transformer was not the true load curve, rather it is a scaled down version of the load curve of the entire state as provided by load despatch centre, Kalamassery [61]. We need to consider a huge quantity of load in the grid induced by the non-domestic users. The share of peak load introduced by the domestic users may be small as compared to the non-domestic users. Hence a better way to decide the triggering pattern will be based on the domestic to non-domestic users ratio under a transformer or distribution section. After a round of field trials, the final triggering logic can be decided, before the project is launched at the state level.

It might help to design smart PLS systems which would gather the load patterns regularly and communicate the same to a processing centre over the grid using spread spectrum communication technology. The processing centre in turn should be able to analyse the data received and set the triggering algorithms on the PLS based on load patterns.

4.2.6 Design of “PV + Energy Efficient Equipment” Packages to Maximise the Return on Investment on Energy Bill Saving Initiatives

From section 4.2.3, it was clear that most of the equipment replacement options were economically viable for higher tariff slabs (> 200 kWh/month) whereas ‘just the saving from electricity bills’ cannot motivate the lower tariff slab consumers for equipment replacements or purchasing a smart solar inverter. Another finding is that most of the equipment replacements in the lower tariff slabs were economically viable just through the reallocation of amount saved by KSEB for cross subsidising the lower tariff consumers. If there is a cost sharing mechanism between the utility and the consumers, then almost all the equipment replacement programs are economically viable in all the tariff slabs. In order to maximise the bill savings, it was already discussed and found out in this section that each user has to first check with their current monthly energy usage and select a particular replacement option which would give them a maximum Rs saved/kWh saved. Sometimes this may be achieved through a combination of replacements. Table 4.7 indicates that the number of units to be saved varies from 1 to 200, depending up on the current slab, and current consumption in kWh. The basic logic to maximise the return to investment will be to select the energy saving option with shortest payback period first. For equipments with same payback period, chose the option with lowest cost of replacement. A typical set of replacement options for a consumer with monthly usage of 550 kWh is given in Table 4.12. The target number of units (kWhs) to be saved to maximise the return on investment for this user is 50 (refer Table 4.7). As per the selection logic of 'least payback period options first', the equipment replacement options were prioritised as given in Table 4.12.

Table 4.12: Prioritising the replacement options based on shorter payback period and higher energy saving per replacement.

Option No.	**Replacement Activity**	**Cost of Replacement (Rs)**	**Energy Saved per Month (kWh)***	**Payback Period (Years)***
Option 1	Resistive Regulator changed to electronic regulator	200	6	< 1
Option 2	Replacing electric water heater with solar heater	13,500	38	3
Option 3	Ordinary ceiling fan replaced with super-efficient fan	2,700	8	3
Option 4	22 W CFL changed to 12W LED	700	2	3
Option 5	15 W CFL changed to 8 W LED	350	1	3
Option 6	T12 fluorescent tube replaced with 12 W LED tube	1,750	4	4
Option 7	T8 fluorescent tube replaced with 12 W LED tube	1,750	4	4
Option 8	CRT TV replaced with LED TV	15,000	15	9
Option 9	Installing a smart inverter with 250 W PV modules	35,000	30	10
Option 10	Replace existing refrigerator with higher star rated one	15,000	8.5	15
Option 11	Replace existing AC with higher star rated one	30,000	14	18

* Here the energy saved and payback are calculated w.r.t. the usage pattern of the users in the slab > 500 kWh/month. In other cases, the energy savings and hence the pay back varies w.r.t. the current slab and average duration of usage of equipment in that slab.

To achieve 50 kWh savings a user can opt to replace three resistive fan regulators with electronic regulators (saving 18 kWh a month) plus three 22W CFL replaced with 12 W LED lamps (saving 6 kWh a month) plus two 15 W CFLs replaced with 8 W LED lamps (saving 2 kWh a month) plus 3 ordinary 60 W ceiling cans replaced with 35 W super-efficient fans (saving 24 kWh a month). In the above scenario, the payback period for individual replacement options were ranging from 1 to 3 years. Whereas if we consider this as a whole package, the total investment on the equipment (Rs. 11,500) pays back in less than 2 years (monthly bill saving of Rs. 775 for 15 months can recover this investment). So the concept of clubbing of energy saving options along with smart solar inverter can be a solution to bring down the 'effective payback period' of the total investment.

4.2.7 Realising Sun Shift Program through Non-Cash Subsidy Mechanism

From the previous sections it was clear that achieving a payback of 5 years or less is not possible for the smart inverter package as designed by the KSEB technical committee (kit including inverter with smart inverter and 250 W PV module and 12 V 150 Ah battery), unless there is a 30 % capital subsidy provided. Even if we club this product with other energy saving options and try to optimise the pay back, the preference order of the product comes very low in the option table (as discussed in Table 4.12). The cost of the product is around Rs. 35,000 and it gives 30 kWh per month savings. So in order to achieve a payback of 5 years, ideally someone should earn/save Rs. 19.4 per kWh. Only a small section of people have the option of monthly saving target >= 30 (as discussed in Table 4.7) and Rs saved/kWh saved >=19 at the optimised saving point. Hence the scope of clubbing up this product with other options is also minimal.

In this case it is proposed that the capital subsidy of 30% from MNRE (Rs. 10,500) is obtained by KSEB and either redistributed monthly as a part of EMIs, contributory to the users bill savings and KSEBs loss savings, or an equivalent amount of redeemable coupons are given to the consumers, with which they can purchase super-efficient energy equipments. The additional energy saving due to equipment replacement added with the energy saving due to smart inverter gives a boost to the bill savings and gives the user a faster rate of return and hence the scheme becomes economically viable. The details of this scheme are as shown in Table 4.13. The cost of a smart inverter kit is kept same as Rs. 35,000. A user has to enter the scheme with Rs. 10,000 (from own sources) + a variable amount (depending on their slab). The rest of the amount is paid as EMIs of Rs. 550. All the slabs above 250 kWh/ month can repay their EMIs just from their savings in the bill. Ideally, KSEB has to work on providing access to finance, arranging the capital subsidy from MNRE, benchmarking the inverters and energy efficient equipments, setting up a m ature market for super-efficient equipments and other facilitative activities. Another advantage of this approach is that, as the load gets reduced due to equipment replacement, the inverter can support it for more time during peak hours, and even if the inverter runs out of energy, the loads are any way lower than the previous case. Even during rainy days, when PV modules fails to charge the batteries; there is a definite saving of peak due to efficient equipments.

Table 4.13: Packages for different tariff slabs for optimal repayment of EMI through electricity bill savings (no cash subsidy involved).

No.	Tariff Slab (kWh/month)	Initial Investment (Rs)	Use of MNRE's Capital Subsidy of Rs.10,500	Products Given in the Package	Energy Saving per Month (Due to Smart Inverter + Equipment Replacement) (kWh)	Bill Saving (Rs)	Contribution from KSEB (Rs)	Remaining Amount Paid by the User as EMI (Rs)
1	0-50	10,000	Redistributed as Rs. 175 per month for 60 months	1 Smart inverter kit with 250 W panel	30 (due to Smart Inverter)	Varies from 0 to 121	55.2	202.5 - 319.8
	E.g.: Current monthly consumption = 45 kWh	10,000	175		30	109.5	55.2	217.2
2	51-100	10,000	Rs.5250 redistributed as coupons for Energy Efficient Equipments and Remaining Rs. 5250 i s distributed as monthly 87.5 for 60 months	1 Smart Inverter, 1 Super-efficient ceiling fan, 2 electronic regulators, 1 16 W LED tube, 1 12 W LED bulb, 1 8 W LED bulb	30 + 20 (Refer table 3.19 for details of energy saving from replacement)	121.25 - 135	85.76	241.73 - 255.48
	E.g.: Current monthly consumption = 75 kWh	10,000	87.5		50	127.25	85.76	249.48
3	101-150	12,000	Entire 10,500 + 2000 from user is redistributed as coupons	1 Smart Inverter, 3 Super-efficient ceiling fan, 2-16 W LED tube,1-12 W LED bulb, 1-8 W LED bulb	30 + 30 = 60	159.4-281	84.54	184.45-306.05
	E.g.: Current monthly consumption = 125 kWh	12,000	0		60	243.5	84.54	221.95
4	151-200	13,500	Entire 10,500 + 3500 from user is redistributed as coupons	1 Smart Inverter, 3 Super-efficient ceiling fan, 3-16 W LED tube,2-12 W LED bulb, 1-8 W LED bulb	30 + 40 = 70	311.1-412	63.37	175.52 - 112.62
	E.g.: Current monthly consumption = 175 kWh	13,500	0		70	380.5	63.37	106.12
5	201-250	14,500	Entire 10,500 + 4500 from user is redistributed as coupons	1 Smart Inverter, 3 Super-efficient ceiling fan, 1 electronic regulator, 3-16 W LED tube,2-12 W LED bulb, 1-8 W LED bulb	30 + 45= 75	374 - 495	23.37	31.62 - 128.82

	E.g.: Current monthly consumption = 225 kWh	14,500	0		75	380.5	23.37	61.62
6	251 -300 and above	14,500	Entire 10,500 + 4500 from user is redistributed as coupons	1 Smart Inverter, 3 Super-efficient ceiling fan, 1 electronic regulator, 3-16 W LED tube,2-12 W LED bulb, 1-8 W LED bulb (or whatever equipments they need to buy within this limit)	30 + 45= 75	525-594	0	Maximum of Rs. 25
	E.g.: Current monthly consumption = 275 kWh	14,500	0		75	575	0	0

Initial Investment - Initial Investment by a user, which he/she has to arrange by himself/herself to enter the scheme.

Bill saving = Function (Current consumption, energy saving).

Contribution from KSEB = No. of kWh saved by the user * (5.87 - Average price per kWh in the slab).

According to a power systems statistics report by KSEB, the average cost of supplying 1 unit of electricity at the consumer end is Rs. 5.87 [35]. But the average cost of electricity paid by a domestic consumer is only Rs. 4.3 up to the tariff slab 250 kWh per month. So if any user (in a tariff slab <250) saves 1 unit of electricity, it will save Rs. (5.87 - Average tariff rate of that slab) for KSEB. Suppose a user saves 30 kWh due to smart inverter and his current consumption is 200 kWh per month. Then the user saves Rs. 30*3.73 (Rs. 3.73 is the average billed amount per unit in this slab as per tariff structure) and KSEB saves Rs. 30*(5.87 - 3.73). In this scheme, the savings obtained by KSEB is passed on to the user so as to minimise his payback period on the investment of smart inverter. If we consider the marginal cost of Rs. 12/ kWh (which is actually applicable for the 30 kW h saved by smart inverter during peak hours), the payback period can be further reduced. .

The total energy saving by the smart inverter and the super-efficient equipment could help the consumer to save enough money in the electricity bills to pay the EMIs. For those people who cannot save enough money in the electricity bills (lower tariff slabs) will have to pay a variable amount from their pocket (maximum of Rs. 320 per month) in addition to their bill saving). In the worst case scenarios, the customer has to pay Rs. 550 per month, which is the actual monthly instalment calculated for Rs. 25,000 at 12% interest for 5 years.

4.2.8 Learnings from the Sun-Shift Project

Dissemination of rooftop PV can be made more effective by tying it up w ith the super-efficient equipment programs. The costly solar inverter kit and the costly super-efficient equipments are not economically attractive if considered individually, but if implemented together, the total energy saving and the corresponding bill saving can help the consumers to pay their monthly instalments and make the total scheme economically viable. The channelization of capital subsidy for PV into the cost of super-efficient equipments seems to be a more sustainable way of utilising those funds. At the end of the day even if the PV system does not produce enough energy (in case of rainy seasons), the users can get an assured bill saving due to the efficiency improvement. From the utilities perspective, this gives an assured peak load saving as well.

In the above proposed scheme, even the lowermost slab user can participate in the process and get a PV system of their own. The capital subsidies from MNRE which were otherwise enjoyed by the people who invested on larger systems (who had higher purchasing power and bankability) will now be channelized towards the lower economical strata of the society. Thus the scheme will help in promoting energy efficiency, green energy and make these so called ‘costly’ technologies more ‘inclusive’ and accessible to the lower strata of the society.

4.3 Conclusions

Case study of Chendamangalam revealed that even in rural and semi-urban areas, there is adequate availability of strong and shade free rooftops. But due to policy restrictions and due to mismatch in supply-demand situation, there need to be an alternate mechanism to implement 'collective rooftop' projects. KSEB should ideally promote more such collective rooftop projects in domestic sector, who otherwise are reason for the major part of their operational losses. A panchayat can be an ideal scale for awareness creation and project inception, but there is a felt gap for an implementation agency with local presence and engineering background to take things forward. Sources of funding and other financial mechanisms are also needed for projects to materialise.

Promoting PV and energy efficient equipments as a combined package along with a finance mechanism can help in better dissemination of PV. The introduction of SEE equipments also result in assured energy saving irrespective of the performance of PV systems. The capital subsidies from MNRE which are otherwise enjoyed by the people who invested on larger systems (who had higher purchasing power and bankability) will now be channelized towards the lower economical strata of the society. Thus the scheme will help in promoting energy efficiency, green energy and make these so called 'costly' technologies more 'inclusive' and accessible to the lower strata of the society.

After the analysis of first hand data from field surveys, which mainly looked into the potential for rooftop PV systems in residential, commercial and allied sectors, the next chapter looks into the scope for adopting PV in agriculture sector, one of the major energy consuming sectors in Kerala.

Chapter 5

Scope for Farmers Co-Operative Societies Entering into 'Grid Connected Solar Water Pumping Systems' in Kole Lands of Kerala

Other than rooftop installations, water pumping using solar power is a major application which has immense potential in Kerala. Hence, after the analysis of rooftop PV potential in the previous chapter, this chapter looks in to the scope for integrating solar PV in the agriculture sector in Kerala. According to the statistics, there are 5,00,082 irrigation pump sets in Kerala and their total connected load is more than 950 M W [35]. The total consumption from this sector is 279.48 million kWh in a year which contributes to more than 1.4% of KSEB's total sales. Tariff in this sector is highly subsidised and they pay only Rs. 2.5/kWh. In this context, a detailed study on the scope of introducing PV based water pumping systems in the agriculture sector of Kerala is explored in this chapter. A detailed study on the scope of solarisation of pumps used in agriculture was undertaken by RAIDCO Kerala Ltd., a co-operative sector institution in Kerala. The study was conducted in the agriculture fields of Thrissur and Malappuram districts in Kerala and a Detailed Project

Report (DPR) was submitted to the Department of Agriculture, Government of Kerala. I was involved in the site surveys, data collection, analysis and the preparation of DPR in the capacities of a technical expert. The DPR is under evaluation by the government and is not available in public domain.

'Kole lands' are vast expanse of low lying lands (with altitude more than a meter below mean sea level) adjacent to the coastal belt of Kerala. When food scarcity was at its peak during the late 18th century, to alleviate the same, the agriculturists, jointly worked to build a strong and effective organizations, to ensure group farming and cultivation of paddy in these lands. Conventionally, they were using wooden wheels operated by men and bullocks to draw water from the adjoining water storage areas, to the paddy field. The Kole lands are mainly surrounded by backwaters. During rains, it is also required to 'de-water' the paddy fields [103].

As developments took place and changes happened from time to time, keeping pace with the developments, the old conventional systems were replaced by 'Petti and Para' (indigenously developed vertical axis pumping systems with wooden and cast iron components), and later by electric motor pump sets. Even though electric motor pumps are being used by the farmers, 'petti-para' systems are still in use at many places, where low head and high discharge of water is required.

The existing system using 'petti and para' (refer Figure 5.1) is an indigenous pumping mechanism with wooden casing and steel impellors, driven by electric motors of varying HP capacities. Petti and para includes a cylindrical wooden case with a cast iron/steel impellor vertically mounted inside the cylinder. The rotating impellor 'pulls up' the water column and pushed it out through the top of the cylinder. A rectangular wooden tunnel attached at the discharge side (top) of the cylindrical casing channelizes the water to the nearest canal or irrigation facility. The uniqueness of the system is its ability to pump at low heads with high discharge rates. The impellors are driven at 960 RPM using a belt and electric motor. The HP rating of the motor is adjusted according to the required volume of water pumping. The cylinder diameter and corresponding impellor design varies accordingly. The belt driven system hence causes a lot of losses while transferring the power. Studies have proven that the energy efficiency of such systems is ranging between 9.6% to 26%, whereas scientifically designed axial flow pumps have efficiencies more than 80% [104]. Details of the existing "Petti and Para" systems are as shown below:

- Low Head, High Discharge.
- 960 RPM, slip ring motor used.
- Head – 2 to 2.7 meter.
- Diameter of the Para – approx. – 1.2 meter for 10 HP systems.
- Height of Para – approx. 1.66 meter for 10 HP systems.

Figure 5.1: Petti and Para (wooden box and cylindrical casing) and the impellor used and the mode of driving with electric motor and belt.

The pumps are installed on a seasonal basis. The ownership of the pumps belongs to the farmers group (Kole Padavu) and the maintenance of the pumps is also taken care by themselves. But the electricity bills of the same are being borne by the Department of Agriculture, Government of Kerala. Hence the government is incurring huge recurring expenses on the energy usage part.

In Thrissur district, cultivable Kole lands are spread over an area of 12,000 hectares. There are about 19,000 farmers who are cultivating paddy in this region. The Kole lands in Ponnani in Malapurram district is spread over 3939 hectares. There are about 6,000 farmers who are cultivating paddy in Ponnani [103]. The information collected during the survey conducted in Thrissur and Ponnani Kole lands by RAIDCO and the scope and viability of solarising the pumping systems in Kole lands is discussed in the sections 5.1 to 5.5.

5.1 Consumption of Electricity

The Petti and Para systems are driven by electric motors of varying power capacities, where the lowest capacity rating found in the field during survey was 10 HP (Horse Power, 1 HP = 746 W) and highest rating was of 80 HP. A few 5, 7.5 and 10 HP monobloc pumps are also in use. During monsoon season, when there are continuous rains, where dewatering requirement is at its peak, almost all the pumps would be running simultaneously, 24 hours 7 days a week, and this creates a huge demand for power in this region. During non-rainy days, where the dewatering requirement is less, the pumps are operated 10-12 hours a day. Again during the last phase of paddy cultivation, when there are no rains, the water will be pumped back into the paddy fields from the canals and backwaters to provide adequate water for the plants. A typical consumption pattern (as per the information from the farmers during survey) and corresponding energy consumption from pumps of varying power rating is summarised in Table 5.1.

Table 5.1: Electricity usage from water pumps in Kole lands.

		Continuous Use		**Discontinuous Use**		
Sl. No	**Power Rating (HP)**	**Hours/Day**	**Days/Year**	**Hours/Day**	**Days/Year**	**Yearly Energy Consumption (kWh)**
1	5	24	60	12	90	9400
2	7.5	24	60	12	90	14,099
3	10	24	60	12	90	18,799
4	15	24	60	12	90	28,199
5	20	24	60	12	90	37,598
6	25	24	60	12	90	46,998
7	30	24	60	12	90	56,398
8	40	24	60	12	90	75,196
9	50	24	60	12	90	93,996
10	60	24	60	12	90	1,12,795

Monthly usage of LT V category connections (agriculture water pumps) was also collected from Assistant Executive Engineer, KSEB sub-division office, Ponnani. The data says that the monthly consumption from some of these systems go as high as 16,000 kWh. The number matches with a 50 HP system (Sl. No 10) in the above table. If we divide the 93996 kWh to the 6 months during which paddy cultivation is in practice, monthly consumption comes close to 15,666 kWh.

5.2 Recurring Public Expenses

According to the tariff rates prevailing in Kerala, the agricultural connections are billed at 2.50 Rs/kWh. Whereas the actual cost of supplying one kWh at the users end is Rs. 5.87 for KSEB [35]. KSEB is managing to supply power to agricultural consumers at this lower price through cross subsidisation (Rs. 3.37 less than the actual cost). Even the 2.50 Rs/kWh is being paid by the Agriculture Department, Government of Kerala, through the Krishi Bhavans (regional agricultural offices of the government). The farmers have to submit their electricity bills to the nearest agricultural office and the payment of the same is taken care off. Effectively the entire cost of Rs. 5.87 is met through 'taxpayers' money'.

In addition to this, frequent replacement of transformers, especially during the monsoon seasons is an additional expenditure for KSEB in this region. Heavy winds and unsteady soil conditions often result in falling on transformers into the paddy fields. Again, this will result in interruption of supply during the rains.

Attempts were already being made by local engineers and pump manufacturers to replace the existing inefficient system using innovative methods. One of the local innovations by Mr. Ali, a farmer from this region is to mount the motor vertically and directly couple the impeller shaft to the rotor. The system is working successfully in the field. M/s Kirloskar has come up with a turbine pump design with vertical motor mounting solution (refer Figure 5.2).

Figure 5.2: Turbine pump with 30 HP vertical mounting from Kirloskar.

M/s Mahindra has tried out a couple of submersible low head-high discharge pumps of 7.5 HP at a different location in Ponnani Kole. So replacing the single bulk unit with smaller lower capacity units is definitely a solution.

Even though all these experiments were tried out, the farmers still prefer the Petti and Para system. The reasons being:

i) Petti and Para systems can be ‘easily maintained locally’ by the native blacksmiths, artisans and carpenters.

ii) None of the experimented systems were able to give the flow rates comparable to the Petti and Para systems.

iii) Petti and Para systems are more rugged and can easily push out slurry type mud, live fishes, aquatic plants, etc. and do not require any additional filtering mechanisms at the suction point.

5.3 Driving Existing High Capacity Motor Pump Sets Using Solar Energy

Since the farmers do not prefer to change the existing pumps with energy efficient submersible pumps, one of the options to save this recurring expense on energy usage is to drive the pumps with solar power. Conventional solar water pumps using Variable Frequency Drives (VFDs) are designed to work on an off-grid mode. In this case, when the pump is not working, the generation from the PV panels is lost. To avoid this loss, a normal grid tied PV system connected to the grid service points of the pumps is proposed. In most cases, these pumps are connected and disconnected on a seasonal basis, according to the pattern of agriculture. Also, when there is a grid failure, the conventional grid tied systems would also stop generation. This would leave the farmer unable to pump during load shedding/interruptions.

Considering the above facts, a PV pump system with both motor drives (modified VFD) and a grid tied inverter with net metering arrangement would be preferable. The schematic diagram for the system is given in Figure 5.3. There is an option to connect a battery bank to the DC bus through a DC-DC converter. This would increase the cost of the system, but can be helpful to run the pumps during critical situations when neither grid nor solar power are available (which can occur during rainy seasons when dewatering is critical).

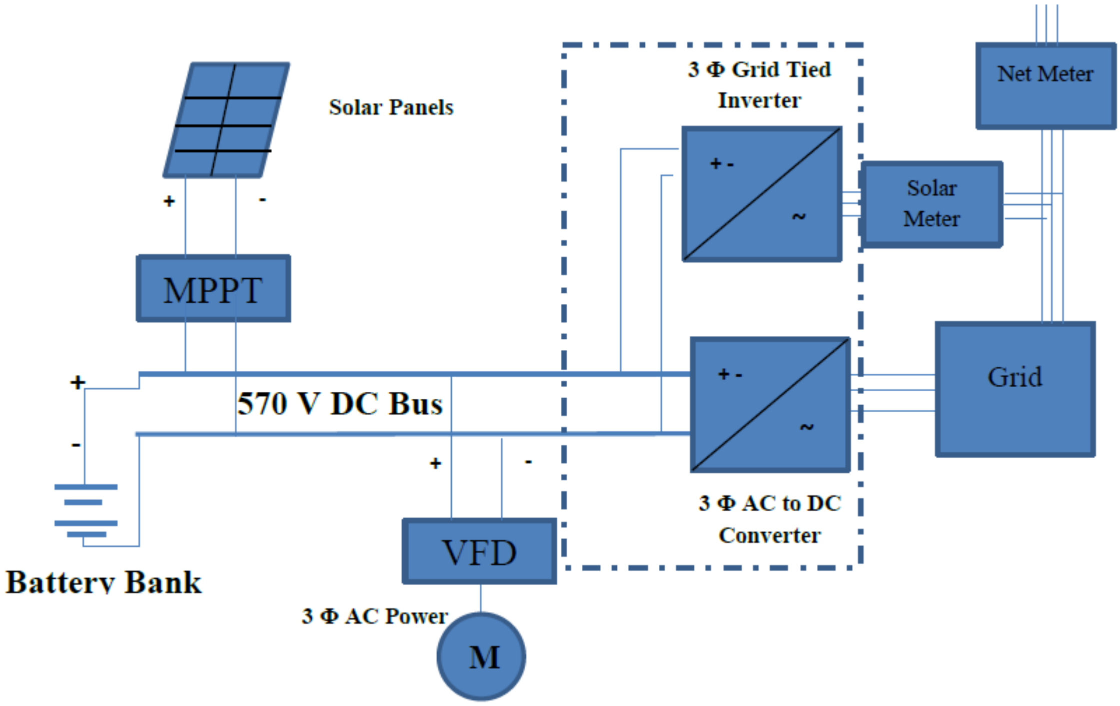


Figure 5.3: Schematic diagram of the components and connections for a grid connected water pumping system with off grid operability.

The 3 phase grid tied inverter and AC-DC rectifier (marked in the dashed line box) can be replaced with a single bidirectinal converter designed to the requirements.

The advantages of the above mentioned system are

1. Even if the grid is not available, the 'need' of the farmer is met through the solar motor drive.
2. Once the water pumping requirement is met, the PV array can be used to feed power to the grid and hence avoiding any wastage of the energy.
3. When there is insufficient solar radiation, the pumps can work smoothly using grid power and the usage from the grid can be compensated using net metering during non-usage hours.
4. The excess power fed to KSEB will be settled with the farmer at APPC rate which 'incentivizes' the farmer to switch off the pump after 'actual use'.
5. The revenue to the farmer from excess production can be used by themselves for PV system maintenance activities.
6. The motor is always soft started by VFD and this enhances the life of the motor, since it avoids inrush current and heating of the stator windings during normal resistive

starters. VFDs with remote operability can also be used, which helps the farmers to remotely run and monitor the pumps.

7. The utilisation factor of the VFD is enhanced, i.e., even while power is drawn from the grid, the VFD is utilised to run the motor.
8. De-segregation of functionalities gives wider choice of component selection, i.e. the farmers can choose from different component manufacturers for different functionalities.
9. Battery bank if provided gives option to operate even during grid failures.
10. Redundant cost on MPPT and DC power conditioning can be limited, if we can find grid tied inverter manufacturers who can provide only the grid feeding section.

The challenges of the above mentioned system are

1. To design and maintain a DC bus at 570 V with multiple power feed in and draw out options, i.e., develop a control system and strategy to synchronise various power sources and sinks.
2. To design a custom made cabinet with adequate safety features and protection and safe control buttons for end user.

5.4 Target Beneficiaries

In order to identify the potential beneficiaries and to ensure that the benefits from the project are judiciously distributed among various farmer co-operatives, a d etailed participative planning and study was conducted in Thrissur-Ponnani Kole region. Initially the project would cater to 9 Kole Samithis in Thrissur and 10 i n Ponnani. The survey team interacted with the secretary of Ponnani Kole Padam Samrakshana Samithi, who is in charge of coordinating all developmental activities in Thrissur-Ponnani Kole region and through him, identified and interacted with the Secretaries and Presidents of all 20 farmer co-operatives. There were 67 pumps with capacities from 7.5 HP to 50 HP identified during the survey, which can be converted to solar driven pumps. While selecting the beneficiaries, the elected representatives of the locality (Members of Legislative Assembly of corresponding constituencies - Ponnani and Kaipamangalam), gram panchayat members and regional agricultural officers were consulted.

Table 5.2 has compiled the roles and responsibilities, cost and benefits of each of the stakeholders of this proposed project.

Table 5.2: Stakeholder analysis of the project.

Stakeholder	**Roles and Responsibility**	**Cost**	**Benefit**
Farmer Societies	• To agree to the installation of PV systems within their paddy field premises. • To co-operate with the implementing agency while installation and for future maintenance of the system	• Loss of nominal amount of land area which would go as the footprint of the PV panel mounting	• Free and reliable electricity for water pumping • Additional income through sales of electricity to the grid
Agricultural Department	• To initiate the project with appropriate fund allocation • To identify and entrust a project implementation agency for detailed engineering, material procurement, installation, commissioning and post commissioning maintenance	• One time investment on solarising the water pumps which otherwise causes recurring expenses	• Free from future expenses on electricity subsidy to farmers in Kole land
Ministry of Power	• To approve connectivity for PV	• Loss of revenue from sales of	• The tariffs for agricultural

and Kerala State Electricity Board	systems installed as a part of solarisation of water pumps • To agree for power purchase and net metering of grid connected PV pumps	electricity to the farmer co-operatives • Cost on improvement of infrastructure to accommodate infirm source of power from PV systems	connections were highly subsidised and in fact the sales to this sector was a loss making process for KSEB.
Project Implementation Agency.	• To design, install, maintain PV driven pumping systems in Kole lands using the funds allotted by the government	• Additional manpower and training, skill development costs • Purchase and maintenance of tools and equipment for design, installation and maintenance of PV systems	• Project management and service charges

All the above mentioned beneficiaries were consulted and briefed about their roles, responsibilities and cost-benefits while conceiving this project and all are quite positive in their approach to involve in this innovative initiative. RAIDCO proposed themselves as the implementation agency in this project.

It was proposed that the total project will be funded by the Department of Agriculture and RKVY (Rashtriya Krishi Vikas Yojana, a central government scheme to promote agriculture based projects in the country through joint funding from state and central governments). The cost sharing from the end user or beneficiary, the farmers, is the space they are providing towards the installation of PV modules. Cost recovery can be through the savings of the electricity expenses.

5.5 Economic Viability

Initially the project was envisaged to cover 67 motor pumps in the region. Table 5.3 shows the total cost involved for the conversion of 67 pumps into solar driven pumps. Table 5.4 shows the detailed cost for conversion of one 50 HP pump to solar driven system. Costs involved for conversion of other capacity pumps from 7.5 HP onwards are given in Annexure VII.

Table 5.3: Cost involved in converting 67 water pumps of varying capacities to solar driven pumps [105].

Pumping System Power Rating (HP)	**Direct Cost Including Material Supply, Installation & Commissioning (Rs)**	**Direct Cost Including KSEB Application Fees, Electrical Inspectorate Fees etc. (Rs)**	**No. of Pumps in Thrissur-Ponnani Region Considered Under the Project**	**Total Direct Cost (Rs)**
7.5	9,69,778	9,84,278	1	9,84,278
10	10,48,199	10,65,199	17	1,81,08,383
15	14,36,054	14,61,054	3	43,83,162
20	18,42,108	18,72,108	2	37,44,216
30	26,18,397	26,58,397	9	2,39,25,573
40	36,34,836	36,86,836	3	1,10,60,508
50	44,27,333	44,89,333	32	14,36,58,656
Total	**2252.5 HP**			**20,58,64,776**
	Indirect costs including project management costs, administrative overheads, insurance, tools and equipments, vehicles, and contingency charges			4,36,99,646
	Total Project Cost			**24,95,64,646**

Table 5.4: Design details and indicative costing for a 50 HP PV driven and grid tied water pumping system.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9,520	/module	148	14,08,960
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	10	10,00,000
3	VFD controller	50 HP, variable frequency drive controller for existing AC motors, with 4 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	2,60,100	/controller	1	2,60,100
4	Grid tied PV inverter	20 kW, 3 phase	2,18,650	/inverter	2	4,37,300
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	10	10,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30,000	/housing (including civil work)	1	30,000
7	DC wiring	1C, 6 sq.mm solar DC cable	50	/m	310	15,500
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter)	170	/m	155	26,350
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	10	900

10	AC wiring	4 Core x 16 s q.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel - for 25 kW inverter	475	/m	74	35,150
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	91,712	/housing (depends on HP rating also)	1	91,712
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14,000
		GI earthing strip for structure and panel frame earthing	70	/m	155	10,850
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	30	/m	30	900
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	10	25,000
14	Miscellaneous	Lights, sign boards etc.				1000
15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour	2000	/pole	10	20,000
	Total					**43,77,722**

Table 5.5: Electricity expenses for water pumps in Kole lands, borne by the government.

Sl. No.	Pumping System Power Rating (HP)	No. of Pumps to be Solarized in Thrissur-Ponnani Kole Lands	Total Yearly Energy Consumption/ per Year (kWh)	Expenses to Government per Year (Rs. 5.87/ kWh) [35]
1	7.5	1	14,099	82,761
2	10	17	3,19,586	18,75,970
3	15	3	84,596	4,96,579
4	20	2	75,197	4,41,406
5	30	9	5,07,578	29,79,483
6	40	3	2,25,590	13,24,213
7	50	32	30,07,872	1,76,56,209
Total			**42,34,520**	**2,48,56,621**

Table 5.5 shows the annual energy consumption and the annual expense incurred to the government's agriculture department for supporting the operation of conventional dewatering pumps. Considering this fact, it can be seen that the simple payback period of this project is around 10 years (**24,96,00,000/2,48,56,621**). Even when we assume if the project can be funded by a development financing organisation at 5% interest and for a tenure of 10 years, the Levelized Cost of Electricity (LCOE) of one kWh of electricity comes to around Rs. 5.38 at an IRR of 6.9% (see Annexure VIII). CAPEX required per kW_p is taken as Rs. 110 /W (2.25 MW_p of solar PV will be installed at an expense of 24.96 crores) considering the direct costs on material, redundant cost of power converters and expensive civil work for installation in the farm lands.

Other assumptions while calculating the LCOE:

1. O&M charges: 1% of the CAPEX per year with 1.5% escalations per year. This is reasonable since there is already an electrician attached to each Kole padavu and incremental cost of maintenance is minimal. Only major activity is to clean the modules and water availability in this region is quite good.

2. Cost per kW : 1,10,00 – This might seem to be on a higher side, but considering the high cost of civil work in the given site condition and the redundant cost on ' power converter' which is required to ensure smooth working of pumps (both grid tied inverter and VFD are used).

3. Grid cost escalation: 4% per year.

4. PV plant life: 25 years.

5. PV generation: 1450 kWh/kW_p/year. Degradation in power output of the panels at 1% per year is assumed and the degradation in the first year after installation is expected to be at 1.5%.

The calculations show that the project is economically viable and if the government can raise funds from external development funding agencies at low interest rates, it can be financially well planned. The project can also make paddy cultivation a less energy intensive activity. The total area under wetland paddy cultivation in Kerala as per state planning board is 1.71 l akh hectare [106]. A study by Kerala Agriculture University reports that 1.57 HP/hectare is the required installed pump capacity in Kole lands. The energy usage is 295 kWh/hectare per season [104]. Even if we consider the Kole lands of Thrissur-Ponnani area and Kuttanad in Alappuzha (52,000 hectare [104]), the potential energy saving is close to 20 million kWh a year.

5.6 Conclusions

Potential for solar based water pumping is huge in the agriculture sector, especially in the wet land paddy cultivation areas in Kerala. High capacity inefficient water pumps run with completely subsidised electricity can be replaced with 'grid connected' solar water pumps, and it can bring down the recurring public expenses in agriculture sector.

The next chapter now looks into some of the past experiences of dissemination of PV projects in the state. Thus attempts to understand the success, failures and shortcomings in various approaches for popularising rooftop PV systems.

Chapter 6

Rooftop PV Systems in Kerala – Outcomes from the Past Schemes and Projects

Having understood the immense potential for rooftop and distributed PV systems in Kerala from the previous chapters, this chapter looks into some of the past attempts in Kerala to disseminate PV technology. Various projects, the approaches, strategies adopted, and their outcomes are analyzed based on secondary data available in public domain and through firsthand information collected through site surveys, interviews, focus group discussions and other research methodologies.

The earliest scaled attempt from the government to promote rooftop PV systems in Kerala is through ANERT (Agency for Non-conventional Energy and Rural Technology) dating back to year 2012 through their "10,000 Rooftop Power Plant Program". The details of this scheme and the ones which followed in the later years are discussed in this chapter. Another important section of this chapter is the case study looking into the details of implementation of a grid connected community rooftop PV project in a tribal hamlet in Palakkad district, Kerala. The outcomes of the attempts to implement the projects and schemes discussed in chapters 3 to 5, i.e., the 'Solar Panchayat', and 'Peak Load Shifter' and 'Grid Connected Water Pumping' are also discussed in this chapter.

6.1 Rooftop PV Programs by ANERT: Packages, Schemes and the Response from the Public

Agency for Non-conventional Energy and Rural Technology (ANERT) is the nodal agency which implements the programs of the Ministry of New and Renewable Energy (MNRE) of the Government of India in Kerala. ANERT is responsible for executing all major government schemes related to renewable energy in Kerala. There were two major schemes executed by ANERT in Kerala for promoting rooftop PV. The first one was the "10,000 Rooftop Power Plant Program 2012-13" which promoted off-grid solar systems on residential buildings [107]. The scheme offered 1 kW_p PV modules, 1 kVA power conditioning unit (PCU) and 7200 Wh battery storage as a package, to 10,000 domestic consumers. ANERT identified and empaneled 25 system integrator companies for executing this project through transparent processes. The details of components used in the projects and the cost details of the packages offered by each of these companies were available in public domain. Customers could select an empaneled company and award their work to them. The cost of the systems ranged from Rs. 1,70,541 to Rs. 1,89,309. ANERT provided a subsidy of Rs. 92,262 (Rs. 53,262 from MNRE funds and Rs. 39,000 from Govt. of Kerala's funds) on each of these systems. So the customer had to pay around Rs. 78,000 to 97000 for owning a system. The project continued till October 2013 and 953 systems were successfully installed [108]. Later in 2015, the project was concluded with 5623 installations completed successfully, which is 56% of the target [109].

The second major scheme was the "Solar Connect 2014-15" which promoted grid connected rooftop PV systems of sizes varying from 2 kW_p to 50 kW_p [110]. Individuals, commercial establishments, industries and all categories of consumers could be beneficiaries of this scheme. The process of empanelling system integrators, approval of components to be used in the projects and the pricing mechanism was similar to that of the previous scheme. For smaller systems (1 – 5 kW_p capacity), prices ranged between Rs. 86,120 per kW_p to Rs.1,10,000 per kW_p. For system sizes between 10 to 30 kW_p the prices were in the range of Rs. 73,712 to Rs. 93,300 per kW_p. Larger systems (40 and 50 kW_p) were priced between Rs.

73,653 to Rs. 82,340 per kW_p. 26.6% of the project cost was provided as subsidy under Central Financial Assistance (CFA) scheme of MNRE and another Rs.10,000/kW_p was provided as subsidy from state funds. In effect the end user had to pay around Rs. 56,185/ kW_p for smaller systems and Rs. 41,450/ kW_p for larger systems. 850 systems were allotted to different empanelled agencies till January 2016 and the implementation of these systems were continuing even in January 2018 [111].

As it happens in every other state utility company, KSEB also resort to cross subsidies to support lower tariff rates to domestic and agriculture sector consumers. Also, KSEB charges the domestic consumers for their energy usage through a slabbed tariff structure. Table 6.1, columns 1 and 2 shows the different tariff slabs, and associated pricing of electricity for domestic consumers in effect during 2014-2015. Tariff slabs are defined based on the total monthly energy consumption of a consumer. Average cost for KSEB to deliver 1 kWh of electricity at the customer end was around Rs. 4.64 during 2014-2015 [36]. Column 3 in Table 6.1 shows the average price of 1 kWh 'recovered' from a domestic consumer or the 'cost realisation' value. It can be noted that only those consumers who consumes more than 250 kWh a month really helps KSEB to recover their cost. Similarly almost all commercial and industrial consumers are paying above the actual cost of Rs. 4.64 [76]. So whenever domestic consumers of higher tariff slabs or consumers from industrial and commercial segments adopts solar PV systems, KSEB loses revenue and it becomes more and more difficult for them to manage the cross subsidies. With this backdrop, we have tried to analyse the implementation level efficacy and impact of "Solar Connect 2014-15" scheme in the power sector of Kerala.

6.1.1 Drawbacks of the Past Schemes and Need for an Alternate Model

There were 850 beneficiaries for the "Solar Connect" programme. 30% of them were selected as samples (260 numbers) and their electricity bills were analysed. Table 6.1 shows the slab wise split up of domestic consumers who were in the beneficiary list of subsidy scheme. Column 4 shows the number of consumers in each slab that availed capital subsidy through the "Solar Connect" scheme. The data was collected from the KSEB's billing server and using the beneficiary details of the scheme published in ANERT's website [112, 113].

After further analysis, it was found that almost 50% of the beneficiaries were industrial or commercial consumers. 131 out of the 260 samples were domestic users. Again, within the domestic consumers, 44% of the consumers were those who consume above 250 kWh/month. This means among the beneficiaries who availed capital subsidy from the government (30% from MNRE funds and 20% from state government funds), almost 72% were those who contributed to recovery or over recovery of KSEB's actual cost. Now all of them have moved into subsidised tariff slabs. This shows the ineffectiveness in using public money resulting in further loss of public sector revenue.

Table 6.1: Tariff slabs, cost realisation and tariff applicable for domestic consumers of KSEB during 2014-2015 [36].

Tariff Slab (kWh Consumed per Month)	**Tariff Levied (Rs/kWh)**	**Realisation of Cost (Rs/kWh)**	**Number of Domestic Consumers who Availed Subsidy in "Solar Connect 2014-15" Programme**	**Average Size of PV Plant Installed (kW_p)**
0-40	1.50	1.50	3	5
0-50	2.80	2.80	0	0
51-100	3.20	2.94	11	4
101-150	4.20	3.24	20	5
151-200	5.80	3.75	28	5
201-250	7.00	4.34	12	4
251-300	5.00	5.00	13	3
301-350	5.70	5.70	6	4
351-400	6.10	6.10	8	5
401-500	6.70	6.70	9	6
Above 500	7.50	7.50	21	7

Another concern regarding the above mentioned projects is the 'non-inclusiveness' of the scheme. The study by Kuthanazhi *et al.* [114] also gave the statistics of the ownership pattern of different home appliances at various households belonging to different tariff slabs. It was clear from the numbers that the number of home appliances and the probability for the presence of expensive appliances increased in households with respect to increase in electricity consumption. Hence the monthly energy consumption and the tariff slabs are a strong indicator of the ‘economic wellbeing’ of the households. Even after capital subsidies, the above mentioned projects required an investment of close to one lakh rupees, which would require a monthly pay out of Rs. 2225 for 5 years. This would be quite unaffordable for a common man. According to the statistics the average annual per capita income in Kerala is around Rs. 1,72,268 /year [115]. Also only 10% people in Kerala have a monthly mean per capita expenditure of above Rs. 4000 [116, 117]. Hence typically the economically well off upper middle class society who can afford to pay one lakh upfront or who has access to ‘banks and other financial mechanisms’ for owning PV systems is who largely gets benefited through the capital subsidy schemes. Higher adoption rate of the scheme by households in higher tariff slabs is an indicator of this fact. There has to be alternate dissemination models to reach the lesser privileged strata of the society and make PV an inclusive technology.

6.1.2 Implementation Status of Projects

A comparison between the average consumption and current consumption of energy from the bills can indicate that the PV system has been installed or not in the premises of the customer. Most of the projects were at a stage of ‘feasibility report submission’ during December 2015. Considering the implementation timeline of 90 days as per the ANERT guidelines and a further time delay in installation of net meter (expected to be another 3 – 4 months), the tentative project completion date is around June 2016. The average bill values are updated in January and in July (refer Figure 6.1). So even if the PV system started working in June, its reflection in the average consumption might not be seen in the bills. So whenever there is a considerable difference in average and current consumption, it can be linked with a successful project completion at that beneficiary site. With this logic, analysis was done on the completion rate of projects within domestic consumers. The project completion had happened with only 21% of the beneficiaries. This shows the administrative delays and implementation difficulties in the domestic sector.

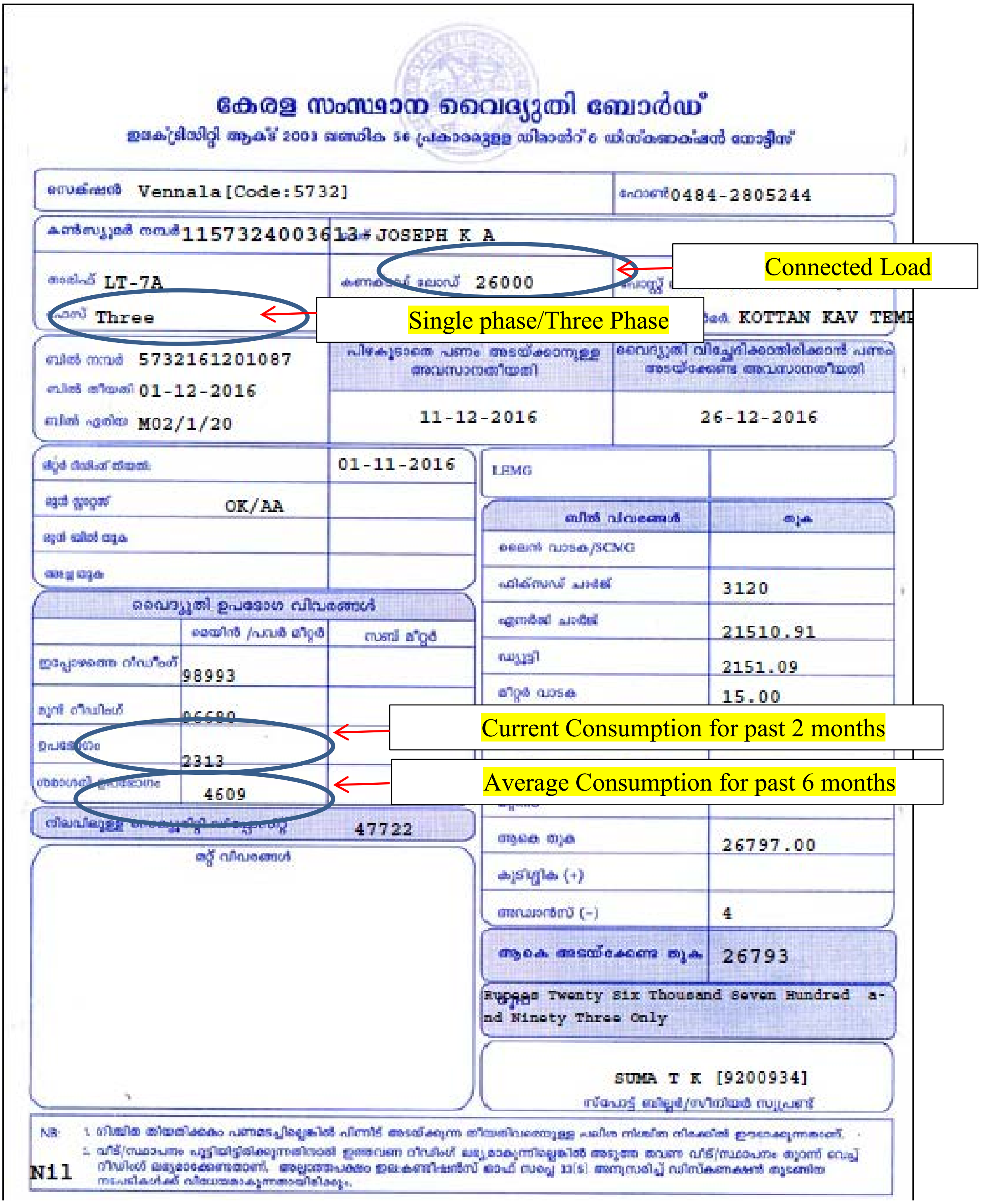


Figure 6.1: Example of a bimonthly bill issued by KSEB. Information relevant for the analysis presented in this chapter are highlighted.

In spite of the inability to complete and commission the target number of installations in the previous schemes in a time bound m anner, ANERT had continued with annual schemes in grid connected and off-grid PV power plants in the years 2016-17 and 2017-18. The grid connected PV project scheme was named as 'Solar Connect' and the off-grid schemes were names as 'Solar Smart'. The process of empanelment of components, system integrators and publishing the price list of packages has definitely helped in bringing in some transparency and healthy competition in rooftop PV sector in Kerala. The reasons behind the delays in implementation of the projects need to be studied and understood before further schemes are planned and executed.

6.1.3 Delay in Subsidy Disbursement

In order to make it convenient for the customer, the payment terms of the rooftop PV packages were in such a way that the customer had to pay only the amount after the subsidy is discounted from the system cost. The subsidy amount was later disbursed to the system integrator companies. It was understood from the system integrators that there was undue delay in the release of subsidy amount [118, 119]. This puts the system integrators under financial stress and operational difficulties. Based on their representations and complaints in ANERT, the 2018-19 scheme announced in October 2018 has made it c lear that in the upcoming scheme, the subsidy amount will be credited directly to the beneficiary account. The customer has to pay the full amount to the system integrator.

6.1.4 Lack of Post Installation Performance Evaluation

One of the major objectives of pilot projects in any technology dissemination program is to generate primary data on the performance of that technology in the field and to get the feedbacks from the customers. Even after rolling out four schemes in Kerala during the years 2012-18, ANERT has not come up with any report on the performance of the PV plants. Even though it was mentioned in the policy documents of the programs, that the beneficiary should allow the visit and evaluation of the performance of the PV plants by ANERT officers, no such performance evaluation studies have been undertaken so far. If a performance report of the PV plants at various geographic locations, and installed by various system integrators can be made available in public, it can help the customers to make more informed decisions on the adoption of PV systems and appropriate system integrator.

6.2 Chendamangalam Solar Panchayat Project

As discussed in section 4.1 of this thesis, C – DIT, in association with IIT Bombay had undertaken a study of rooftop PV potential of Chandamangalam panchayat. After the completion of the survey in January 2013, a detailed report on t he potential and implementation strategies which can be adopted for solar panchayat project was released on 4th December 2013. The event was attended by members of state planning board, energy sector experts, principal secretary for LSG department, chairman of Kerala State Electricity Board, representatives from PV industry associations, and other stakeholders. It was decided during the event that the project shall kick off with the implementation of a few PV systems in the government offices in the panchayat. Unfortunately, none of the organisations involved in the survey and study took ownership of this project and there were no continued efforts to take this proposal into implementation.

6.3 Results of Implementation of Peak Load Shifter Project

We had already discussed about KSEB's efforts in introducing smart solar inverters among their domestic consumers, with an intention to reduce the peak demand, in section 4.2 of this thesis. As a response to the Expression of Interest (EoI) invited by KSEB to come up with products with technical and functional requirement as discussed in section 3.3.4 (see Annexure V), 14 system integrators submitted their products to KSEB. The products were sent for testing to the Department of Electrical Engineering, College of Engineering, Thiruvananthapuram. Products from seven out of these 14 companies qualified in the testing procedure. They were empanelled by KSEB as partner institutions in the PLS project implementation. After lab testing, the prototypes were installed for a month in a few houses in Cantonment section. It was found the system could save 1 to 1.5 kWh a day.

The Sun Shift Project was officially launched on 3rd March 2015 with 7 "Empanelled Vendors". The price details and technical details of the package were published in KSEB's official website (refer Figure 6.2). Instead of channelizing the capital subsidy to the cost of SEE equipments, the implementation scheme resorted to upfront distribution of subsidy as cash discount. The cost of the kit from various empanelled vendors varied from Rs. 43,000 to Rs. 53,000. Capital subsidy of Rs. 5000 was offered to the first 2750 consumers registering for the scheme.

The response from the consumers was not very exciting. Only 17 people registered in the program and availed subsidy in the first 6 months of programme [120]. There may be various reasons for the mild response from the public. Another parallel programme was being run by ANERT (10,000 rooftop program) which offered 1 kW off grid system for less than Rs. 1,00,000. So those people who could really afford for Rs. 53,000 for a PLS kit might have been attracted to this scheme. Another programme run by ANERT offered 1 kW grid tied systems for less than Rs.80,000. These two programs may be the major reason people were not involving in the sun shift programme. Lack of EMI schemes can also be stated as a reason.

Figure 6.2: KSEB official web site home page showing the link to the details of 'Sunshift' project.

6.4 Grid Connected Solar Water Pumping Systems in Kole Lands of Kerala: Project Status

The Detailed Project Report (DPR) for solarizing 67 conventional 'Petti and Para' water pumping systems was prepared and submitted to the Project Planning and Monitoring (PPM) cell of the Department of Agriculture, Government of Kerala on 8th September 2017 by RAIDCO Kerala Ltd., a co-operative sector company in Kerala. The department then studied the same and had reverted that the project can be funded through Rashtriya Krishi Vikas Yojana (RKVY), a Central Government scheme to promote agriculture based projects in the country through joint funding from State and Central Governments. It was proposed by PPM cell that, out of the total Rs. 24.9 crore requirements, the Central Government would contribute Rs. 20 crore and the remaining would be funded by the state. The proposal was later presented to a state level selection committee headed by the Principal Secretary for the Department of Agriculture on 19th December 2017. The committee suggested a few modifications on the proposal and demanded a certification from the Director of Agriculture Department and was asked to be resubmitted. The DPR with appropriate modifications was resubmitted to PPM cell on 1st of March 2018. Thereafter there was no progress reported on the project proposal. The Department of Agriculture was also not able to find fund allocation of Rs. 4.9 crore as the contribution from the state [121].

However, RAIDCO succeeded in getting a grant of Rs. 1.15 crore from ANERT to implement two 50 HP Petti and Para based pumping projects using PV power, one in Thrissur and one in Ponnani Kole. The development of a 50 HP VFD for driving the high power capacity motors and the installation of these systems is planned to be finished by January 2019 [121]. It is also worth to mention that the Minister for Agriculture in Kerala had announced the intention of the Government to go ahead with this project in one of the question and answers sessions in the legislative assembly [122].

6.5 Community Based Rooftop PV Systems – Challenges in Replicability

Based on the findings from the surveys in Chendamangalam and Thiruvananthapuram, which are discussed in chapter 4 of this thesis, one of the major strategies proposed for dissemination of rooftop PV systems was to promote community based or collective rooftop PV systems. Pooling a group of consumers under similar category and based on their collective rooftop availability and consumption statistics, it was proposed that a community rooftop PV system could be implemented. In this section of the thesis, the details of a community rooftop PV system implemented in Chalayoor tribal hamlet in Palakkad district of Kerala are presented. The general challenges in designing, implementing, maintaining and replicating community based rooftop PV projects are examined in the light of the findings from this case study.

Community based solar PV systems are generally systems owned and operated by a community for meeting some of their common electricity needs. The needs can be home lighting, street lighting, irrigation, drinking water supply, cold storage and other similar applications [123]. Most of the early community based PV installations in India were off-grid or micro grid based systems implemented as a part of rural electrification programmes by Central or State government agencies and voluntary organisations. Techno-economic comparison studies have proven that community based solar micro-grids are better solutions for rural electrification programs when compared to individually owned solar home lighting systems (SHS) [124]. In terms of ease of design, operational and component efficiencies, range of applications and loads that can be supported, community based micro grid projects were found better than SHSs. For institutionalising operation and maintenance activities and for availing financial credit facilities, micro grids were better option than individual home lighting systems. One of the earliest examples for community based PV system in India is the Kamalpur solar hybrid plant in Sagar Island, Sunderbans [125]. The system is operational since 1996 and is a part of the solar-hybrid mini-grid projects installed by the West Bengal Renewable Energy Development Agency (WBREDA). Due to the increasing demand (loads), overuse of electricity and growing aspirations of the people to get connected to the national grid and avail 24 hours uninterrupted electricity, community micro grids are also becoming less preferable nowadays.

A new dimension to rooftop PV projects came into existence in India with the advent of Gandhinagar Solar Rooftop Program by the Gujarat Energy Development Authority (GEDA). The project which started in 2012 with a target of installing 5 MW of distributed rooftop PV systems in the city of Gandhinagar, Gujarat completed successfully in 2016 with a cumulative installation of 4688 kW across 38 government buildings and 274 residential buildings [126]. The concept of 'leased rooftops' was introduced in this project where the owners of a building can lease out their rooftops to a third party independent power producer (IPP). This IPP will install PV systems at their expense on the leased rooftops and sell it to the grid at a predetermined tariff. The owner of the building would receive a certain share of the tariff as 'lease' for the rooftop from the IPP. So a new model of 'grid connected community based rooftop systems' came into existence where a group of rooftop owners, mostly domestic consumers of a housing complex, come together and lease their rooftops to IPPs. After the success of the Gandhinagar project, Government of Gujarat (GoG) has initiated similar projects in 5 other cities in Gujarat [127]. Similar project are expected to come up in other parts of the country as well through the smart cities initiative by the Government of India [128].

An attempt was made by the Government of Kerala to replicate similar 'community based grid connected solar rooftop systems' in one of the tribal hamlets in Attappadi, a remote village in Palakkad district. This is in contrast to the attempts by many other state governments who plan for 'smart cities'.

6.5.1 Chalayoor Tribal Hamlet: Test Bed for Community Based Rooftop PV Model

The Chalayoor hamlet of Attappady administrative block, Palakkad district, Kerala is situated in the eastward slopes of Western Ghats at latitude of 11° North and longitude of 76° East. The hamlet consists of 83 tribal households. Most of the inhabitants are casual labourers or farmers and a typical family is of 5 members. The locality is connected to KSEB's distribution grid and the grid availability is fairly good throughout the year. The nearest office of the KSEB is located at a distance of 20 km from the hamlet. This village was identified as a potential site for trying out the feasibility of community based rooftop PV systems by KSEB's 'Innovation Team' in January 2014. KSEB's Innovation Team is responsible for conceiving and implementing innovative projects in the areas of renewable energy and energy conservation utilising the government funds available to them. The project was meant to uplift the status of tribal households from just energy consumers to that of energy producers, thereby to enable the tribal hamlets to be self-sufficient in terms of energy. Out of the 83 households, only 65 were electrified and all of them were using less than 150 kW h a month. Hence, through this trial project, KSEB wanted to extend the advantages of rooftop PV systems to the customers in the lower 'non-lucrative' tariff slabs and solve twin issues of 'non-inclusiveness' of PV as well as 'revenue-losses' from lower slab customers. Sections 6.5.2 to 6.5.5 of this thesis presents the findings from the evaluation of the project with respect to its technical design and performance, costing and economics, and social impact. Major points to be taken into consideration while replicating similar projects in other tribal hamlets in future are also discussed.

6.5.2 Objectives of the Case Study

This case study of grid connected community rooftop system in Chalayoor had mainly four objectives.

- To understand the acceptance of community based rooftop solar project within tribal communities and analyse the advantages and disadvantages of such an implementation model.
- To perform an energy yield analysis, techno-economic and social impact evaluation of the power plant.
- To understand the perspectives and feedbacks of various stakeholders of this project.
- To study the scope for replicability of similar projects in other hamlets and to understand areas where there is scope for improvement while replication.

6.5.3 Evaluation of the Project

This section explains about the observations, findings and analysis of data collected from the field activities at Chalayoor. Technical details of the plant and its performance along with the cost involved and economic viability are discussed here.

Plant Details

It is a 96 kW_p grid tied installation. The system size of 96 kW_p was decided based on the consumption data of the households in this locality. There are 83 numbers of houses in this tribal hamlet, out of which 65 are supplied power by KSEB. The collective consumption of these 65 households per month is around 8,500 kWh. Kerala State Electricity Regulatory Commission (arm of the government which makes laws and regulations for the state's power sector) has made legal provisions for generating and exporting excess power from rooftop PV power plants to the service providing power utility company (in this case KSEB). This regulation provides a facility called 'net metering' to the rooftop PV system owners [59]. In this metering arrangement, whoever installs a rooftop grid connected PV system; their existing energy meter will be replaced by a new bi-directional meter, which can account for flow of energy in both directions. i.e. from within the consumer premises to the grid and vice versa. Whenever the PV generation is less than the local loads from the premises, the additional energy is drawn from the grid. Whenever PV production is excess, it is pumped into the grid. The customers who produce more energy than what they consume in a month will be exempted from bill payment in that month and the excess energy produced will be carried forward for adjustment in the next month. Even after a year of billing cycle, if the consumers have some excess energy banked with the utility, they will be paid a fixed amount per kWh of excess energy pumped into the grid. This amount is called as 'feed in tariff'.

Based on the climatic conditions of Chalayoor, feasibility study conducted by KSEB Innovation Team found that a 70 kW_p system was sufficient to generate 8,500 kWh a month. Hence to compensate 8500 units using 'net metering', and to offer the roof owners some revenue as 'roof rent', a cumulative system size of 100 kW_p was initially decided. Whatever feed in tariff received for excess generation by the additional 30 kW_p was planned to be given as 'roof rent' for the tribal community and this also would help them to meet the operational expenses of the plant. The cumulative size 100 kW_p was planned to be realised through five separate system of 20 kW_p each. But due to lack of suitable roof space, only 96 kW_p modules were able to be placed on various roofs. The 3 phase AC supply from each of these 5 systems were combined at an AC combiner box and fed into 11 kV transmission line using a 415V /11 kV transformer.

Figure 6.3: Satellite view of Chalayoor hamlet with the rooftop PV systems.

Implementation Model

The initial conceptualisation and feasibility study for this project was done by innovation team, KSEB. Later they came up with the DPR and tender documents for implementing this project. The tender was released in December 2014 and they didn't receive any Expression of Interest (EoI) from companies. Finally, the work was awarded to M/s KELTRON (Kerala State Electronic Development Corporation), a Government of Kerala undertaking company. The financial support for this was given by KSEB through their innovation funds and through 'tribal welfare funds' from the state government. Other than the EPC (Engineering Procurement and Construction) and funding, the project also needed some level of social engineering required to take into confidence, the tribal community of the region. This task of facilitating the project implementation through mobilizing local community was done by 'Kudumbashree' (local women self-help groups formed as a part of National Rural Livelihood Mission). The major stakeholders in the project and their roles are explained below:

- *KSEB*: Initiated technical feasibility study and partially funded the project.
- *KELTRON*: Execution of the work at site and future maintenance.
- *Kudumbashree* (Women Self-Help Groups): Facilitator for local acceptance, participatory planning.

- *Govt. of Kerala*: Funded the project through its Tribal Development Fund.
- *Tribal Community:* "Supposed to be" given electricity free of cost for leasing out their rooftops to KSEB.

Since it is a grid connected system (with no battery), to ensure maximum yield, KSEB has to ensure grid supply all through the day. Since they themselves have invested on this project, and since they would like to recover their cost at the earliest, it was expected that the grid availability would be continuously monitored over internet by KSEB/KELTRON and this would reduce the number of and duration of power outages in this region. Instead of putting 1-2 kW_p systems (as proposed in DPR by 'Innovation Team'), KELTRON has installed larger systems of 20-25 kW_p to reduce the costs of the system. The additional roof structure with the panels on top of the houses (see Figure 6.3) prevents excess heating of roof during summer and also addresses water leakage problems during monsoon.

Technical Design and Performance

Design: The design seems to be good. The modules are kept south facing at an optimal angle of 12°. Modules were IEC61215 certified and the inverters also having relevant quality and safety certificates (IEC61727, IEC 62116, IEC60068, and IEC61683). Initial idea was to install 400 numbers of 250 W_p panels and a cumulative capacity of 100 kWp. Due to design constraints, only 384 modules could be installed. 5 numbers of 20 kW inverters were used. It is a good practice to keep the DC to AC ratio of a power plant above unity [129]. But in this case, it is below 1.

Layout and Safety: The project developer (M/s KELTRON) tried to form clusters of houses where they can install a single large system over the rooftop, sizing between 20-30 kW_p instead of installing 2-3 kW_p systems on individual roofs. In the process, they have routed cables and power lines through the individual household (see Figure 6.4) premise which has created trouble for the home owners and restricts their free movement in their own premises.

Figure 6.4: Power lines drawn through private spaces causing safety risks and hindering free movement of inhabitants.

Generation: The expected yield from the system (from September 2015 to May 2016) was around 69853 kWh, but the actual yield was only 59640 kWh. The possible reasons for under generation can be high grid failure rates, failure of inverters, module degradation or shading. Figure 6.5 show the generation data from the plant on a clear sunny day. The production was as high as 503 kWh, which is 25% more than the expected daily average generation of 400 kWh. The data is an indication towards the good condition of inverters and PV modules. Energy production is good whenever there is good irradiance and grid connection. Similarly Figure 6.6 shows the daily generation data for the month of February 2016. Daily generation values almost consistently touches the expected generation of 400 kWh/day in the favourable climatic conditions and due to grid availability.

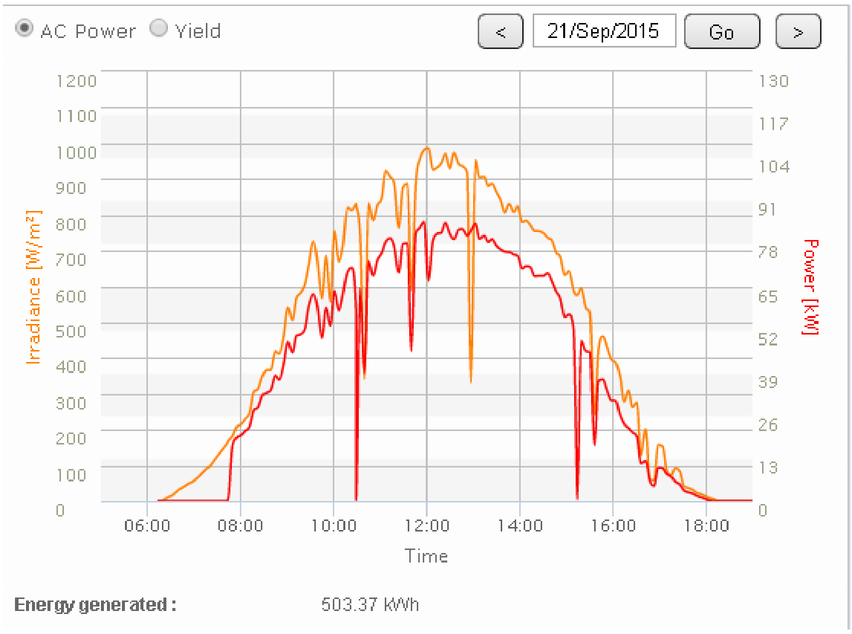


Figure 6.5: Full day data of irradiance v/s generation on 21st September 2015 [130].

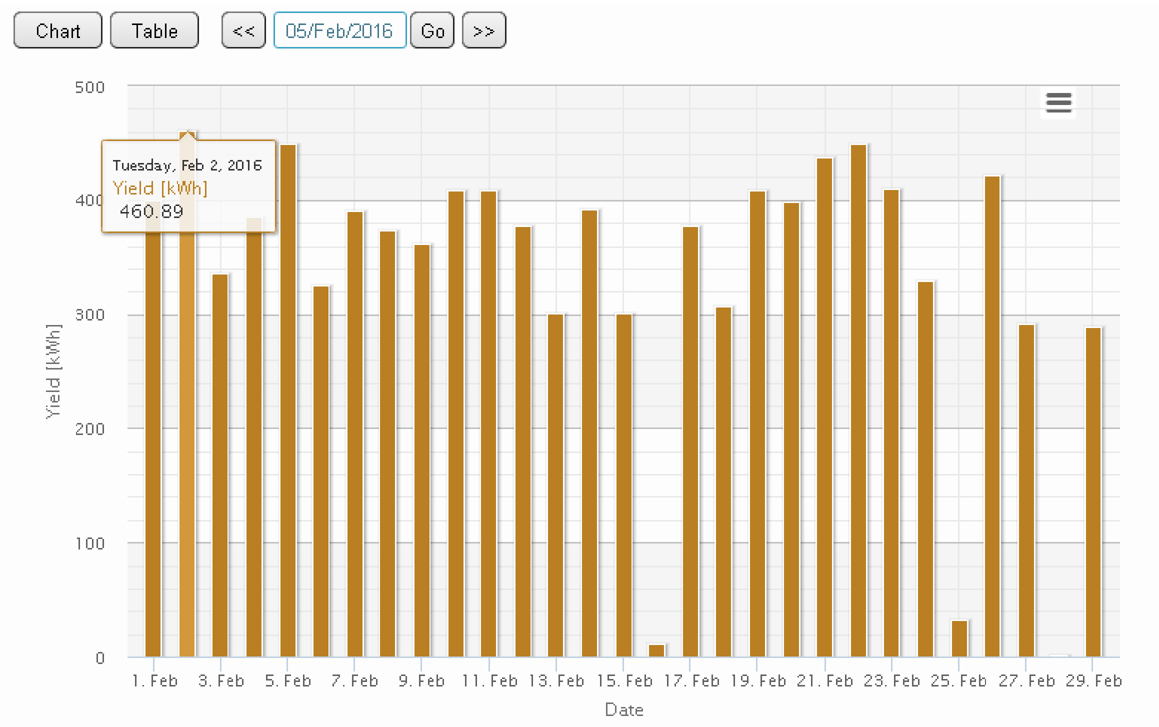


Figure 6.6: Daily energy yield from the 96 kW_p power plant for the month of February 2016 [130].

Table 6.2: Bimonthly generation from the solar plant and consumption in the tribal hamlet [131].

Month	Energy Generated from the SPV Plant (kWh)	Total Energy Generated for the Bimonthly Billing Period (kWh)	Billing Period	Bimonthly Energy Consumption of Consumers in the Hamlet (kWh)
Sep-15	6579	**11620**	09/2015 to 10/2015	**4113**
Oct-15	5041			
Nov-15	6794	**16197**	11/2015 to 12/2015	**5420**
Dec-15	9403			
Jan-16	8968	**18808**	01/2016 to 02/2016	**4482**
Feb-16	9840			
Mar-16	4660	**6000**	03/2016 to 04/2016	**4864**
Apr-16	1340			

Table 6.2 shows that in spite of the frequent grid failure issues, the total generation from the rooftop plant has always been more than the cumulative consumption from the tribal hamlet.

Operation and Maintenance: KELTRON had hired an engineering graduate from the same hamlet for preliminary level of support and maintenance of the system. His scope of work includes:

a) Monitoring the generation from the system at an inverter level.

b) Basic repair of the inverters.

c) Cleaning and maintaining the system.

d) Reporting of errors that cannot be handled locally.

This is a good practise to have local trained manpower for the better performance of the system.

Issue of cleaning: There was no provision for cleaning of modules. There was no access to the modules for cleaning since there were no stairs to reach the roof. There was no spacing between the arrays so that people can move around for cleaning the modules. There was no provision for water supply for cleaning as well.

Economics

The initial investment for the system was Rs.1,20,00,000/. The MNRE bench mark cost for a 96 kW_p system during the time of implementation of this project was Rs. 1,00,00,000 [132]. Hence the project seems to be 20% over priced. This can be justified based on the difficulty of transportation of materials to the project location (hence higher transportation costs) and the additional expense on erecting the false roofs on the cluster of houses. Based on the expected generation values the payback period for the investment is around 14 years, the Levelized Cost of Electricity (LCOE) is Rs. 7.1/kWh. Hence the economics does not seem to be attractive. Considering the fact that the cost per kW of grid tied systems have further come down and MNRE has revised their bench mark price to Rs. 65,000 per kW [75] , the economics should be recalculated while replicating such projects. The new LCOE would be around Rs. 4.62/kWh, which is comparable to KSEB's cost of supply of electricity at the consumer end during the project period (year 2014-2015).

6.5.4 Social Impact

The overall success of the project depends on how well the project was accepted by the end users. In this case, the following reasons have caused dissatisfaction for the tribal community

a) There were still houses which did not have grid connection from KSEB (18 houses) and still their roofs were used for cluster level rooftop PV installation. This led to social issues and the people who did not have grid connection were protesting. Ideally, KSEB should have electrified the entire hamlet first, before they used the roof of the houses for PV installation.
b) Promising free electricity to the tribes has created huge expectation among the people and the promise was never met. This even has affected the relationship between the 'Kudumbashree' co-ordinators and the inhabitants. The execution of previous projects facilitated by Kudumbashree for national livelihood mission was also affected due to this 'breach of trust'.

c) The people were also annoyed by the restriction of their movement and safety risks due to improper laying of power cables.
d) The only person who had tangible benefits from this project in the hamlet was the technician who was employed for maintenance of the system. The technician's family was also alienated by the rest of the community due to the general distress caused to the hamlet by the project.
e) The project was originally planned for the improvement of 'Energy Access' and bring in an 'Energy Autonomy' among the tribal community whereas the final results shows that these goals were only partially achieved.

6.5.5 Scope for Replicability: Findings and Recommendations

The power generation, even though not reaching the expected levels, was definitely higher than the total consumption in the hamlet. The additional revenue expected through the sales of electricity would depend on achieving the actual generation potential from the system. In spite of being a stakeholder and beneficiary of this project, KSEB has not proactively tried to resolve this issue. If necessary, while replicating such projects, the scope for integrating a storage element such as batteries needs to be explored. This would make sure that the system could work on an islanded mode and store the energy generated in batteries during the non-availability of the grid. Additional benefit of such a scheme would be uninterrupted power availability in the hamlet.

The legal ownership of the rooftops and the systems should be clearly stated as with KSEB (or a suitable authority) and should be documented in an agreement with the tribal families involved in the project. Priority should be given to first completely electrify the houses in the hamlet with grid and resolve the local wiring and earth leakage issues, before any initiative for PV system installation is taken.

Even though the technical design and layout of the systems would be custom made and will vary from site to site, a certain set of 'best practices' can be followed throughout the projects. MNRE has released a guide for best practises and the technical standards for grid connected solar rooftop projects [133, 134].

KSEB need to enhance their skilled manpower resources and capabilities to cater to the needs of increasing penetration of grid connected rooftop PV systems in the state. The promises made by KSEB has to be met very soon as the tribal population is not happy about the delay and thus has hampered the harmony between the inhabitants, Kudumbashree, KSEB and KELTRON. The social viability of the project is solely dependent on this part.

Power lines should have been drawn through underground pipes instead of overhead lines. These lines, when passing through private spaces, deny the right to property for the households. There must be a proper provision for cleaning. The panels should be accessible for inspection and cleaning.

The economics and costing of the project should be re-considered in the future projects, since the prices have come down during past 3 years. Rs. 120 / W_p is 20% higher than the then existing MNRE bench mark price and more than double, the present bench mark price of Rs. 55,000/ kW_p [135].

The project implementation strategy needs to be reconsidered and the roles and responsibilities of the stakeholders should be redefined. Unnecessary bureaucratic delays and unfulfilled promises are creating distress among the tribal community. The survey results indicated that 83% households in the hamlet use less than 100 kWh bimonthly. Hence the decision from the government to waive off the energy charges would not affect the revenue of KSEB in a big way, but at the same time can result in a general acceptance among the community. But the consumption above 100 kWh should be charged at a non-subsidised rate.

A new implementation model in which the funds coming in from the tribal welfare department (who otherwise pay for the arrears in bill payment) and the financial matters handled by the Ooru Samithi (local governance mechanism for the tribes) can be considered. Here the role of KSEB shall be to just buy back power and settle the balance amount with the Ooru Samithi. They also should ensure good grid availability. They can help the Ooru Samithi in preparing the technical requirements of the tender document at a nominal consultancy charge. Later the project can be tendered out by the Samithi and invite the best vendor (need not be KELTRON), in consultation with KSEB. Ooru Samithi can also judiciously use the revenue from energy sales for the welfare of the community, meeting future expenses on r epair and also for hiring the technician for maintenance. Being a local institution, they can ensure prompt cleaning of PV modules and other maintenance activities.

6.6 Conclusions

ANERT's existing schemes are not very successful due to inequitable distribution of subsidy, or subsidy money directed to less needy categories of customers. Undue delay in project commissioning due to non-coherent activities of the government departments is also a deterrent factor. The lack of information in public domain about the performance of the PV systems installed during the first three rounds of schemes undertaken by ANERT (during 2012-2017) is a major shortcoming. This leaves out the opportunity to generate more public awareness and confidence about the technology through reference projects.

In spite of having clear plans and guidelines for implementing a panchayat level solar dissemination project, the LSG offices were not able to put that into practice. There can be various reasons, such as inability to raise funds, inability to build local institutions, incapability to technically design, procure components and install systems etc. are some of them. This points to the need for capacity building of LSG offices and need for a well-equipped government or semi-government organisation or department to take ownership of such projects.

Providing better financial mechanisms such as EMIs can help in better adoption rates for rooftop PV systems. Technically and functionally excellent products can be a failure in market, unless they are properly promoted in a sensible way to the customers. Lack of co-ordination between different organisations (ANERT and KSEB) under same government department (Department of Power) for the same end result (propagation of rooftop PV) can result in failure of the schemes targeted towards the common objective.

Joint efforts between the state and central government is required in conceptualising and realising projects with high capital expenditure, such as conversion of 2252 HP pumps into solar powered pumps. But the time delay in getting the sanctions and approvals for such projects and associated funding may take quite a long time (in the case of Kole land project, the process was incomplete after 14 months).

The concept of community based grid connected distributed rooftop PV systems was introduced in Indian cities by early 2012. The same concept was tried out in a rural context or rather a t ribal settlement context by the state government of Kerala. The model was an alternative to the then existed ‘non inclusive’ capital subsidy schemes for disseminating PV. A total of 96 kW_p systems were designed and deployed over the roofs of 83 tribal houses in Chalayoor tribal hamlet and a detailed study was conducted of the model’s technical design, performance, economic viability, implementation model and social impacts. The study brings out the need for participatory planning with multiple stakeholder involvement and need for clarity in terms of liabilities, responsibilities and incentives for each stakeholders associated with the project. Even though the project was technically and economically viable, the social acceptance was not achieved due to the poor layout design leading to flouting of safety norms, lack of clarity and improper distribution of incentives from the project.

The entire work regarding the evaluation of this project, the study methodology and its implementation was planned and executed by myself, along with the support of a graduate student, Mr. Athul. K. Shibu from the ‘Centre for Technology Alternatives for Rural Areas’, IIT Bombay. This work has resulted in a journal publication listed as number 3 in the ‘Publications from Thesis’ at the end of this thesis.

After the case studies of PV projects implemented in Kerala in this chapter, the next chapter details the outcomes and experiences of similar rooftop and distributed PV projects implemented in other parts of India.

Chapter 7

Understanding the Different Models of PV System Ownerships and the Linkages between Ownership, Financial Models, End Use and System Performance

After examining the potential for rooftop and distributed PV systems and the outcomes of various projects and schemes on rooftop PV in Kerala, this chapter focuses on the study of various ownership models, financial models, purposes met by the PV installations and the interlinkage between these various factors. It looks into the influence of these factors on the performance and sustainability of PV systems. This study has helped in understanding which models have been successful and which models have failed in the field. The data collected during the All India Survey of PV Module Reliability executed by the National Centre for Photovoltaic Research and Education (NCPRE) was used for this study [136, 137]. The analysis revealed that the appropriateness in system design, installation, maintenance and hence the performance are influenced by the model of ownership, source of finance, end purpose met by the system and by the social and behavioral aspects of the end users. The insights earned through this study can help in preparing a framework for designing more sustainable methods and schemes for PV dissemination, taking into consideration, the socio economic aspects of the end users. Even though the study considers data from PV systems from all parts of India, its results are very relevant in the Kerala context as well. After this new learning exercise, we may look back at the case studies discussed in chapters 3 to 6 of this thesis and may find out new dimensions for the reasons for the limited success, failures and scope for improvement of past schemes in Kerala.

Another sub section of this chapter discusses the deployability of PV based irrigation systems in a grid connected mode and the case study of community based PV irrigation systems from Dhundi, Anand district, Gujarat. This case study draws a parallel with the grid connected water pumping project for the Kole lands in Kerala, discussed in chapter 5 of this thesis. Hence the review of this project, its achievements and the challenges, can feed into the formulation of a better implementation model for similar projects in Kerala.

7.1 All India Survey of PV Module Reliability

In December 2012, MNRE constituted a "High Powered Task Force" under JNNSM to promote the use of solar PV power in India. The task force was supposed to develop understanding about the possible areas of use of PV in India, available technology and solutions worldwide, and advice the government in matters related to policy making, programmes for deployment, domestic PV manufacturing and working arrangement with power utilities [138]. During one of its meetings, held on 4th March 2013, they entrusted the Solar Energy Centre, Gurgaon (SEC, later renamed as National Institute of Solar Energy) and the National Centre for Photovoltaic Research and Education (NCPRE), IIT Bombay to undertake a national level survey of PV systems installed in India during the past 1 to 30 years. The objective of this survey was to generate valuable data and information about the real performance of PV systems in the field and to understand the degradation modes and degradation rates of output power of the modules. It was also intended to understand the performance of different PV technologies in different climatic zones of India.

In 2013 a team consisting of researchers from both SEC and NCPRE visited 26 different sites in India and inspected 63 PV modules. In 2014, a six member team, three from NISE and three from NCPRE visited 51 sites in six climate zones (see Figure 7.1) of India and inspected 1148 PV modules (majority of them were c-Si modules but there were samples from other technologies like a-Si, CdTe, CIGS and HIT). The team travelled from site to site for three months i.e. from September to November 2014 to complete the survey. Visual inspection of the modules, measurement of I-V (current – voltage) characteristics, infra-red thermography, interconnect continuity test, electroluminescence (EL) imaging, insulation resistance test, measurement of irradiation, measurement of ambient and module temperature etc. were carried out as a part of the survey. There were separate questionnaires and observation sheets for visual observations and electrical measurements, filled at the field during the survey. All these inspections and measurements helped to understand the physical damages and electrical performance degradation of the modules. Other than these measurements, another set of questionnaire which asked for information on the ownership model, source of finance, operation and maintenance practices and other perspective questions of the system owners were also included in the survey. These questions helped to analyse the influence of factors such as ownership, finance, purpose met by the system etc. on the maintenance and performance of the system.

It was later decided by MNRE that such surveys may be executed every two years by the same institutions and as a result, there were similar surveys executed in 2016 and 2018. I was a member of the team which conducted surveys in 2013, 2014 and 2016. I have performed site measurements and documentation of electrical parameters of the modules, visual degradations observed at site and mainly lead the documentation of 'socio-economic' aspects related to the adoption and proper maintenance of the PV plants surveyed. Further I have contributed in developing a framework for data entry from these survey forms and in developing an analysis methodology with the lead authors of survey reports, Mr. Shashwatha Chattopadhyay and Mr. Rajeev Dubey. Detailed reports of the 'All India Surveys' are available in NCPRE website [136, 137, 139]. This work has resulted in several journal and conference publications. Journal papers numbered 1 and 2 and the conference papers numbered 2,4,6,8 and 9 listed in section 'Publications from Thesis' at the end of this thesis have been based on the data and analysis from All India Surveys.

(http://ncpre.iitb.ac.in/research/reports.html)

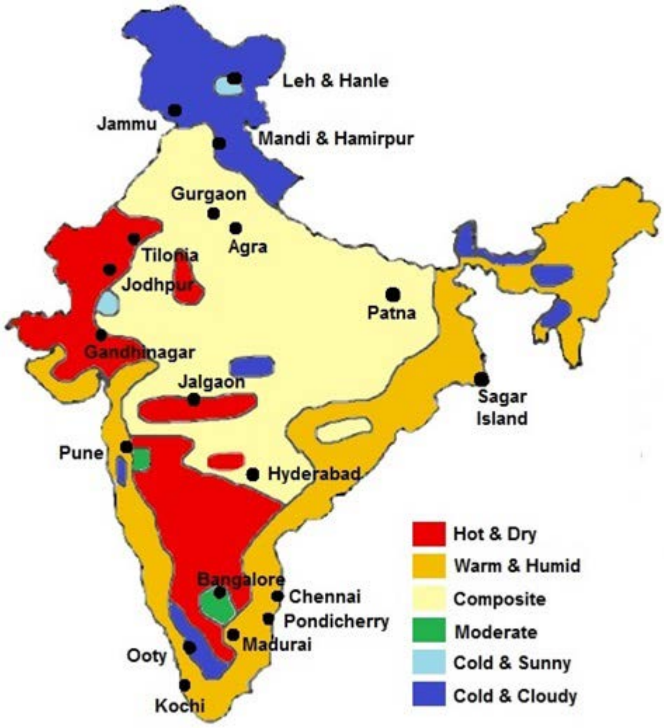


Figure 7.1: Outline map of India showing six different climatic zones and the locations of the PV power plants surveyed in 2014 [137].

7.1.1 Design of Questionnaire

Degradation, underperformance and even failure of PV systems due to improper installation and lack of maintenance are often reported in literature [140, 141]. Jafar *et al.* [142] states that the nature of maintenance support and the expenses on maintenance can be studied effectively by categorising the installations based on their ownership. A detailed study by Cust *et al.* [143] explains the design of a framework for analysing renewable energy based rural electrification projects, based on the ownership of assets of generation and distribution and end use of the generated power. Based on the insights from the above literature as well as a few other case studies [125, 144 – 147], a questionnaire was developed to capture the complex relationship between society, technology, policy and other market drivers.

First section of the questionnaire had 10 questions capturing the information related to ownership, implementation agency, source of finance, details of O&M activities, skill level of technicians, purpose met by the installation, and the factors preventing adoption of solar as per the customers view. The questionnaire is available in Annexure III. It can be seen that the questions were mostly designed as objective type questions. This helped the surveyor to present the questions in a clear and consistent way to the respondents every time. It also made the response analysis easier. Second section of the questionnaire had four questions regarding the performance and condition of off-grid inverters and batteries if present in a particular site surveyed. 'Two watt meter method' was used to measure the input and output power of the inverter and hence its efficiency, power factor, and THD (Total Harmonic Distortion) were also measured [148].

A question asking the respondent about the deterrent factors that delayed them in adopting solar and another question on the issues related to transportation of modules was also asked. Wherever possible, an attempt was made to capture the design of the system through sketching the layout diagram or the schematic diagram and hence a space was provided in the questionnaire for sketching.

Classification of Surveyed Systems based on Ownership

The questionnaire classified systems into four categories of ownership models.

Private and Individual ownership of systems – Here the PV systems are owned by private individuals. Typical examples are the individual houses having home lighting systems.

Privately owned systems by Institutions/Organizations – This type of ownership applies to PV systems owned by private and autonomous institutions or organisations. PV systems installed and owned by commercial and industrial buildings, engineering colleges, hotels, corporate offices etc. comes under this category

Systems owned by a user group or a community: These are generally systems with a few kW capacity installed and operated by a group of individuals for a common use. Examples are the community water pumping system by farmers, community street light system in a village, rooftop systems powering the common loads of a housing society and other similar applications.

Installations owned by Government and Semi-government Institutions: These are typically the systems installed on government or semi-government organisations as a part of some government scheme.

Even though the questionnaire had the above four categories, during the analysis of the data, it was found that, the installations under 'private individual ownership category' covered in the survey were in fact installed and maintained by not-for profit non-government organisations (NGOs). The PV installations in the individual houses covered in the survey were actually installed by the NGOs through domestic and foreign aids. Hence a new category of ownership was added as 'private/autonomous non-profit institutions' in the place of private individual ownership.

Various Financial Models for PV Systems

The questionnaire helped in classifying the installations into four categories, based on the mode of finance adopted for installing the system.

Self-financed systems without government incentives: These are systems where individuals or communities have paid 100% of the initial investment as well as the maintenance charges. In some cases they might have availed loans from the banks to bear the initial cost of the project.

Self-financed with capital subsidy – These are installations which have availed a capital subsidy (varying between 30 - 70%) from the central/state governments and are self-financing the maintenance charges.

Government / External funded capital and users bearing the O&M charges – Here the government (local or state) have given 100% investment of capital and they are trying for a cost recovery through monthly charges for the users.

Government funded capital investment and O&M – These are the cases where the local, state or central government has invested on P V modules mainly for promotion of technology and research, and is also bearing the O&M charges.

Motivation for Installation and the End Purpose Met by the PV Systems

The basic motivation or end purpose for the installation of the surveyed PV systems were analysed and categorised as below.

- *Necessity:* These are installations which are absolutely necessary in their given context. The proper functioning of the system is essential for meeting some unavoidable needs of the installer. Solar home lighting systems in areas where there was no grid supply in places without grid are examples for such installations.

- *Optional back up power:* These are installations where the installer has an alternate option for power. PV is a backup option to meet emergency situations when grid is not available. Solar home lighting systems where grid is available are examles for such instances.
- *Income generation/Savings:* There are installations where the major driving force was the income generation (like agriculture) or saving money on electricity bills or diesel. The savings could also be in terms of tax holidays and 'accelerated depreciation' benefits on investments made on PV systems. Other than agricultural installations, installations for public space lighting in the housing societies, industries and corporates availing accelerated depreciation benefits are examples.
- *Promotion of green energy:* Here the basic motivation for installing a PV system is to promote green energy. Some of the systems are installed as a part of government schemes (with some installation target to be achieved) and some are projects initiated by NGOs to demonstrate the viability of PV systems. Some systems are installed by the interests of the owners to project themselves as 'pro-green' organisations.
- *Research* – These are installations meant only for research activities.

7.1.2 Analysis of Small/Medium Scale Installations

51 different PV installation sites were surveyed in 2014 survey. Based on the size of the PV arrays installed, the systems were categorised into small/medium scale installations and large installations. Most of the sites had small or medium scale installations where the installed PV array size was less than 100 kW_p. Only six sites had large scale installations greater than 100 kW_p capacity (large power plants). In the context of this thesis which deals with the dissemination of rooftop and distributed PV systems, analysis of only the small and medium scale system (which are less than 100 kW_p installed capacity) are discussed in detail.

Whenever multiple power plants owned by the same owner were visited in a location, only one site is considered from that group for analysis. For example, there were three different sites surveyed in Hanle in Jammu and Kashmir, but all the three were under the ownership of Indian Astronomical Observatory. All these plants were designed, installed and maintained in a similar way by the same team of engineers. Hence they do not add three different data points; rather only one of the sites was considered to compare the performance parameters with other systems.

The small PV systems installed in research institutions were neglected in this analysis. In order to evaluate the appropriateness of installation and maintenance, certain criteria were used such as appropriate tilt angle, proper installation without shading, frequent cleaning cycle etc. to assign points for each installation. In research institutes, the modules were intentionally installed at various tilt angles, kept without cleaning, kept at open circuit condition for long time as a part of experiments to study various degradation modes. Hence we could not accommodate them in our common framework for comparison of systems. Finally, out of the 51 sites surveyed, 31 unique small/medium scale systems were considered for analysis based on the criteria mentioned above.

Motivation for Adopting PV

Figure 7.2 shows the various reasons which were reported as the 'motivation' for installing the PV system, by different system owners. Analysis of the figure shows that private institutions have opted for PV mainly for two reasons: either the systems support income generation or savings (through reduction in energy bills or savings in tax) or they want to project themselves as a 'pro-green' organisation supporting solar PV technology. In six out of seven sites surveyed under this ownership category, the motivation was reported to be either 'income generation/saving' or 'promotion of green energy'. Government institutions have mainly installed PV as a part of some schemes and programs to promote PV. NGOs have played a major role in promoting PV in areas where they are absolute necessities, like home lighting systems in rural areas and power in remote hospitals. Four out of eight installations owned and operated by NGOs are installed mainly to meet some 'necessities'. Community-owned micro-grids and water pumping systems are examples for systems with regular income generation or saving. They save considerable amount of money which was otherwise spent on diesel.

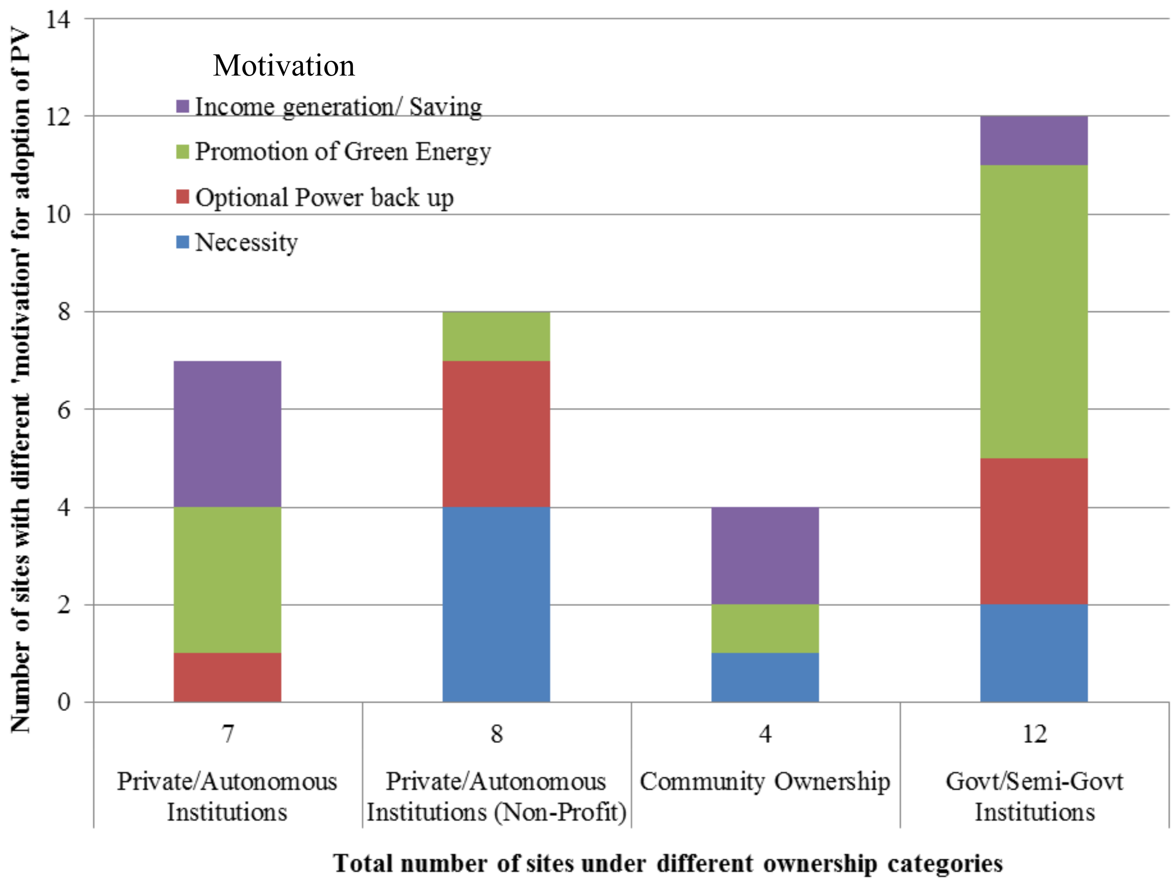


Figure 7.2: Motivation for adopting PV for different ownership categories.

Mode of Implementation of the Project

Who installed the system is an important factor which may affect the quality of design, installation and maintenance of PV systems. Figure 7.3 shows that most of the government and private institutions as well as community-based user groups have approached EPC contractors for the design and completion of their projects. This shows that institutionalisation of ownership of system can result in a proper procedure for identifying and entrusting the responsibilities of system design and installation to a professional company. Especially, the presence of a documented 'technical specification' and 'functional requirements' of a PV system will be ensured and proper tendering procedure will be followed if the ownership of a system is with an 'institution'. Studies conducted as early as the 1980s have concluded that village energy centres are technically and economically more viable than individual rooftop systems [149]. Better maintenance, superior load management and better security are some of the advantages of centralised systems. It was noted that the

NGOs are mostly dependent on local electricians for the design and implementation of the projects. It was also revealed in the survey that these were professionally trained local electricians under the institutional umbrella of the NGOs.

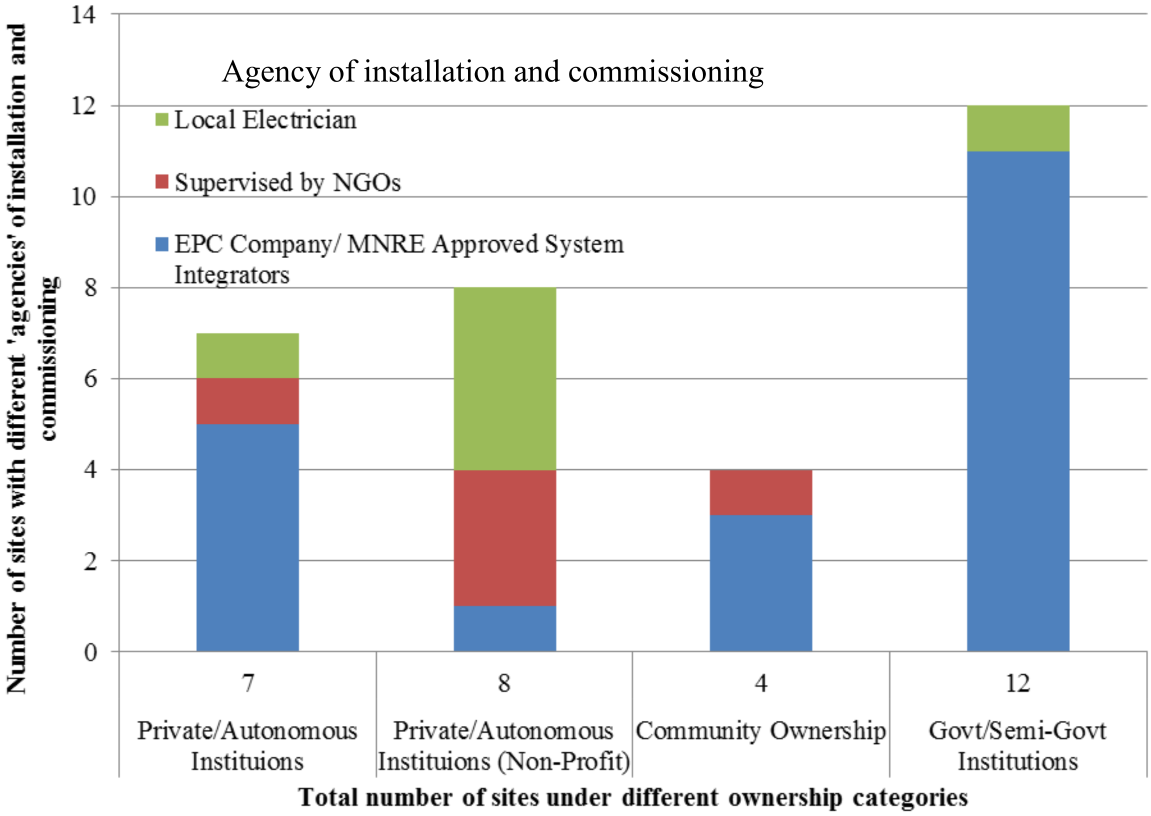


Figure 7.3: Agency installing and commissioning PV systems for different ownership categories.

Financial Facilitation for Different Types of Owners

Lack of financial facilitation is often reported as a barrier for penetration of PV into society. Figure 7.4 shows the various sources from which the projects were funded at various sites surveyed. The figure shows that most of the institutional consumers have availed loans and government support for PV installation. Some of them were able to get both government and external funding. All the community-owned systems and a few private institutions have adopted PV even without any financial facilitation from the government. Motivation behind installing such systems was mostly income generation or tax saving. This shows that people are willing to invest on PV if they are convinced about the economic advantage resulting from the system. The service offered by some NGOs in availing loans and external aids for solar home lighting projects and community-owned PV systems is often useful.

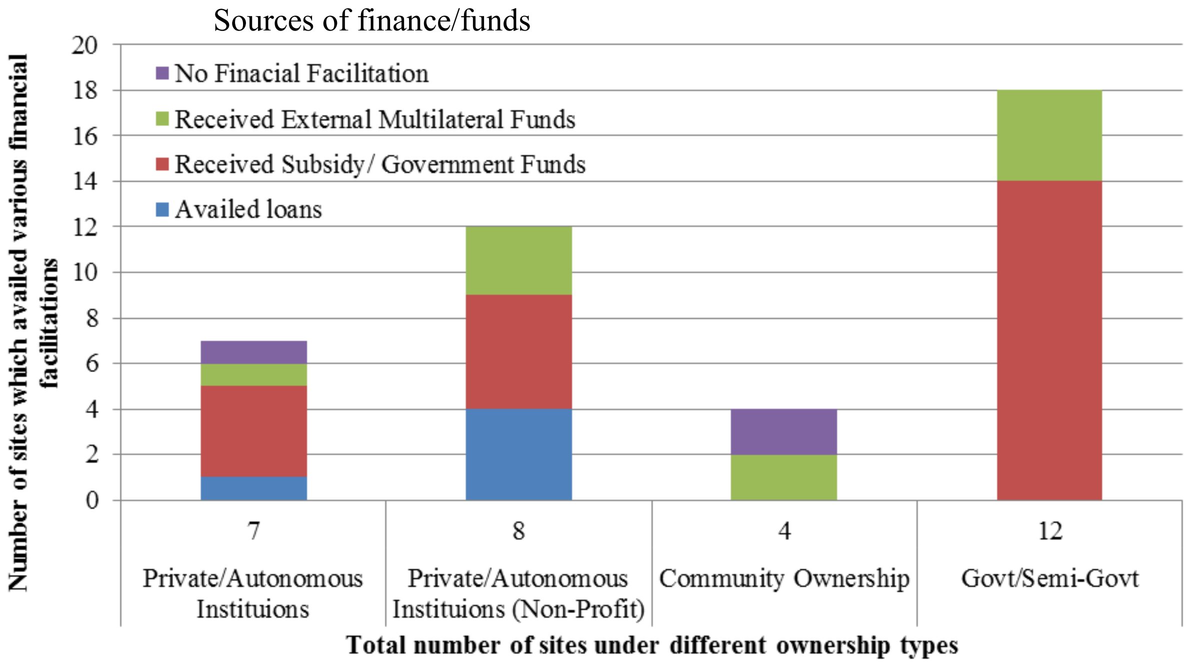


Figure 7.4: Access to financial facilitation for different ownership categories.

Nature of System Maintenance

Whether the systems are maintained on a preventive basis or on a remedial basis is a good indication of the system owner's concern towards system performance. The frequency at which routine check-ups are carried out and modules are cleaned also indicates the appropriateness of maintenance.

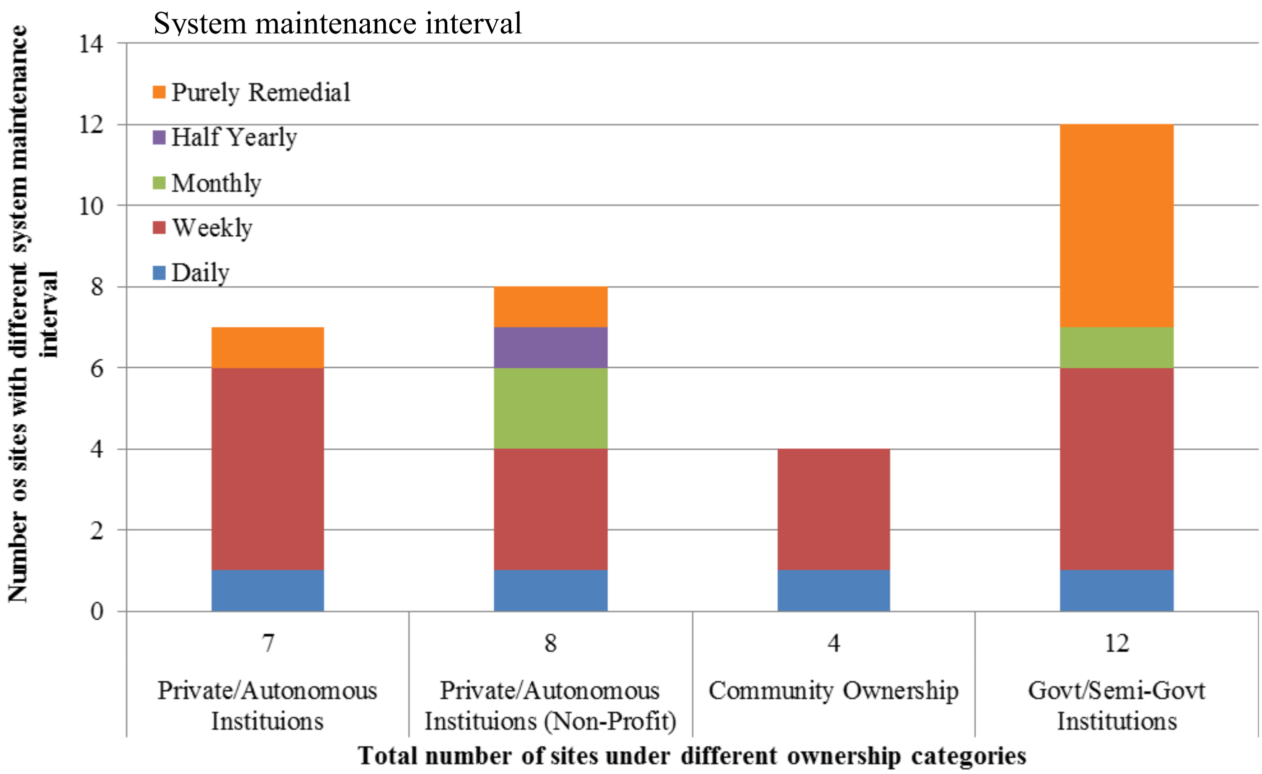


Figure 7.5: Frequency and nature of system maintenance for different ownership categories.

Figure 7.5 shows that most of the private institutions, NGO and community owned systems are maintained on a preventive basis and are checked regularly on a weekly or monthly basis, whereas negligence in system maintenance is seen from the part of government institutions and some NGOs. It may be noted that most of the latter systems are installed at the expense of public exchequer or through aid. Since the end-users have not spent anything, there appears to be a lack of 'ownership' that leads to the negligence.

The importance of installing the modules at an easily accessible place has been emphasised in a case study by El-Shobokshy *et al.* [150] in their paper dealing with the degradation of solar cells due to accumulation of dust. The importance of regular cleaning of modules is also highlighted in a study from Algeria [141]. Similarly, shading of single module based rooftop home lighting PV systems was found to be a serious issue resulting from improper installation location [151]. Though the frequency for module cleaning depends on the nature and amount of dust getting accumulated, it is a good practice to clean the modules regularly. But this has not been observed to be a general practice across all types of ownerships. Figure 7.6 shows that among all types of system owners, the cleaning cycle of the modules are on a monthly basis or not regular for at least 50% of the sites. Ignorance of the deleterious effect of dust on yield reduction may be one reason.

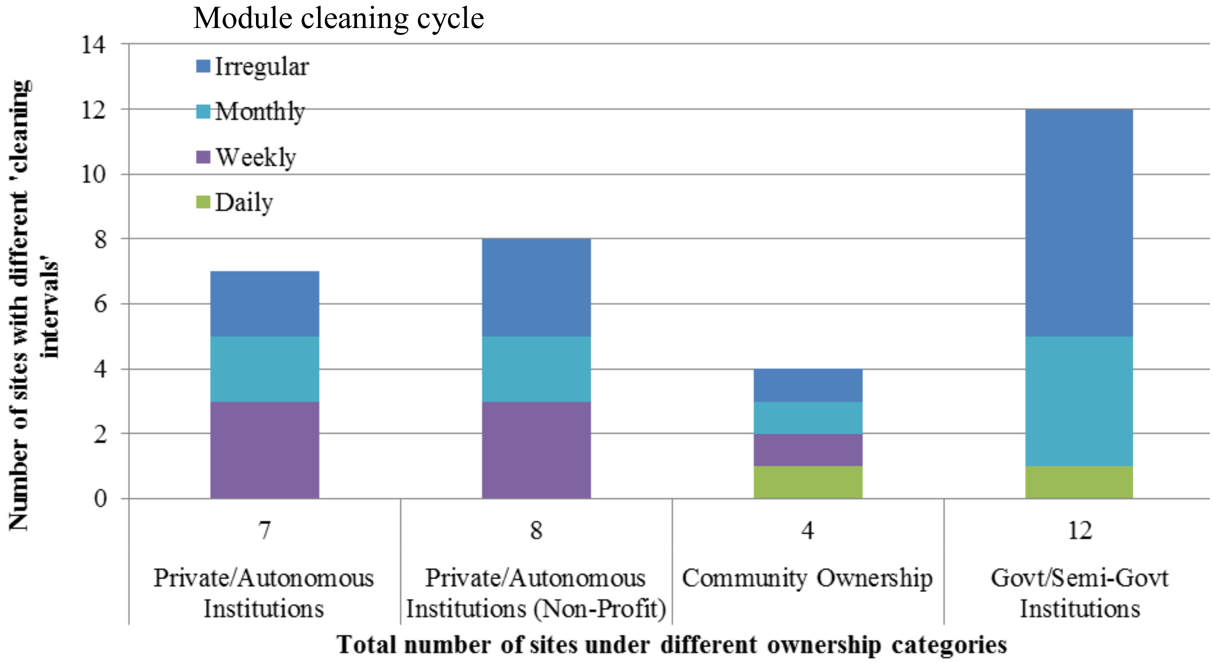


Figure 7.6: Frequency of module cleaning for different ownership categories.

The data regarding the degradation of maximum power output of the PV modules (P_{max}) was analysed from the electrical measurements made on t he modules during the survey. Figure 7.7 shows that there is some correlation between the frequency of module cleaning and the P_{max} degradation rate of the modules. More regularly cleaned modules were degrading at a lesser rate.

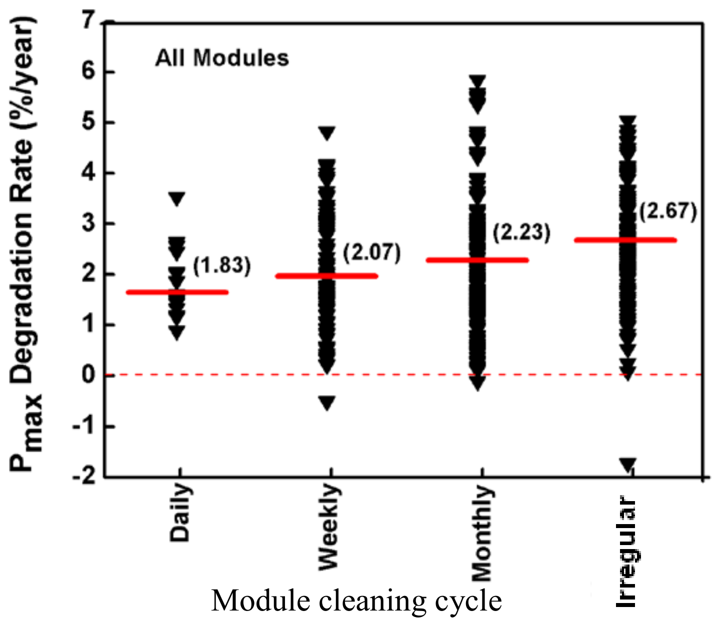


Figure 7.7: Frequency of module cleaning and its correlation with Pmax degradation.

During visual inspection, the modules were classified into lightly soiled and heavily soiled modules. Lightly soiled modules were the ones with negligible thin layer of dust which can be easily removed by rubbing with a dry cloth. Whereas the heavily soiled modules were having considerable amount of dust deposited on them, due to improper cleaning. Most of the times, removal of dust was possible by using wet cloth, and with a little pressure on the glass. Heavily soiled modules were having haziness near the bottom frame. Figure 7.8 shows that lightly soiled modules degrade at a lesser rate than the heavily soiled modules. This is another indication towards the need of regular module cleaning.

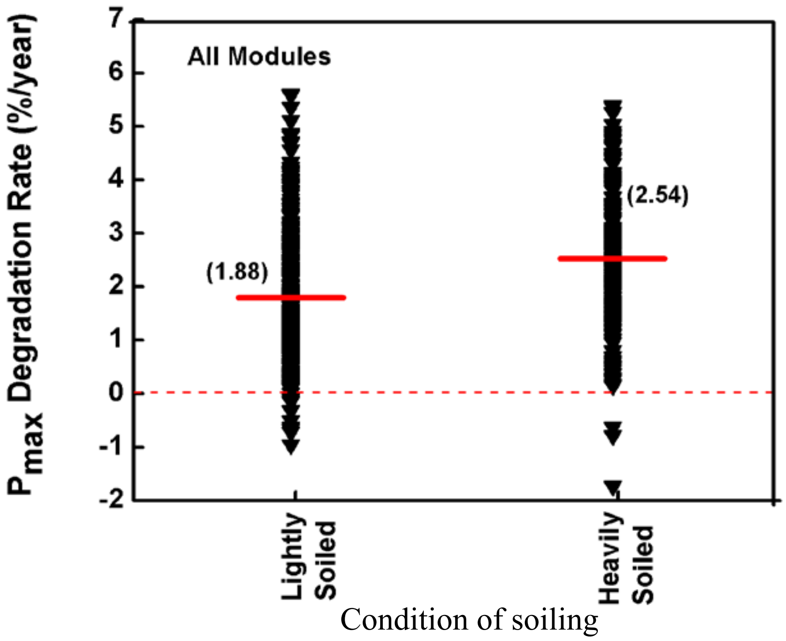


Figure 7.8: Condition of soiling on module and its correlation with P_{max} degradation.

Similarly, shading of modules by buildings and trees was observed in many sites. Figure 7.9 shows that the mean value of P_{max} degradation of modules from sites which do not have the problem of shading are better when compared to the modules from systems which are shaded by surrounding trees and buildings. Hence enough care must be given in the selection of installation site and layout of the modules. Shading analysis of the installation site, especially for rooftop projects is very important for better performance of the system.

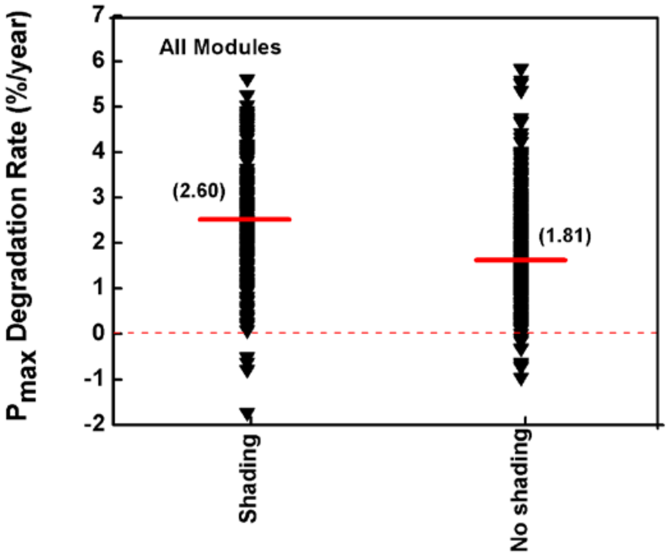


Figure 7.9: Correlation between shaded systems and degradation: Modules from systems which have shading have higher degradation rates compared to modules from unshaded sites.

Availability of Skilled Local Technicians

After spending a substantial amount on PV systems, people often expect them to work without failure. Even a small down time of the system can cause dissatisfaction for the owner and create a negative impact on P V technology's popularity. The availability of a local technician who is trained and capable of fixing system failures becomes very important. A better practice for smaller systems is to train the system owner to do the basic trouble-shooting and repairing. Analysis shows that around 25-30% system owners are self-trained for basic trouble shooting in the government, community-owned and NGO sectors.

Figures 7.10 and 7.11 shows that the NGOs played an important role in promoting PV through proper training of local technicians. The overall statistics show that 48% of site owners resort to trained technicians for major repairs, but the rest depend on technicians who are not formally trained in PV. If the 'training' aspect is kept apart, 45% systems are maintained by local technicians and the rest are by out-station technicians. Another statistics shows that 49% of the technicians are diploma or degree holders or ITI (Industrial Training Institutes) graduates. This shows the importance and need for including PV related training content in the syllabus of ITIs and polytechnics through government initiatives.

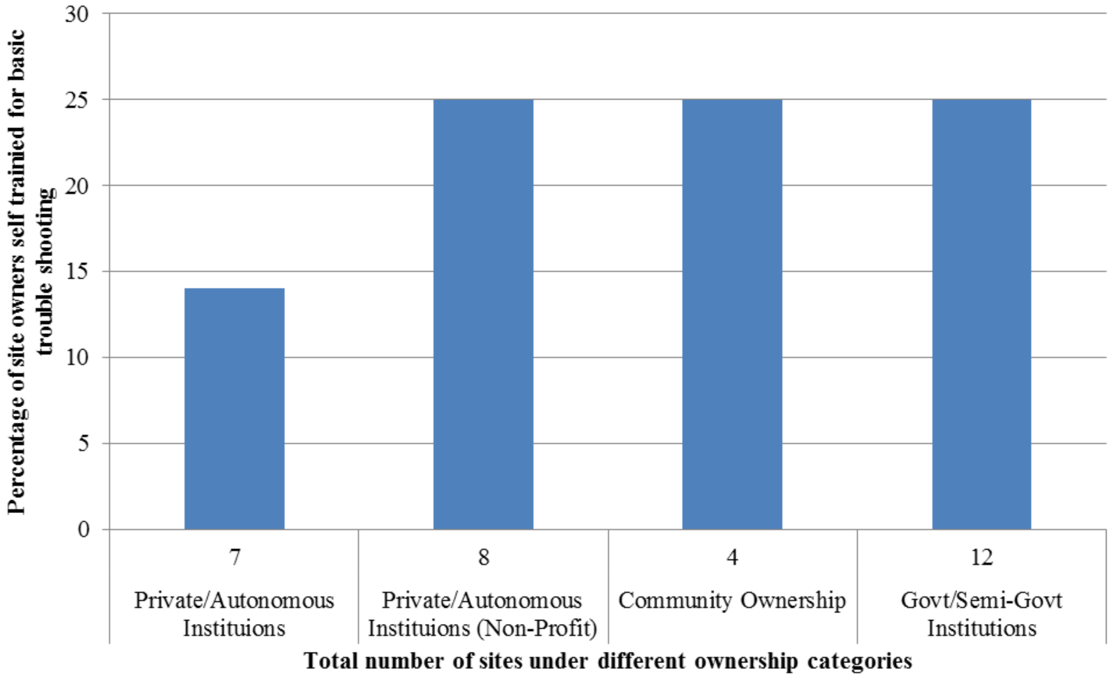


Figure 7.10: Percentage of system owners self-trained for basic trouble shooting of PV systems.

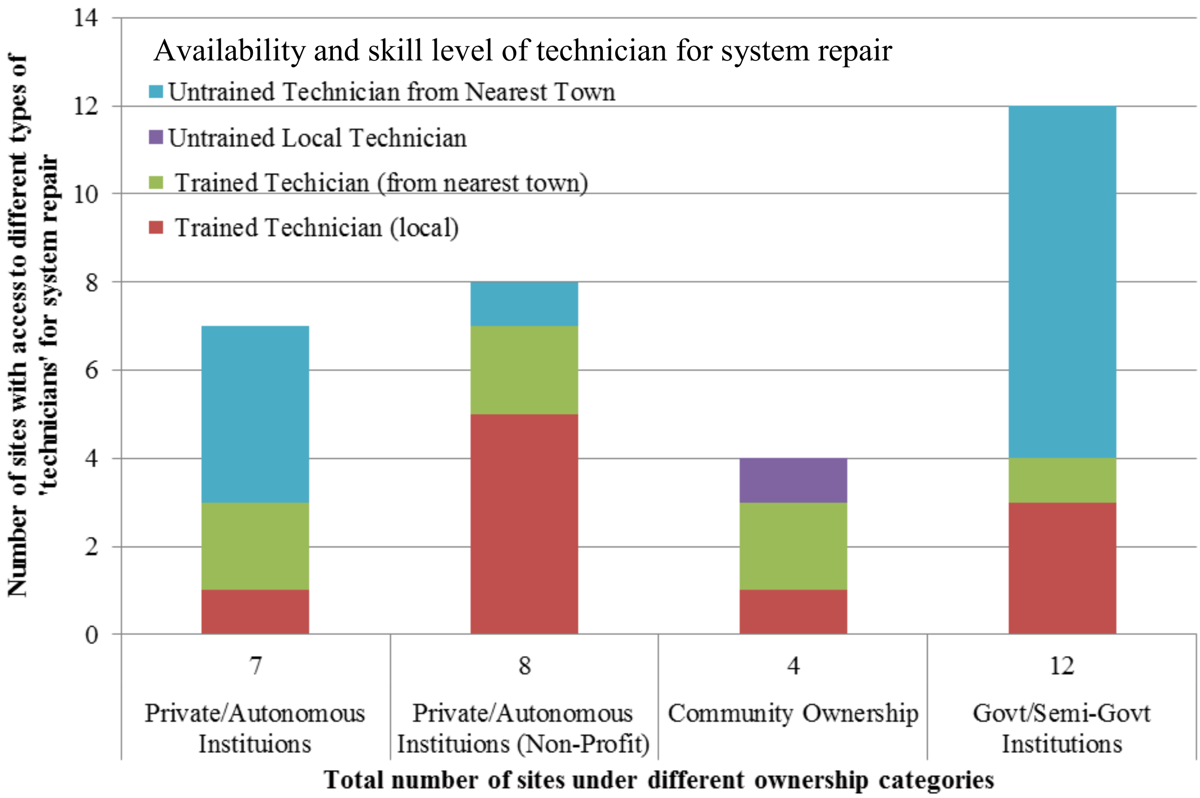


Figure 7.11: Human resources available for system repair for major faults: Technician availability and skill level of technician for system repair.

Figure 7.12 shows the mean degradation in P_{max} of the modules from various systems installed and maintained by trained and untrained technicians. The data shows that in those sites where the work is done by trained technicians, modules have degraded less. There may be various other reasons for degradation, but the care given in the execution of the project can be one reason for better performance.

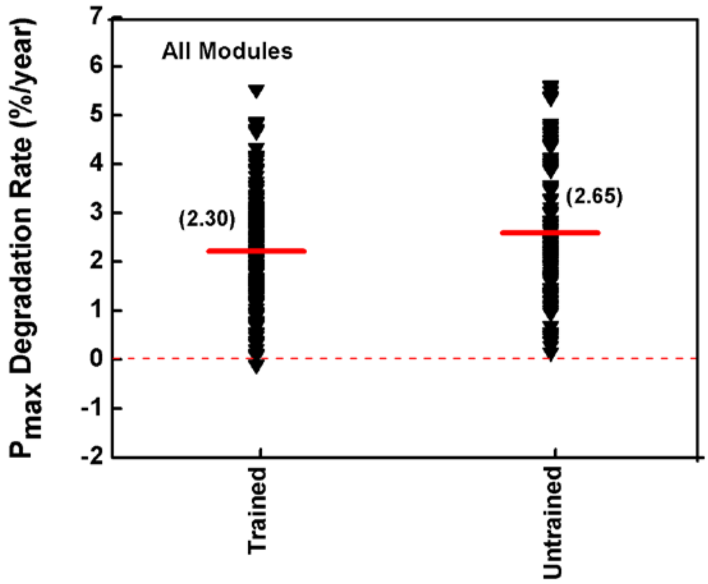
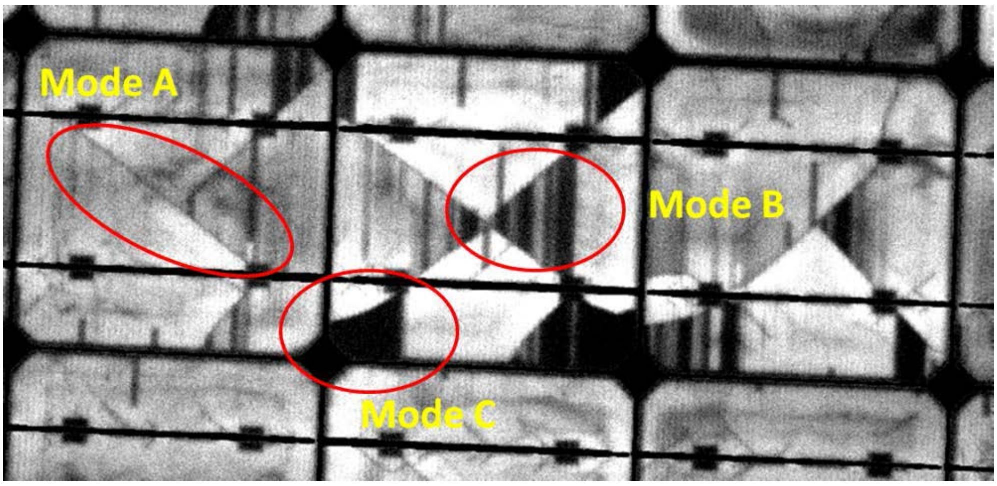


Figure 7.12: Comparison of P_{max} degradation of modules from sites installed and maintained by trained and untrained technicians.

The analysis of the EL images in the surveyed modules have identified that there are cracked cells in some of the modules inspected. The cracks were classified into modes A, B and C based on the severness of the crack.

Mode A cracks were hairline cracks, which normally do not affect the power output of the module. Mode B cracks are those which can affect the power output of the modules and they are seen as grey (not very dark) patches in the EL image. Mode C cracks completely isolates a section of the cell and reduces the power output from that cell and hence the module in a considerable way. Mode C cracks are seen as dark patches in the EL image. A sample image with differet modes of cracks is presented in Figure 7.13.



c

Figure 7.13: Different types of cracks in the cells as visible in EL images [137].

Cracks can be induced in the modules if they are not handled properly at the site and this can lead to P_{max} degradation. Data from the EL images of modules were taken, and grouped into two categories, based on whether the project was executed by trained technicians or not. Table 7.1 shows that the percentage of cells affected with mode A and B cracks in sites which are installed by trained technicians is less when compared to the sites installed by untrained technicians.

Table 7.1: Correlation between presence of cracks in modules and the skill level of technician handling the modules.

	Percentage of Cells Affected by Different Types of Cracks			**Total No. of Cells**
	Mode A Cracks	**Mode B Cracks**	**Mode C Cracks**	
Trained	9.22%	15.89%	4.44%	900
Untrained	16.22%	26.13%	3.15%	444

Flaws in the Design Philosophy: Over Sizing the Inverters

In many of the off-grid systems, the size (power rating) of the inverters has not been chosen based on pr oper load estimation. In many cases, the inverter ratings were chosen based on the installed PV 'array capacity', rather than on the load it has to drive. Due to this, most of the times, the inverters run on low loads and at poor efficiency. The reason why the higher size inverters were chosen was mainly because it has to handle higher PV array size in the battery charging circuit. Size of the PV array is basically decided by the energy requirement per day. Most of the off-grid inverters come with an integrated solar charge controller. The PV power handling capacity of this charge controller is usually proportional or close to the load handling capacity of the inverter. This results in the selection of larger kVA rating of inverters for handling larger PV power (but actually driving lower loads). In such a situation, a better cost-effective solution is to isolate the battery charging circuit with an external charge controller and to drive the load using a lower rated inverter appropriate for the load. The expense of buying a higher kVA rated inverter is more than that of buying an additional charge controller along with a lower kVA rated inverter matching the load requirement [152]. Table 7.2 shows that the inverter load power capacity has been oversized in many of the sites surveyed and hence the efficiency at normal operating conditions is much smaller than the full load efficiency and the full load itself is much smaller than the actual rated capacity of the inverter.

Table 7.2: Issue of inverter oversizing.

Site	PV Array (kW_p)	Inverter Rating (kVA)	Full Load (kVA)	η – Normal Load	η - Full Load	Inverter Oversized
Site A	15	15	3.25	71%	79%	Yes
Site B	0.9	2	0.375	77%	84%	Yes
Site C	30	30	15	90%	92%	Yes
Site D	4	3	1.5	90%	95%	Yes
Site E	20	10	2	NA	82%	Yes
Site F	2	2	0.1	NA	NA	Yes
Site G	4	4	1	NA	NA	Yes

Overall Scores for System Owners

From the previous sections, we could identify various factors affecting the system performance apart from the local climatic conditions. Some of them are the design, workmanship, shading of modules, cleaning cycles, frequency of preventive maintenance checks and skill level of technician. The systems were then evaluated on a 25-point scale by quantifying all the observations in the field. The criteria for points allocation is as shown in Table 7.3. The criteria and weightages were determined through group discussions and consultation in NCPRE PV module reliability group meetings. Also various literature referred in section 7.1.1 were used to identify the criteria and their weightages. The analysis shows that the systems owned by government institutions have low scores. Community owned systems were ranked at the top when considered for the appropriateness in system installation and maintenance practices. Table 7.4 shows the maximum, minimum and the average score achieved by different groups of sites categorised based on ownership.

Table 7.3: Criteria for quantifying the observations in the field for overall ranking.

Criteria	Observation and Associated Points Allotted
Overall System Design and Workmanship (Maximum 5 points)	Proper sizing of inverter based on load analysis – 2; or else 0 Proper sizing and configuration of modules and battery bank – 1; or else 0 Right selection of wiring thicknesses based on currents carried – 1; or else 0 Good workmanship and finishing of work (including safety) – 1; or else 0
Shading of Modules (Maximum 3 points)	Modules are un-shaded – 3, A few modules have shading issue – 1.5, Many modules are shaded – 0
Module Orientation and Tilt Angle (Maximum 3 points)	Modules are facing true south – 1.5, Modules are mounted at a tilt angle equal to latitude angle – 1.5, Deviation in tilt angle from latitude (deviation < ± 25% of optimum – 1, < ± 50% – 0.5, > ± 50% – 0
Module Mounting (Maximum 3 points)	Modules are mounted on proper structures which are in good condition – 3, Structures rusted – 2, Structure broken or bended – 1, No structure – 0
Module Cleaning (Maximum 3 points)	Modules are clean – 3, Lightly soiled – 2 , Heavily soiled – 0
Maintenance Checks (Maximum 3 points)	Daily/ Weekly – 3, Monthly – 2 , Half yearly – 1, Purely remedial maintenance – 0
Availability and Skill of Technicians (Maximum 2 points)	Trained technician available locally – 2, Untrained technician available locally – 1.5, Outstation trained technician – 0.5, Outstation untrained technician – 0
Self-training (Maximum 3 points)	System owner self-trained in basic trouble shooting and repair – 3 System owner unaware of trouble shooting system failures – 0

Table 7.4: Maximum, minimum and average overall score for systems owned by different categories.

Ownership	Max. Score Achieved	Min. Score Achieved	Average Score	Rank
Private/Autonomous Institutions	18	14	15.71	2
Private Institutions (Non-Profit)	19	7	14.63	3
Community Ownership	18	15	16.86	1
Government/Semi-Government Institutions	19.5	6	12.38	4

When the average scores obtained by different ownership models were compared with the mean value of P_{max} degradation of the modules from these sites, it was seen that the private not-for-profit institutions are best in terms of lowest degradation rates, closely followed by community owned systems. Figure 7.14 shows the trend of P_{max} degradation of the systems under different ownership models. This result is a little different from the trend of the scores obtained in the previous section. Still the difference in the scores between the community-owned systems and the systems owned by NGOs were very low. Similarly the difference in the average degradation values of P_{max} from these categories of systems is also very small. The low scores obtained by the government institutions are compatible with the high degradation value obtained in this category.

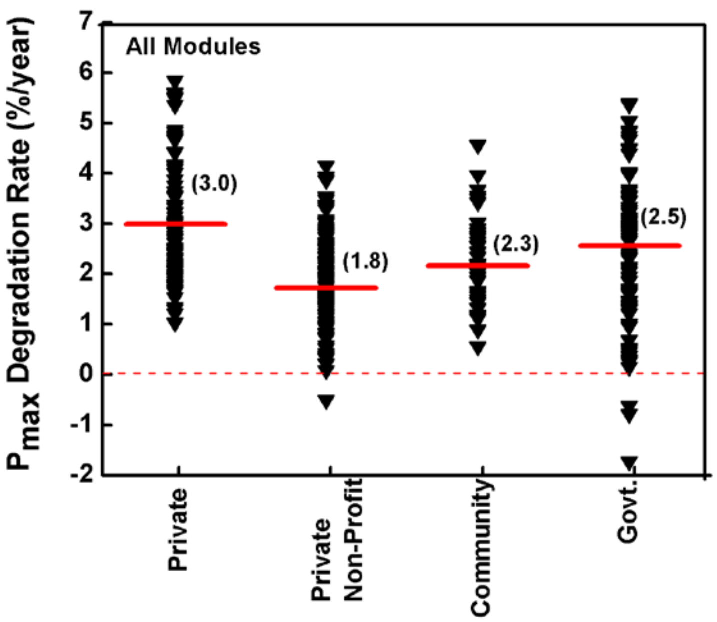


Figure 7.14: Comparison of Pmax degradation of modules from sites under different ownership categories.

7.1.3 Summary

- Major motivation for private installations under institutional ownership and community users is income generation, saving in electricity bills or saving of taxes. Many of them have invested in PV even if they have not availed capital subsidies from the government.
- Many of the government funded installations are for promoting green energy, but in many cases they are not properly maintained.
- From a financial facilitation perspective, institutional system owners are finding it easier to get access to loans, government and external funds.
- Generally, government and private institutions get the design, installation and commissioning work of PV systems done by EPC contractors. NGOs, individuals and community owners resort to local electricians for getting their work done.
- NGOs have played a major role in 'localizing' PV technology by training the local electricians in PV technology.
- Community owned PV systems are having better maintenance practices in the field, especially when the systems help in meeting the necessities or provide an income

source to the community. Unfortunately the degradation rates of modules in such systems are seen to be high, may be because of the selection of poor quality modules.

- A large chunk of technicians who actually undertake system installation and maintenance are either high school or diploma school graduates. There is a need to train local electricians to maintain the PV systems.
- Inverter oversizing in off-grid systems was found to be a major design flaw, even among the systems designed by the so called ‘knowledgeable’ EPC contractors.
- Improper orientation, tilt angle, poor support structure, soiling, and shading are some of the problems in the site which give rise to degradation and failure of PV systems.
- More regularly cleaned modules were having less P_{max} degradation rate and those modules which were observed as heavily soiled in the field were having high P_{max} degradation rates.
- Mean value of P_{max} degradation of shaded modules was higher by 0.8%/year than the unshaded modules, showing the evidence of deleterious effect of shading in module output power.
- The number of mode A and B cracks appearing in the modules is more in the installations done by untrained technicians, possibly due to improper handling of modules. This has resulted in higher P_{max} degradation rate in such sites.

7.2 Case Study of Solar Pump Irrigators Co-operative Enterprise (SPICE), in Dhundi Village, Anand District, Gujarat

In chapter 5 of this thesis, the scope for farmers' co-operatives in Kole lands of Kerala adopting grid connected water pumping systems was discussed in detail. In this section, a review of a similar project executed in a village called Dhundi in Anand district of Gujarat is presented. This review helps in understanding the implementation level difficulties and factors to be considered for replicable and scalable models of community based water pumping schemes. Dhundi village mainly resorted to diesel motor pumps for irrigation. There were 49 irrigation wells owned by comparatively rich farmers with larger land holdings and they had 7.5 – 10 HP diesel engines to pump ground water. Cost of one unit of electricity from diesel engines is Rs. 18-25/kWh [153]. Farmers in the nearby villages availed grid power for irrigation at Rs. 0.70/kWh from local DISCOM, Madhya Gujarat Vij Company Limited (MGVCL). Nearly 200 farmers with smaller land holdings and who did not have wells or irrigation facility of their own, had to pay a rent of Rs. 100/hour for irrigating their fields using the facilities of diesel pump owners.

In that kind of a state of affairs, an alternate solution for irrigation was conceptualised and implemented in Dhundi by International Water Management Institute (IWMI), an international NGO and research institute working in the area of sustainable use of water in developing countries. IWMI availed funds, established an institutional mechanism and operational guidelines for 'Solar Pump Irrigators Co-operative Enterprise (SPICE)', a farmers' co-operative who could own and operate a set of PV operated 'grid connected' irrigation pumps in Dhundi. Centre for Technology Alternatives for Rural Areas (CTARA), a centre in IIT Bombay offered courses for undergraduate students under their 'Technology and Development Supervisory Learning (TDSL)' programme. Three undergraduate students who opted for this course during the spring semester (January to June) of 2017 were assigned an evaluation project of this SPICE model. I was the teaching assistant for this project and was involved in this study. The three students and I had visited the farm lands of Dhundi and interacted with the farmers to understand the ground realities of the implementation of the SPICE model. We also visited and had detailed discussions with the officers in MGVCL and the SPICE programme co-ordinators in IWMI.

7.2.1 Objectives

The major objectives of this study were:

- To find out the performance of the pumps and the PV system implemented under first SPICE model.
- To find out the level of satisfaction with the functioning of the SPICE model among the stakeholders (farmers, IWMI, MGVCL).
- To find out any technical or operational level draw backs of the system.
- To find out any implication on the ground water levels and cropping patterns in the region after the implementation of SPICE model.
- To find out the challenges in replicating and scaling up (through more number of such co-operatives installing such irrigation method) such models.

7.2.2 Design of the Questionnaire

There were three sets of questionnaires prepared, one for the farmers who were members of the SPICE co-operative society, one for the MGVCL authorities and one for IWMI programme co-ordinators. The questionnaires are available in Annexure IX.

The questionnaire for the farmers had questions about the different crops they grow and their duration of farming (no. of days for a crop from sowing to harvesting). It asked for water pumping duration (no. of hours a day and no. of days per cropping season) for each crop they cultivate. The source of water, the types of pumps used and the expense on water pumping were asked. The difficulties they faced while running and maintaining a diesel pump and the associated repair costs were interrogated. The revenue from each crop per season and the revenue from 'sales of water' to other farmers who neither had own irrigation facilities nor were a part of co-operative was asked. Questions regarding any dissatisfaction on the performance and benefits from the SPICE model were also there in the questionnaire. Queries about the revenue the society generated through sales of energy to the DISCOM and the promptness in DISCOM paying the farmers for this energy sale were also present. The interests of the farmers in adopting new crops which would need more water for cultivation (since they had access to more water through solar pumps) and the usage of excess revenue they earn through SPICE model was enquired. Questions regarding the farmers' prior experience and knowledge of a co-operative society, its formation and functioning and their level of conviction on a co-operative model were also asked.

The questionnaire for MGVCL had queries regarding their acceptance towards the SPICE model. It asked whether they were in favour of the pooling of power from smaller generation centres and integrating to the grid at a HV level through a transformer. It had questions regarding their scepticism towards the distributed PV systems including the possibility of harmonic injection and voltage rise at the tail end. It had questions regarding the limitations from MGVCL in terms of their limited number of trained manpower in PV sector and inability to source bi-directional meters, additional transformers and additional cost involved in extending grid to new villages.

The questionnaire for IWMI was more directed towards the institutional model and sources of funds they availed for this project. The difficulties they faced while executing the project in terms of technical design, availability of trained manpower, poor response from the DISCOM, policy limitation etc. were also asked. Their suggestions to improve the existing model were also asked.

7.2.3 Implementation of the Project

The central pillar of SPICE model is the farmers' co-operative society. The co-operative consist of a president, a secretary and ordinary members. Secretary runs the operations of the unit on a day to day basis and is a paid employee. President has tenure of 3 years and is elected by the members. Monthly meetings are held to review the issues of the farmers and secretary addresses the issues (if any) in consensus with the president. Initially, six members formed the co-operative and installed six solar water pumps (three numbers of 5 HP pumps and three numbers of 7.5 HP pumps) at their fields. Along with the 5 HP pumps, PV array of capacity 8 kW_p was installed and along with the 7.5 HP pumps, 10.8 kW_p panels were installed. The total cost of the project including the transformer, meters, cabling, changeover switches, inverters, VFDs, PV panels and grid extension cost for the total 56.4 kW_p system was Rs. 50.65 lakh [153]. The farmers contributed Rs. 5000/kW_p and the remaining amount was provided by IWMI from their research grants.

Each solar system installed had an option to either use the PV power to drive the pump using a VFD or to export the power to the grid using a grid tied inverter. So, whenever there was no need for irrigation, the farmers would use the changeover switch provided in the system to prevent the PV power from going into the VFD, and divert it to the inverter and hence to the grid. MGVCL entered into a 25 year PPA with the co-operative at Rs. 4.63/kWh Feed-in-Tariff. In return, the farmers of the co-operative surrendered their right to get subsidised energy from MGVCL for the same 25 years.

Farmers who have bore wells in their farm land and who want to join the co-operative may apply for membership. They have to produce documents of ownership of the land and a 'no objection certificate' to avail grid extension and an agreement to surrender their right for subsidised electricity for 25 years. Once the existing members approve for the membership of new members in the monthly meeting, the newly joined farmers will be given a PV water pump according to their requirement. The new members have to pay Rs. 25,000/ kW_p (40% of the cost involved in the installation of the new pumps, whereas the first six members paid only 10%, Rs.5000/kW_p). The remaining share is taken by IWMI.

Previous to the use of PV pumps, the farmers used diesel pumps for irrigation. Hence to incentivise switching into clean energy sources, IWMI and CCAFS (CGIAR Research Program on Climate Change Agriculture and Food Security; CGIAR is Consultative Group on International Agricultural Research, a consortium of international agricultural research centres) offered the farmers to top up the MGVCL FiT with a 'Green Energy Bonus' of Rs. 1.25/kWh. When electricity is provided nearly free of cost to the farmers, there have been instances in the past, where the farmers indulge into indiscriminate pumping and exploitation of ground water [153]. To prevent such unwise pumping practices, a 'Water Conservation Bonus' of another Rs. 1.25/kWh was offered to the SPICE members. This would prompt a farmer to stop irrigation when it is actually not required, and start export the excess power to the grid. So, every kWh of energy exported to grid by SPICE members in fact indicates conservation of ground water. Finally the total effective FiT for SPICE members came to Rs. 7.13/kWh.

Figure 7.15 and 7.16 shows the technical design and components used for the 5 and 7.5 HP pumps installed by the members of the SPICE model which initially started working in Dhundi. Figure 7.17 shows the detail of pooling the power from all the six installations and evacuating it to the MGVCL HT line. Figure 7.18 is the actual photograph of the PV modules installed in the field and the power pooling facility of the six installations.

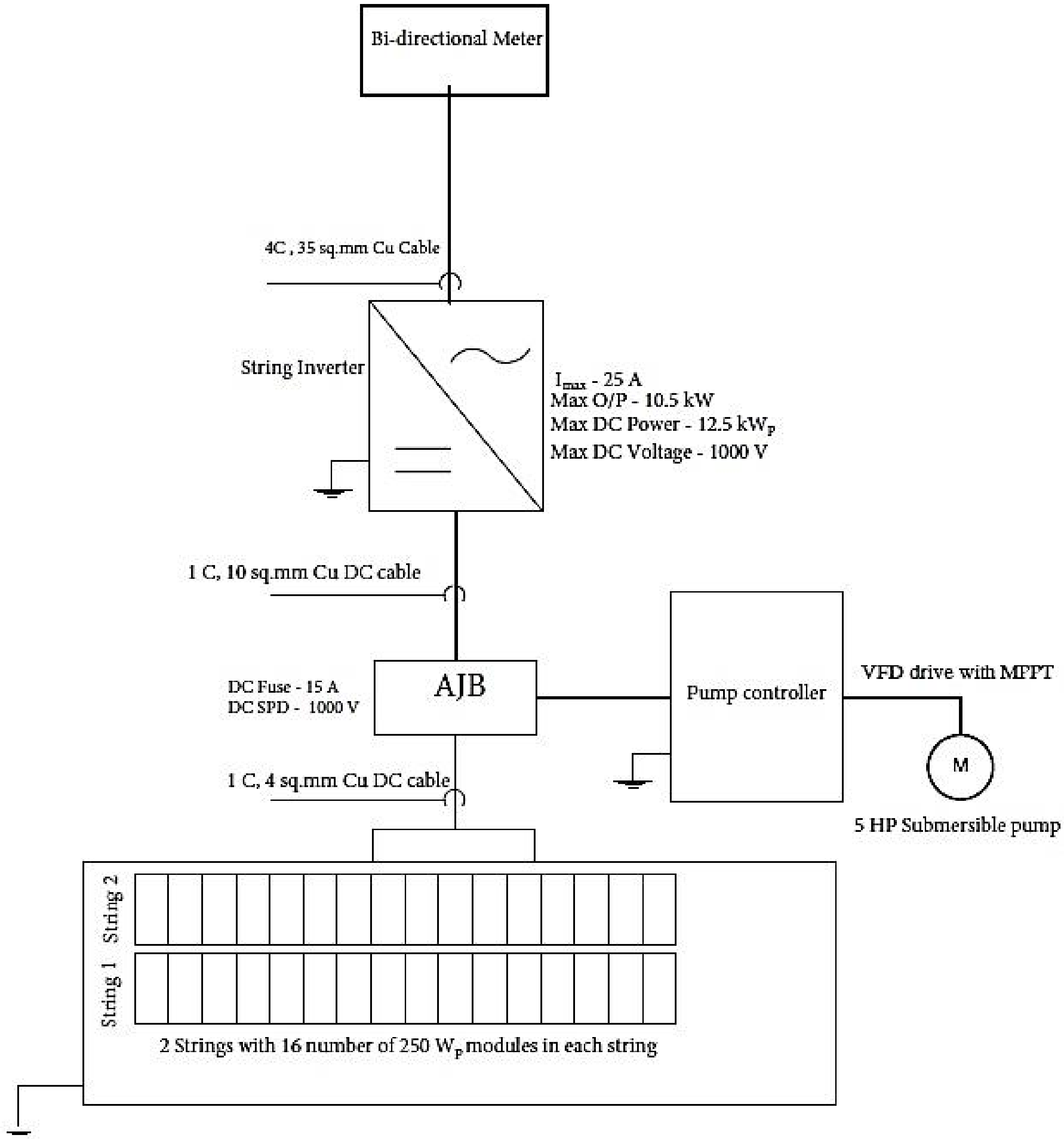


Figure 7.15: Schematic diagram of 5 HP water pumping system with grid feed option adopted by SPICE farmers co-operative.

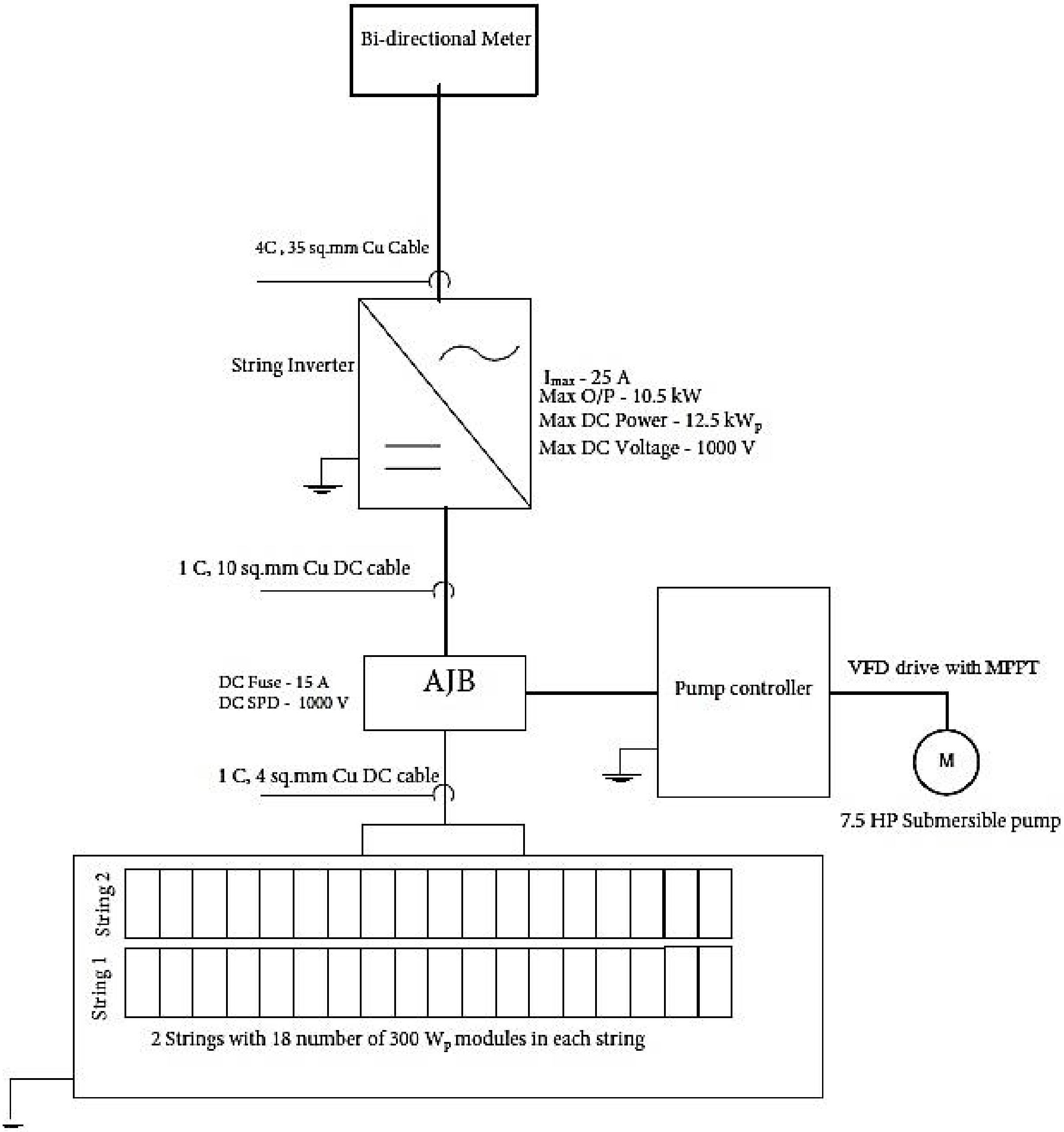


Figure 7.16: Schematic diagram of 7.5 H P water pumping system with grid feed option adopted by SPICE farmers co-operative.

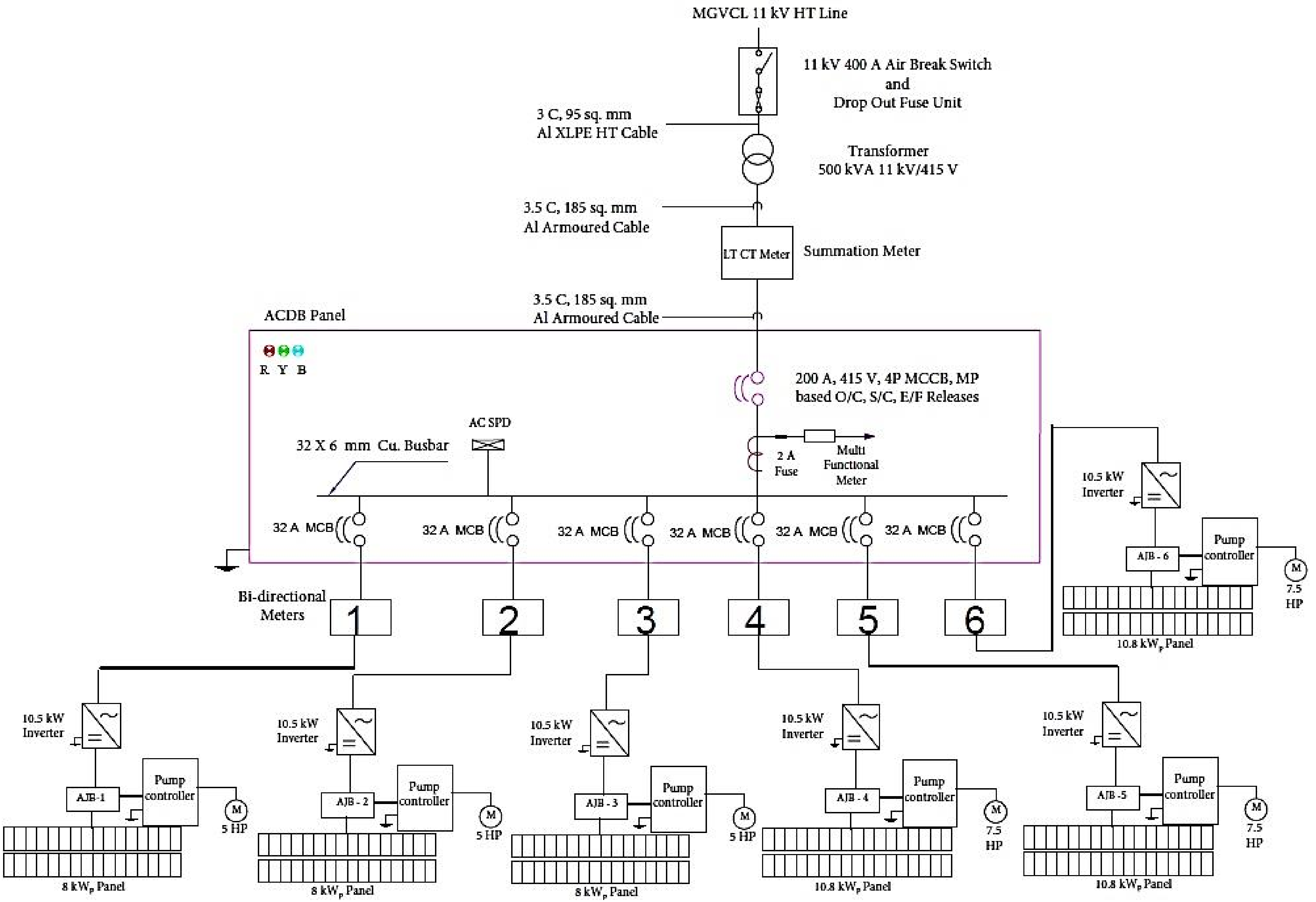


Figure 7.17: Schematic diagram of power evacuation to HT line adopted by SPICE farmers co-operative.

Figure 7.18: PV installation in the field and the meter room at Dhundi.

7.2.4 Impact of the Project

The SPICE model has three groups of direct beneficiaries; one is the farmers who own the wells and diesel pumps who later formed the SPICE co-operative and switched to PV pumps, second is the farmers who buy water from the diesel pump owners (now buying from SPICE), and third is the DISCOM (MGVCL).

Table 7.5 summarises the costs and revenues to each stakeholders before and after the implementation of SPICE.

Table 7.5: Costs and benefits for various stakeholders in SPICE model (Calculated based on [153 – 155]).

Parameter for Comparison	When Using Diesel Pumps	When Using Solar Pumps	Incremental Savings or Benefits (Rs)		
			Farmers who are Members of SPICE	Farmers who Buy Water from SPICE	MGVCL
Hours of irrigation spent by SPICE members in their own fields[1]	1,033	1,697			
Monetary value of irrigation hours spent in their own fields (Rs)[2]	1,03,300	1,69,700	66,450		
Hours of irrigation spent on ot her farmers' field (water sales)[1]	1,857	2,840			
Monetary value of irrigation hours during water sales (Rs)[2]	1,85,700	2,84,000			
Net income from sale of water (Rs)[3]	55,695	1,42,000	86,405	1,42,000	
Income from sales of energy to MGVCL (Rs)[4]	-	3,64,500	3,64,500		
Running cost for diesel pumps for equivalent solar pump hours (Rs)[5]	1,73,340	3,38,184	3,38,184		

Equivalent saving by MGVCL considering subsidised amount of Rs 0.7/kWh for 28,500 kWh (PV energy used during pumping at their own fields and during water sales by SPICE) (Rs)[6]					1,08,300
Equivalent saving by MGVCL considering Renewable Energy Certificates (REC) for 79,622 kWh at Rs 3.5/kWh (Rs)[7]					2,78,677
Total			**8,55,539**	**1,42,000**	**3,86,977**

1. Based on questionnaire survey, and the first biannual report of Dhundi Solar Energy Producers' Co-operative Society [154].

2. It was told in the interviews that Rs. 100/ hour was the rate at which the diesel pump owners used to charge for irrigation. This was when diesel cost in India was around Rs. 60/litre [156]. Hence one hour of irrigation in their own fields can also be evaluated at Rs. 100/hour.

3. Assumed that Rs. 30/hour is the net income after reducing the fuel and other running costs for diesel pumps. For PV pumps SPICE is charging Rs. 50/hour (half the rate of diesel pumps).

4. The total excess energy exported to grid during 2016-2017 was 51,122 kWh and the farmers get an effective FiT of Rs 7.13/kWh.

5. A 5 HP pump uses approximately 1.2 litres per hour at full load [157]. Hence 2730 hours of running (including self-consumption and sales while using diesel pumps) would use 2730*1.2 = 3276 litres diesel, and Rs. 60/litre is considered as diesel cost. Similar calculation for equivalent diesel usage for 4697 running hours of PV pumps is calculated.

6. 28500 kWh was used by the farmers for water pumping during the year 2016-2017. If MGVCL had supplied this much energy, they would have incurred a loss of Rs. (4.5-0.7)/kWh. Rs. 4.5/kWh is their average cost to serve 1 kWh at user end and the tariff is only Rs. 0.7/kWh.

7. Renewable Energy Certificate (REC) trade happened at Rs. 3,500/MWh during 2016-2017 [158].

Table 7.6: Solar PV energy production data from Dhundi SPICE during 2016-2017 [154, 155].

Month	Energy used for irrigation (kWh)	Energy sold to grid (kWh)
May	6,800	1,622
June	3,100	2,900
July	2,200	2,400
August	1,800	1,700
September	2,000	2,100
October	600	4,100
November	800	5,800
December	2,400	6,200
January	1,200	5,800
February	1,200	6,000
March	1,400	8,000
April	5,000	4,500
Total	**28,500**	**51,122**

Table 7.6 shows the generation from the PV system during May 2016 to April 2017. The total generation from the 56.4 kW_p system is 79622 kW h for one year. A PVSyst simulation (see Annexure X) shows that a 56.4 kW_p should generate 1,17,988 kWh in one year for the radiation and climatic condition available in Dundi. This means that the system has performed up t o 67.5% of its expected performance. Even with this moderate performance the economic benefits the system has caused to the stakeholders are considerable.

Benefits to Farmers who are Members of SPICE

The investment from the farmers is only 10% of the capital expense and the land footprint they lose due to the installation of PV modules in the agricultural field. The farmers have now adapted to new crops which would grow well under the shade of elevated solar panels. Since they have access to more water due to the presence of solar pumps, many of them have started farming high value crops such as spring onion, spinach, carrot and garlic. The farmers also responded that the neighbouring villages which depend on grid power for irrigation gets supply for hardly seven to eight hours a day and that too with frequent interruptions. Compared to that, they are more satisfied with the more predictive PV power which comes free of cost. As shown in table 7.5, the members of SPICE have made a saving or additional income worth Rs. 8,53,539. They started getting more pumping hours for their own cultivation, more hours for providing water to other farmers and a decent amount as income from energy sales to MGVCL. Even with half the rate of rent (Rs. 50/hour) they used to charge for diesel pumps, they earn Rs. 86,405 more in a year as compared to the case of diesel pumps. Table 7.7 shows that the increase in household income is almost by 50% and the income from energy sales contribute to 36% of the total annual income. Now they see the PV energy sold to MGVCL as a ‘cash crop’ which is free from all risks like crop failures and floods and which does not need any other inputs like fertiliser, seeds, irrigation or labour.

Table 7.7: Increase in household income of SPICE members after PV pump installation [153].

	Year	
Income in Rs from	**2015-2016**	**2016-2017**
Crops	5,28,670	4,97,792
Sale of water using solar pump	1,33,550	1,42,000
Sale of excess generation of energy from PV plant	6,523	3,64,500
Net household income/year	6,68,743	10,04,292

Benefits to Farmers who Purchase Water from SPICE

The small and medium scale farmers who purchase water from the well owners now benefitted from the reduced rate of water pumping services. A straight reduction by 50% (from Rs. 100 to Rs. 50 per hour) was available when the well owners switched to PV pumping. The number of irrigation hours they could avail also increased from 1857 to 2840.

Due to the increased availability of water at lesser price (due to the availability of solar electricity), land area under cultivation was also increased as compared to the previous years.

Benefits to MGVCL

The cost for extending grid to Dhundi and providing electricity connection to the premises where the tube wells are situated would have cost the DISCOM at least Rs. 12 lakh [153]. With 56.4 kW connected load, the farmers are entitled to get 1,62,432 kWh per year at Rs. 0.7/kWh (8 hours/day * 56.4 kW * 360 da ys). Even if two third of this is used by the farmers, the DISCOM would have incurred close to Rs. 4 lakh (1,62,432 kWh * 2/3 * (4.5-0.7) Rs/kWh) as subsidy. The DISCOM could also meet their REC obligation worth Rs 2.7 lakh as shown in Table 7.5. In short, the DISCOM is saved from Rs. 12 lakhs capital expense and around Rs. 7 to 8 lakhs per year recurring expense due to SPICE implementation. The 56.4 kW_p system generated 79622 kWh in one year. The saving on recurring expenses for DISCOM is Rs. 800000/- in one year. So the effective saving for the DSICOM in the first year is approximately Rs. 10/kWh. Even if they share Rs. 3.5/kWh of this saving back with the co-operative, they could top up on their APPC rate of Rs. 3.5/kWh, and they can offer an attractive PPA rate of Rs. 7/kWh, without any intervention using IWMI funds [153].

7.2.5 Other Models for Integrating PV into Agriculture Sector and Comparison with SPICE

DISCOM Centred Model with Capital Subsidy for Farmers

This is the current practice in most of the states under MNRE subsidy scheme, where the farmers who apply for grid connection are offered with off-grid solar water pumps with as high as 70% capital subsidies. The intention of this model is to rescue the DISCOM from further expenses in grid extension and losses through subsidies. But here, the farmers have to still contribute a considerable amount of Rs. 21,450/HP to own the pump whereas a 7.5 HP diesel pump cost only less than Rs. 30,000 [135, 159]. Moreover, the farmers do not have any incentive to preserve ground water since there is no option to feed excess power to the grid.

Developer Centred Agriculture Dedicated Solar Plants

Prayas Energy Group, Pune had advocated for a model in which PV plant developers may invest on a one to two MW_p PV plant in the panchayat lands and connect it with the local agricultural feeders [160]. Farmers would get free electricity throughout the day and the excess energy would be purchased by the DISCOM. The economies of scale can be benefitted in this model and the developers would be offered panchayat land free of cost. Standards bidding procedures and PPAs can be adopted and this does not involve any subsidies from the government. DISCOMs can meet the RPOs. This model however wouldn't motivate the farmers to save energy or ground water and there is no additional income generation to the farmers.

Developer Centred Distributed Model by Sun Edison

Sun Edison, an EPC company based in the USA came up with a model in 2016 where they offered grid connected solar water pumps to 220 farmers on a Build Own Operate Transfer mode [153]. Whatever was the PV module installation required for water pumping, the company would install 1.5 times of that capacity. Here the farmers had to contribute their land which is required to install the PV modules and the developer saves the cost of land. Farmers could use free electricity during day time and excess power generated was sold to grid at Rs. 9/kWh. Out of this, Rs. 8/kWh would be taken by Sun Edison towards their cost recovery and profit and Rs. 1/kWh was given as additional income to the farmers. The ownership of the system would be transferred to the farmers after 20 years. In this model, the incentive for energy and water conservation and opportunity for additional income for farmers is not very attractive.

Developer Centred Distributed Model by Gujarat Government

Government of Gujarat had announced a draft policy in 2016 which envisaged installation of three times of PV panels compared to the pump capacity in the farm lands, at the expense of a developer. The government would give capital subsidy of Rs. $41/W_p$ (if the developer do not avail accelerated depreciation) or Rs. $34/W_p$ (if the developer avails accelerated depreciation). The ownership of the system will be with the developer for first five years and the farmer will get one third of the electricity generated for free. Remaining energy would be sold to the DISCOM by the developer at a predetermined FiT. If the farmers do not want the entire one third energy entitled to them, they can also sell the same to DISCOM, but at 85% of the FiT. Remaining 15% of FiT will be directed towards the developer. In this model, the developer gets free land and capital subsidy from the government whereas the farmers get free electricity and have some incentive to save energy and ground water (because they can get additional income at 85% of FiT if they save on their entitled one third share of energy produced).

Farmer Centred Distributed Model by Gujarat Government

In June 2018, the Gujarat government announced 'Surya Shakti Kisan Yojana', a scheme which provides loans to farmers through NABARD and helps them install grid connected PV pumps [161]. The farmers have to pay 5% of the initial investment as their contribution and another 35% of the project cost in instalments in seven years. The government would subsidise remaining 60% of capital cost. The DISCOM would enter into a 25 year PPA with the farmers with Rs. 7/kWh for the first seven years (until the farmers repay their loans) and at Rs. 3.5/kWh for the remaining tenure.

Comparison

The first model (DISCOM centred capital subsidy) does not have any component which encourages the farmers to reduce their energy consumption or ground water usage. Also the upfront investment is unaffordable for small and medium farmers even after subsidy. In the second model (dedicated MW scale plants at villages), the farmers do not have any role in the maintenance of the power plant (since it is a centralised power plant managed by the developer) and continues to enjoy free electricity, which in turn may result in excessive pumping and water table depletion. The third model (developer centric distributed model in Karnataka) has some element of encouragement for the farmers to save energy and water, but it is not very attractive. The developer centric distributed model proposed by Gujarat in fact diverts huge amount of public money as subsidies into the accounts of private developers. Also, installing PV modules three times the actual requirement for pumping indicates more land footprint on the agriculture lands. Also, all developer centric distributed models are proposed with an assumption that the developers would be attracted by the fact that they will save on the land cost. But the land cost is only less than 5% of a MW scale plant [162]. It is not logically sound to argue that, to save this 5%, the investors wold risk their assets (PV systems) to be placed as bits and pieces in different fields under complex ownership and management conditions. They will also have to forego the economies of scale and have to spend more in monitoring and managing the distributed assets. The problem of power theft, higher transaction costs and vigilance cost are also issues. When compared to these models, SPICE has advantages of 'involvement' from the farmers in operation and maintenance, incentivises the farmers for saving water and energy and at the same time, have a collective ownership of the system hence enabling organised operations and lesser transaction costs to the utility. The farmer centred distributed model from Gujarat focues more on individual farmers, where the DISCOMs faces the issue of higher transaction costs. It does not has a provision for SPICE model co-operatives to avail loans from NABARD or invite investment from private parties and operate at a scale, with better stakeholder involvement.

7.2.6 Challenges in Replication and Scaling of SPICE Model

One of the major challenges faced during the formation of co-operative in Dhundi was the unavailability of clear land documents with the farmers. Most of the agricultural lands were owned my multiple members of a family and have been transferred from one generation to another without proper documentation. For the formation of the co-operative, the land owners have to prove their ownership of the land and hence on the well, and also provide an agreement which forfeits the right for subsidised electricity from DISCOM for 25 years. The minimum number of members to form a co-operative was reported to be six. So organising six farmers with clear land documents and with a well present in their premises was difficult.

The small and marginal farmers who did not have a well in their farm land were not eligible for joining the co-operative. The concept and spirit of a co-operative society was unknown to the farmers unless IWMI intervened and educated the farmers about this institutional structure. Hence an intervention from similar NGOs would be required in other regions for replication of such models.

The FiT from the DISCOM gets revised every year by the regulatory commission. Hence when a new member joins the Dhundi co-operative, the existing FiT from DISCOM is only Rs. 3.5/kWh (whereas the initial members were entitled to get Rs. 4.63/kWh). So there is unpredictability in the revenue from FiT. The water conservation bonus and the green energy bonus introduced by IWMI makes the revenue from sales of electricity to grid look attractive. But this amount is from the research grant of IWMI. Hence similar additional incentives cannot be extended to the new joiners of the co-operative.

Similarly, 90% of the capital cost of the first six pumps was provided by IWMI. So, in order to replicate more such co-operatives, the government should contribute a major share as capital subsidy. The 'Surya Shakti Kisan Yojana' initiated by Gujarat government provides 60% capital subsidy and 35% as loans to the farmers. The scheme also offers Rs. 7/kWh until the farmers repay the loans. If this offer is extended to farmer co-operatives as well, the scheme can result in more successful implementation.

7.3 Reflecting on Case Studies from Kerala after the Learnings from All India Surveys and SPICE Model

The learnings from the All India Surveys and the SPICE model had given rich insights about factors like types of ownership of the systems, need for institutional mechanism for regular maintenance of the systems, adoption of appropriate financial models, need for an end user centric technical and implementation strategy design and need for local training and capacity building of technicians. The studies mainly pointed out that collective ownership of systems or bringing together similar kind of users to form a user group would help in several ways. This can result in more formalised and organised way of system maintenance. The user groups can hire experts for design and implementation of systems, which may not be that easy, accessible and affordable for individual users. The group also provide a collective bargaining power and brings in some advantages of economies of scale. Such institutional ownership can also make it easier to have access to financial services like loans, grants, subsidies and other benefits.

The studies have repeatedly pointed out the fact that PV systems which are linked with regular cash flows (which can be income generation due to the use of the system, or saving in taxes and electricity bills, or additional income generation due to sales of energy with FiT etc.) are taken care off in a better way, irrespective of the system ownership model. This in fact indicates the need for moving towards policy instruments like FiTs and development finance from the current widely practised capital subsidy schemes. An attractive FiT would motivate the end user to bother about the performance of the system, to maintain it well and to take prompt corrective measures during failures.

It is very important to take the local DISCOMs into confidence while designing a PV dissemination strategy. Without grid connectivity, it will be difficult to maximise the usage of the PV systems and grid connectivity also helps in reduction of unnecessary cost in oversized storage systems. If it is possible to convince the DISCOMs about the possible benefits they could achieve, especially while promoting PV among their subsidised customer groups, much faster project completion cycles can be achieved. As a next level, if the DISCOMs would agree in sharing a portion of the benefits from the PV systems back with the customers, it can accelerate the adoption rate of PV.

The role of NGOs in various phases of PV dissemination shall be explored while strategizing PV dissemination programs. NGOs have contributed well in areas like awareness creation, training and capacity building of technicians, local institution building, and bringing in funds and aids related to PV projects.

Reflecting on the Chendamangalam case study, we can observe that the solutions proposed were addressing only the technology challenges. There were no financial models proposed. The products were very well designed based on unde rstanding the end user requirement, but the focus was more on i ndividual ownership of systems. The study suggested an approach for promoting a 'collective ownership' for domestic users under same distribution transformer, but there was lack of clarity in the financial aspects. The role of a local NGO in awareness creation and liaisoning with the public was taken care of by the women self-help groups in the locality. The assumption that just the energy bill saving would be good enough to motivate individual domestic consumers to adopt PV did not hold well.

The 'peak load shifter' project discussed in section 4.2 of this thesis primarily failed because it was more of a 'DISCOM centric' project. The product was designed primarily for managing the peak loads using PV panels and batteries. The customers' interest was not taken care of properly, nor where they offered any attractive FiTs or loan facilities. There was a missing link for awareness creation and 'localisation' of the product, rather it was launched as a state wide scheme with just seven vendors under the umbrella of KSEB. However, the concept of clubbing together the energy efficiency products with PV systems remains unique and was not observed in any of the models inspected during the surveys.

The learnings from SPICE model reinforces the proposal to have farmer co-operatives involved in solar pumping in the Kole lands. SPICE model had initial difficulties in the formation of a co-operative, since the idea itself was novel to the farmers. In Kerala, the farmers are already organised as a co-operative and hence the institutional model is already built. Even though there is no need for ground water conservation in the Kole lands, there is enormous potential for energy saving. The concept of 5% capital expense contribution from the farmer groups (as followed in SPICE model) can be considered in the proposal after consultation with the farmers. Another advantage of the project in Kole lands is that the project size is fairly large (2.25 MW_p). Land availability is not a major problem, since there are large tracts of uncultivable lands adjacent to the Kole. So the farmers need not worry about the footprint of the PV systems. Since there is a possibility of scaled operations, the project might look attractive for developers. If KSEB can be convinced to share a portion of their benefits from this project back with the farmers as FiTs, the project can be made more attractive to the farmers.

ANERT schemes were already proven ineffective in the field in terms of its inclusiveness as discussed in section 6.1 of this thesis. The schemes were purely based on capital subsidy mechanism and no methods were incorporated to make sure of the proper maintenance of the systems. ANERT had later in 2017 come up with establishment of regional repair centres for PV systems called “Akshaya Urja Service Centres” and trained technicians called “Urja Mitra” throughout Kerala [163]. This would expect help in providing better service for the PV systems installed. Another initiative from ANERT is to provide personal loans with three years tenure and at 9-10% interest rates [164]. This would also help the customers to manage the upfront cost of the systems.

The community rooftop PV project in Chalayoor tribal hamlet, discussed in section 6.5 of this thesis had all major components for a successful PV project. The project envisaged a group ownership model for the PV system, it had a component for income generation for the end users through energy sales to KSEB (event though it was not attractive at approximately Rs. 3.26/kWh (APPC rate, [165]), it had taken care of the need for a local trained technician for regular maintenance of the system, the government spent the capital expense of the system and there was no burden on the customers to pay upfront money. The local Kudumbashree (Women Self-Help Groups) handled the role of a local NGO and did their part of awareness creation and bringing together the consumers. The missing link was the lack of a formal local institution which owned and operated the project. Non-payment for the excess energy exported to KSEB grid was also a reason for the partial success of the system.

After the critical analysis of the success and failures of PV projects in Kerala and other parts of India in the present and previous chapter, it was also understood that the economics and financial viability of such projects play a vital role in the success or failure of the project. Hence in the next chapter, the cost components, return on investment from PV plants and associated economics in analysed in detail.

Chapter 8

Economic Viability of Rooftop and Distributed PV Systems, Business Models and Role of Financial Institutions

From the discussions in chapters 3 to 7 of this thesis, it was understood that the evaluation of the economic viability and adoption of appropriate financial models is very important for successful implementation and sustenance of distributed solar PV programmes. Hence in this chapter, reviews of the financial viability calculation tools and indicators which can be used for the economic viability evaluation of PV projects are undertaken. There are various financial viability tools used for evaluating an investment decision. Rooftop PV systems are now a days an excellent investment option for many, since it ensures regular returns at lower risks. The provision of availing accelerated depreciation benefits also makes PV an option for many industrialists and investors to claim tax exemptions. There are both static and dynamic methods for calculating financial viability for projects.

- **Static methods**: In these methods, the time value for money, i.e. discounting rates, interest rates etc. are not considered.

- **Payback Period**: A simple payback period calculates the duration required for an investment to start giving profits. Payback period = Capital Cost /Annual Net Savings
- **Return on Investment**: ROI is the annual return expected from a project represented as a percentage of its capital cost. It is the inverse of payback period.

* **Dynamic methods**: In these methods, the value of cash flows will be adjusted to the time or year in which the cash flow occurs. The interest rates and inflation rates are considered in this method.
  - **Net Present Value (NPV):** The capital expense is considered as a negative cash flow in the current year and the returns or cash flows in future years are adjusted for a discounting rate and translated to the present time. NPV is the difference between the initial capital expense and the sum of the returns for the entire project duration (translated to the current year). The net present value should always be positive for economic viability of a project.
  - **Internal Rate of Return:** The Internal rate of return is the discount rate at which the NPV is zero. It should always be more than the prevailing interest rates for availing capital from debt funds.

8.1 Levelized Cost of Electricity (LCOE)

Levelized Cost of Electricity is the cost of one unit of electricity from a power plant project, considering all its expenses for the life time. The cost is dependent on capital expenditure, cost of capital (debt equity ratio and interest on debts), cost on fuel inputs, and operational expenditures. LCOE is a convenient measure of overall competitiveness of different generating technologies [166]. As an attempt to understand the input costs of a PV system and its sensitivity on LCOE, I had developed a simple, Microsoft Excel based LCOE calculator. Later it was converted into a web page application with the help of two intern students in NCPRE during summer internship period of 2017 (June-July). The algorithm developed for the calculation of LCOE is attached as Annexure XI.

Familiarising the LCOE tool: Figure 68.1 shows the snap shot of the Microsoft Excel based LCOE calculation tool. The variables and inputs to this tool are explained below:

Capital expense: The initial cost will be dependent on the module technology and inverter technology you are using and also is determined by the source of material. Whether the inverters and modules are imported or indigenously manufactured also determine the cost. Even though there are import duty exemptions and price advantages for imported modules, there were many disputes at different ports regarding the import duties applicable to modules and inverters [167]. A typical breakup of capital expense of a 100 kW_p rooftop PV project is as shown in Table 8.1. The figures are in consensus with the MNRE bench mark price of Rs 55/W_p.

Table 8.1: Indicative cost split up of a 100 kW_p rooftop PV system [118, 168,169].

		Rate per	**Rs**	**Rate per kW_p (Rs)**
Materials	Panels	W_p	25	25,000
	Inverters	kW	7,500	7,500
	Mounting Structure	kW_p	4,000	4,000
	AC Cable	kW_p	500	500
	DC Cable	kW_p	500	500
	Combiner Box	kW_p	2,500	2,500
	Main Junction Box	kW_p	800	800
	Energy Monitoring Meters	unit	4,000	40
	Weather and Remote Monitoring System	unit	1,20,000	1,200
	Total			42,040
	GST	5%		2102
	Transport and Installation Charges	W_p	3	3,000
	Miscellaneous	5%		2,102
Services	Project Management, Design and Engineering	10%		4,204
	Service Tax	18%		1,675
Total				**55,123**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
2	*LCOE CALCULATOR*			Capacity of the Project		MW	0.5		Current grid cost		INR/unit	8.00		AD Available			40%		Plant Life	25	years		
3	**Net Returns to Investor (INR mn)**	**153.70**		Cost of Project		INR mn/MW	55.00		Expected escalation		% p.a.	4%		Corporate tax rate			33.99%		Loan Period	12	years		
4	**Total Savings for Consumer as Electricity Bills (INR mn)**	**206.54**		% of cost by Consumer		Themselves (I	30%		O&M Fees			2%							Generation	1.45	Mn units/MW		
5	**Pre-Tax IRR for Customer**	**58.6%**		Interest Payment to Bank			12.0%		O&M Escalation offer		% p.a.	4%							Deration	1.00%	p.a.		
6	**Total generation from the plant in life time (mn kWh)**	15.81600		**LCOE**	**3.88**	**INR/kWh**													First Year Deratio	1.50%			
7	**Cost of the Plant (Initial +O&M+Interest+Principal)**	(61.40)																					
8	**Total Project IRR**	**28.3%**																					
9	Financial Year		Mar-19	Mar-20	Mar-21	Mar-22	Mar-23	Mar-24	Mar-25	Mar-26	Mar-27	Mar-28	Mar-29	Mar-30	Mar-31	Mar-32	Mar-33	Mar-34	Mar-35	Mar-36	Mar-37	Mar-38	Mar-39
10	Year count		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
11																							
12	Generation from plant	Mn units		0.711860	0.70	0.70	0.69	0.68	0.68	0.67	0.66	0.66	0.65	0.64	0.64	0.63	0.62	0.62	0.61	0.61	0.60	0.59	0.59
13	Grid tariff trend	INR/unit		8.00	8.32	8.65	9.00	9.36	9.73	10.12	10.53	10.95	11.39	11.84	12.32	12.81	13.32	13.85	14.41	14.98	15.58	16.21	16.85
14	**Savings for Power Consumer**	**INR mn**		**5.69**	**5.86**	**6.04**	**6.22**	**6.40**	**6.59**	**6.78**	**6.98**	**7.19**	**7.40**	**7.62**	**7.85**	**8.08**	**8.32**	**8.57**	**8.82**	**9.08**	**9.35**	**9.63**	**9.91**
15																							
16	**Cashflow for Consumer**																						
17	Tax Benefit through AD and Interest Exemption	INR mn		4.49	2.93	1.97	1.36	0.98	0.72	0.53	0.40	0.29	0.20	0.12	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Initial Investment	INR mn	(8.25)	-	-	-	-	-	-	-	-	-	(2.75)	-	-	-	-	-	-	-	-	-	(2.75)
19	**Revenue from Bill Saving**	INR mn		5.69	5.86	6.04	6.22	6.40	6.59	6.78	6.98	7.19	7.40	7.62	7.85	8.08	8.32	8.57	8.82	9.08	9.35	9.63	9.91
20	O&M Fees	INR mn		(0.48)	(0.50)	(0.52)	(0.54)	(0.56)	(0.59)	(0.61)	(0.63)	(0.66)	(0.68)	(0.71)	(0.74)	(0.77)	(0.80)	(0.83)	(0.87)	(0.90)	(0.94)	(0.97)	(1.01)
21	Debt Repayment	INR mn		(3.82)	(3.63)	(3.43)	(3.24)	(3.05)	(2.86)	(2.66)	(2.47)	(2.28)	(2.09)	(1.89)	(1.70)	-	-	-	-	-	-	-	-
22	**Net Cash Flows W.R.T Consumer**	INR mn	(8.25)	**5.89**	**4.67**	**4.05**	**3.80**	**3.76**	**3.86**	**4.05**	**4.28**	**4.55**	**2.09**	**5.14**	**5.45**	**7.32**	**7.52**	**7.74**	**7.96**	**8.18**	**8.41**	**8.65**	**6.15**
23	**Cumulative Cash Flows W.R.T Consumer (and Equity Pa**	INR mn	(8.25)	(2.36)	2.30	6.36	10.15	13.92	17.78	21.83	26.11	30.66	32.74	37.88	43.34	50.65	58.18	65.92	73.87	82.05	90.47	99.12	105.27
24	**Net Cash Flows for the Project**	INR mn	(27.50)	9.70	8.29	7.48	7.04	6.81	6.72	6.71	6.75	6.82	4.17	7.03	7.15	7.32	7.52	7.74	7.96	8.18	8.41	8.65	6.15
25	**Cumulative Cash Flows of the Project (and Project Paybac**	INR mn	(27.50)	(17.80)	(9.50)	(2.02)	5.02	11.83	18.55	25.26	32.01	38.84	43.01	50.04	57.20	64.51	72.04	79.78	87.73	95.91	104.33	112.98	119.13
26																							
27	***Debt Repayment Schedule***																						
28	Interest Payment	INR mn		(2.21)	(2.02)	(1.83)	(1.64)	(1.44)	(1.25)	(1.06)	(0.87)	(0.67)	(0.48)	(0.29)	(0.10)	-	-	-	-	-	-	-	-
29	Principal Payment	INR mn		(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	(1.60)	-	-	-	-	-	-	-	-
30	**Total Debt Repayment**	**INR mn**		**(3.82)**	**(3.63)**	**(3.43)**	**(3.24)**	**(3.05)**	**(2.86)**	**(2.66)**	**(2.47)**	**(2.28)**	**(2.09)**	**(1.89)**	**(1.70)**	-	-	-	-	-	-	-	-
31																							
32	**Bank Credit Schedule**																						
33	Bank Credit extended			19.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	Opening Balance	INR mn		-	17.65	16.04	14.44	12.83	11.23	9.63	8.02	6.42	4.81	3.21	1.60	-	-	-	-	-	-	-	-
35	(-) AD benefit Sharing	INR mn		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	(-) Bank Credit repayment	INR mn		1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	-	-	-	-	-	-	-	-
37	Closing Balance	INR mn		17.65	16.04	14.44	12.83	11.23	9.63	8.02	6.42	4.81	3.21	1.60	-	-	-	-	-	-	-	-	-
38	Interest On Bank Credit	INR mn		2.21	2.02	1.83	1.64	1.44	1.25	1.06	0.87	0.67	0.48	0.29	0.10	-	-	-	-	-	-	-	-
39																							
40	**Depreciation and Tax Schedule**																						
41	Opening asset block	INR mn		-	16.5	9.9	5.9	3.6	2.1	1.3	0.8	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	(+) Addtion	INR mn		27.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	(-) Asset depreciated	INR mn		11.0	6.6	4.0	2.4	1.4	0.9	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	Closing Balance	INR mn		16.5	9.9	5.9	3.6	2.1	1.3	0.8	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	TAX BENEFIT via AD	INR mn		3.7	2.2	1.3	0.8	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	TAX BENEFIT via Interest	INR mn		0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.3	0.2	0.2	0.1	0.0	-	-	-	-	-	-	-	-
47	**Total Tax Benefit**	INR mn		**4.5**	**2.93**	**2.0**	**1.4**	**1.0**	**0.7**	**0.5**	**0.3991**	**0.3**	**0.2**	**0.1208**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Figure 8.1: Image of Microsoft Excel based LCOE calculation tool.

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It can be seen that almost 66% of the project cost is for modules, inverters and the mounting system. Again, 45% of the project cost accounts for just the module price.

- **Operation cost:** Project developers typically consider 1-3% of the capital expense as O&M expense. The rate is fixed based on the access to the site and availability of resources such as water, manpower etc. in the vicinity of the power plant. The escalation in O&M rates per annum was considered to be 4%.
- **Generation from the plant:** The amount of energy generated and injected to the grid on a year to year basis is a major factor affecting the LCOE. The generation from a plant depends on the local geo-climatic conditions and this is often captured in the capacity utilisation factor (CUF) of the plant. CUF is the ratio of the actual generation from a solar plant over a year to the maximum possible generation from it for the year. Maximum generation is considered with the plant generating at its maximum rated capacity for 24 hours and 365 days and with no grid interruption. Since PV plants work only during the day time, straight away 50% of CUF is lost. Again, since the generation follow a bell curve (not at maximum capacity all the time), further reduction in CUF occurs. The realistic values of CUF approved by various state electricity regulatory commissions for tariff fixation for solar power is 16-19% [170]. In our calculation, we have considered 16.5% i.e. a 1 MW_p plant will generate 1.45 million kWh a year.

- **Other factors affecting LCOE:**
    - ***Debt to Equity Ratio on capital investment:*** Debt to equity ratio of 70:30 is considered, i.e. only 30 % of the CAPEX is invested by the plant owner. Remaining 70% comes as debt funds at a particular interest rate.
    - ***Interest rates on debt funds and loan tenure:*** The tool has considered 12% interest rates for duration of 12 years.
    - ***First year and further annual degradation rates of modules:*** The generation from the plant is highly dependent on the degradation rates in modules. Generally a first year degradation rate of 1.5% and 0.8% degradation per year is assumed in financial calculations.

- *Current Energy Tariff:* The existing rate at which the PV system owner pays for electricity will determine the return of his investment. This value is used in calculating the paybacks and IRR.
- *Price escalation of electricity from grid:* The rate at which grid tariffs are increasing will also reflect on the viability of investment on solar. As per the Ujwal DISCOM Assurance Yojana (UDAY) by the Government of India, the tariff rates are supposed to be revised on e very quarter of the year and the tariffs are supposed to be increased at a rate of 5% per annum [171].
- *Accelerated Depreciation rates:* 80% of the CAPEX made on PV plants could be depreciated at the end of first year of the plant's operation as per government norms [172]. From the financial year 2018-2019 onwards the depreciation value has been revised to 40%.
- *Corporate tax rate:* The corporate income tax rate determines how much amount can be saved under tax benefits under AD provision. This will cut short the payback period by at least 2 years in general. Tax rate of 33.99% is considered, since the basic tax itself is 30% for domestic companies and there are further surcharges and cesses on top of this [173].

With the following parameters, the cash flows for 25 years life time of the plant was calculated and the LCOE for a typical 100 kW_p plant was calculated. The value was found to be Rs. 3.91/ kWh and the payback for an industrial consumer (assuming Rs. 9/ kWh as current tariff) availing AD benefit was found to be 3 years.

The payback period can be found out from the 'cumulative cash flows' of the project (refer row 25 of the table shown in Figure 8.1). The number of years taken for cumulative cash flow to become positive indicates the payback period. IRR was calculated by the inbuilt function in Excel with input being the net cash flows of the project. Net cash flow of any given year is (savings from electricity bill + savings from tax – debt repayment – O&M cost). AD benefit plays a major role in reducing the payback period. 40% AD benefit for a 100 kW_p project at Rs. 55,000/kW_p results in a payback period of 3 years. A diesel or gas based power generating unit has depreciation rate of 8.24% [172]. If the same was applicable in PV, the payback period would have been 4 years.

This tool can be effectively used in making a decision on whether or not to go for an investment in a PV power plant. The 'net cash flow' modelled in this tool also helps to understand whether the customer can manage their cash flows related to the PV system. In the example shown in Figure 68.1, row 22, the net cash flows are positive right from year two onwards. This means, the customer can maintain the system (O&M expenses) and repay the debt (term pay of the loan and its interest) with the savings from the electricity bills due to the installation of PV system. So, an appropriate debt-equity ratio and loan tenure to make net cash flows positive from year two itself can make the project proposal attractive to the customers.

The tool can also be used to study the sensitivity of various factors in the LCOE and economics of PV. The values of variables such as CAPEX, Debt: Equity ratio, interest rates, grid cost, CUF, degradation rates of panels etc. could be changed and study of its impact on LCOE could be done.

8.1.1 Sensitivity of LCOE to Various Input Variables

Module Price

In order to understand the sensitivity of LCOE to module price, the module prices where varied from Rs. 18/W_p to Rs. 30/W_p and the total cost of the project was calculated as per Table 8.1. LCOE corresponding to these different costs were calculated. Figure 8.2 shows relation between module cost and LCOE. A linear function fitting was also done on the trend line which is also shown super imposed to the original line plotted.

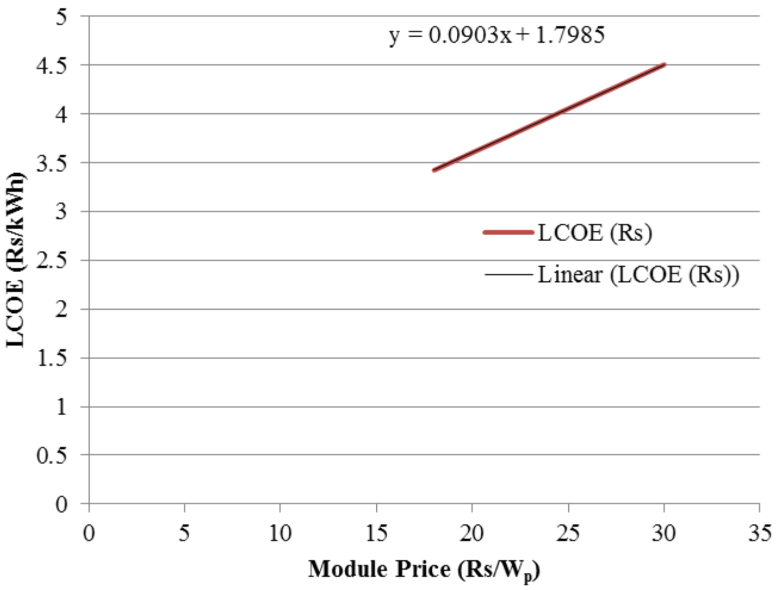

Figure 8.2: Change in LCOE with respect to change in module price.

The analysis shows that the relationship between the module price and LCOE is almost linear and the equation of the fitted curve was y = 0.0903x + 1.7985. A 10% reduction in module price would result in a 5.5% reduction in LCOE.

Capital Expense

The capital expense was varied from Rs. 6000/kW to Rs. 65,000/kW$_p$ and corresponding LCOEs were calculated with all other variables kept constant. Figure 8.3 shows the relation between capital expense and LCOE.

The relationship is linear and with every percentage change in capital expense, a corresponding percentage in LCOE was observed. This means a 10% reduction in capital expense would reflect in a 10% reduction in LCOE.

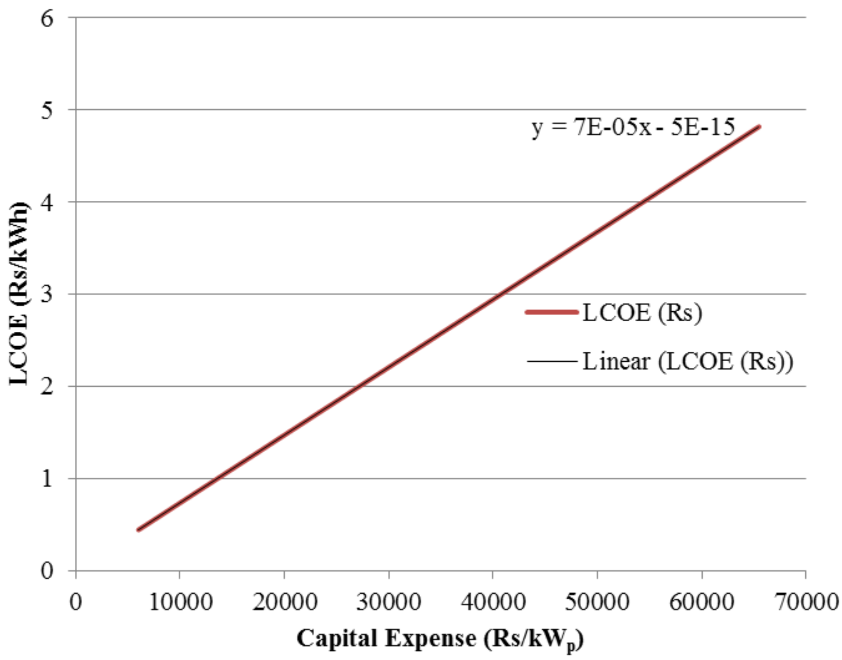

Figure 8.3: Change in LCOE with respect to change in CAPEX of PV plant.

Debt Ratio

A standard debt ratio generally considered in financial calculations is 70%. Remaining 30% of the expense is infused as equity. In order to understand the variation in LCOE as a function of debt percentage, the debt percentage was varied from 0 to 100 percentage and corresponding LCOE values were calculated. As the debt percentage was increased linearly, the contribution to the life time cost of the project increased proportionately as interest cost increases with debt.

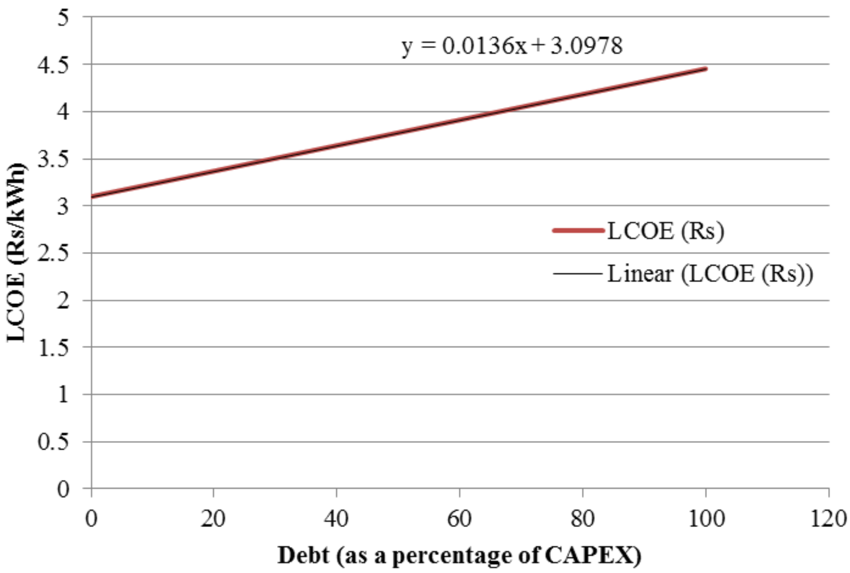

Figure 8.4: Change in LCOE with respect to change in debt ratio in CAPEX.

Calculations from Figure 8.4 show that a 10 % increase in debt percentage would result in a 2.35% increase in LCOE.

Interest Rate on Debt

10 – 12 % was the bank lending rate for industrial projects in India during 2008-2018 [174]. In order to understand the impact of change in interest rates on LCOE, an analysis was done by varying the interest rates from 2.5% to 22.5% linearly. Figure 8.5 shows the results of the analysis and the relation between both the variables was found to be linear. It was calculated that with every 10% increase in interest rate, the LCOE would increase by 2%.

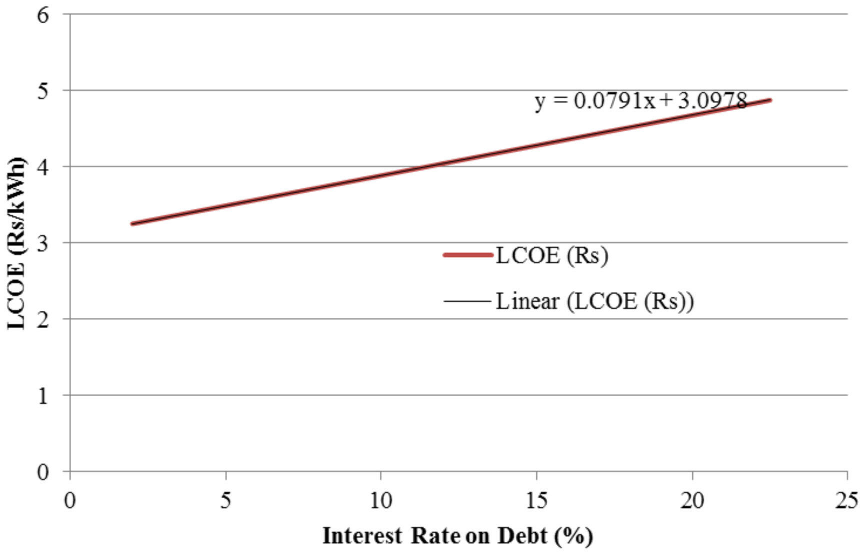

Figure 8.5: Change in LCOE with respect to change in interest rate on debt.

Degradation Rate of Output Power of Modules

The annual degradation rate in power output of the module decreases the annual generation year on year. Hence the annual degradation of power has great impact on the lifetime generation of the plant and hence the LCOE. All India Survey reports from NCPRE, shows that degradation rates as high as 6%/year was observed in field [139]. Hence the degradation rate was varied from 0.05%/year to 6%/year in steps of 0.05% and the corresponding LCOE values were calculated. Figure 8.6 shows the result and the curve fitting of data points resulted in a polynomial function of second order.

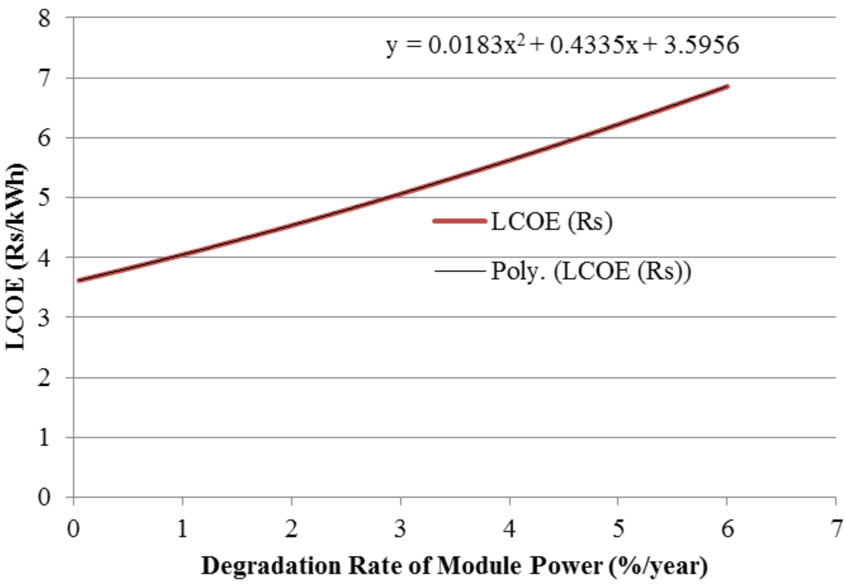

Figure 8.6: Change in LCOE with respect to change in module degradation rate.

Sensitivity analysis shows that a 10% relative increase in degradation rate would induce a 1.2% increase in LCOE. This means if the degradation rate increases from 1% per annum to 1.1% per annum, the LCOE increases by 1.2%.

Debt Repayment Tenure

The loan repayment period and yearly repayment amount would determine the total cost incurred as interest. Other than the interest rate, this would also influence the life time cost and LCOE. Figure 8.7 shows that the change in loan tenure is linearly and directly related to LCOE. A 10% change in repayment tenure would result in 2.2% change in LCOE.

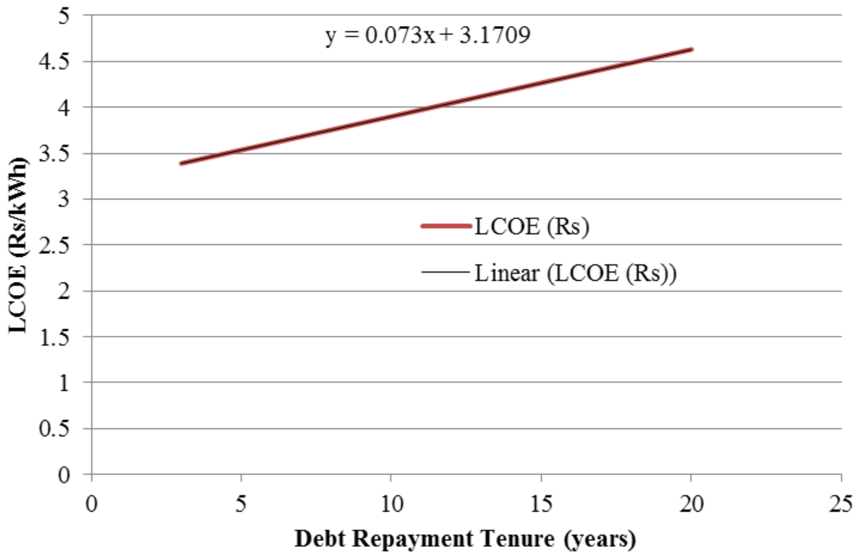

Figure 8.7: Change in LCOE with respect to change debt repayment tenure.

Capacity Utilisation Factor (CUF)

CUF considered for calculation determines the annual generation from the plant. CUF was found to be related to LCOE in a non-linear manner. A linear increase in CUF would result in second degree decrease in LCOE. Figure 8.8 shows the correlation between CUF and LCOE. At CUF value 16.5% (considered in Table 8.1), sensitivity analysis shows that with 10% relative increase in CUF, LCOE would decrease by 8.25%.

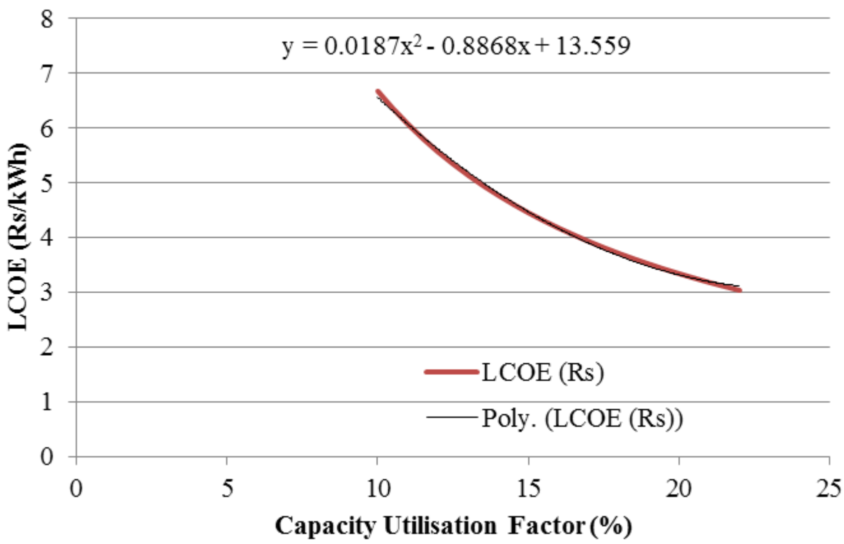

Figure 8.8: Change in LCOE with respect to change in CUF.

Life of the Power Plant

Generally 25 years is considered as the useful life of the plant. In certain cases, when the power plant is built by a developer and handed over to the end user after a fixed period of operations under BOOT method, the LCOE and hence the PPA rates have to be determined with different time duration. The relationship between LCOE and plant life was also found to be non-linear as shown in Figure 8.9. If the useful life of the plant could be extended by another 10%, LCOE would decrease by 2.2%.

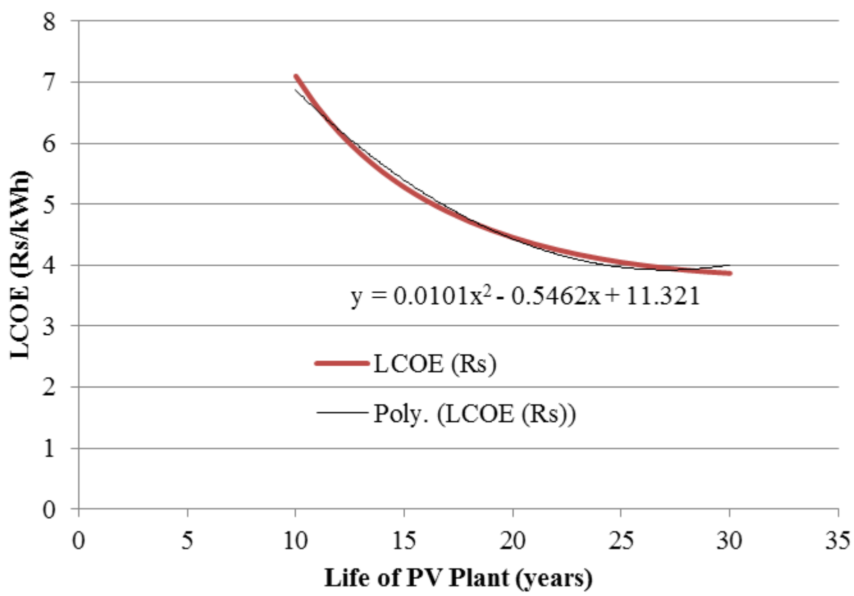

Figure 8.9: Change in LCOE with respect to change in useful life of PV plant.

Operation and Maintenance Cost

The O&M expense is generally calculated as percentage of CAPEX. For large power plants, this figure comes around 1 – 2 % of CAPEX [175]. Hence the O&M cost was varied between 0.5 to 6.75 % and the corresponding changes in LCOE was studied. For every 10% relative change in O&M cost, the LCOE would change by 3.35%.

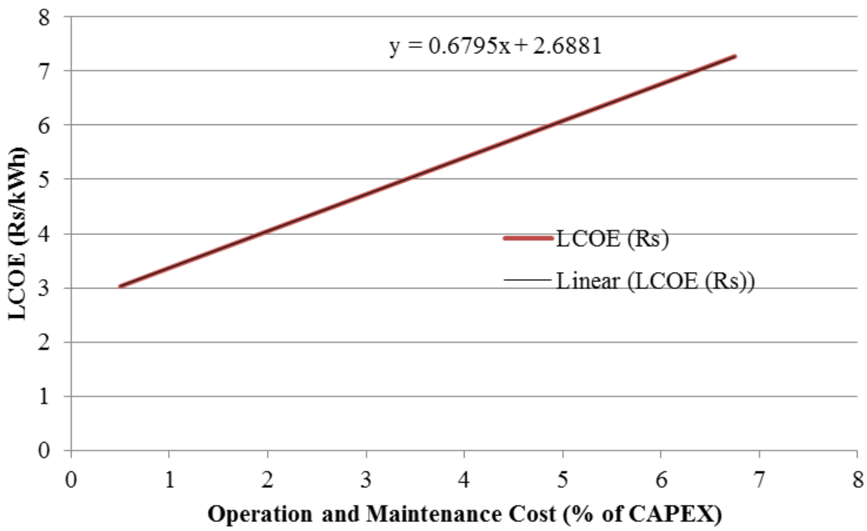

Figure 8.10: Change in LCOE with respect to change in O&M cost of PV plant.

Escalation in Operation and Maintenance Cost

The O&M expenses are revised year after year at a predetermined escalation rate to capture the increments in salaries for labour and to negate inflation and other factors which reduces the net value of currency. Central Electricity Regulatory Commission (CERC) has recommended 5.72% as O&M expense escalation rate [175]. The escalation value was changed from 1.5% to 5% per year. Sensitivity analysis shows that if the O&M escalation changes by 10%, LCOE would also change by 2%. Figure 8.10 shows the rate of change of LCOE w.r.t. recurring annual O&M expense and Figure 8.11 shows the sensitivity of LCOE towards annual O&M escalation rates.

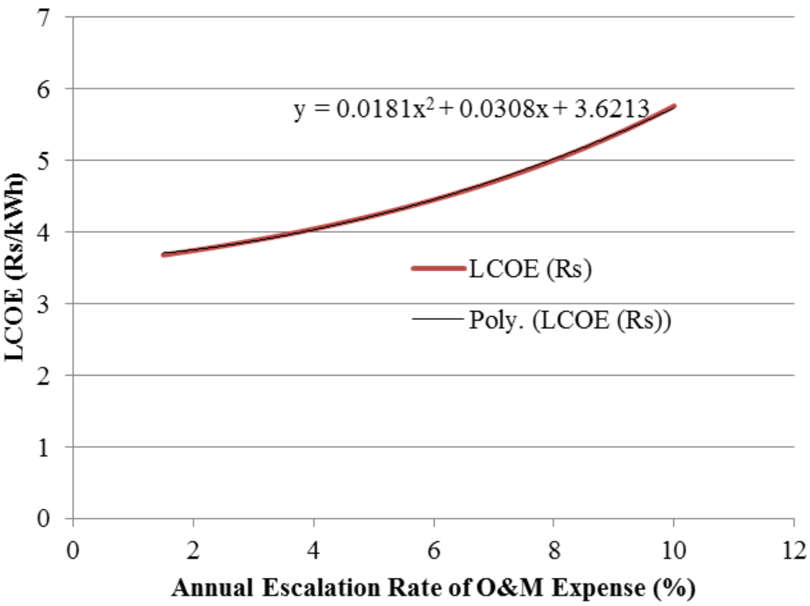

Figure 8.11: Change in LCOE with respect to change in escalation rate of O&M cost.

Table 8.2 has summarised the results of sensitivity analysis of LCOE to various input variables.

Table 8.2: Sensitivity of LCOE to various input variables.

Variable	Nominal Value	Percentage Change in LCOE when the Input Variable Changes by 10% of Its Nominal Value (%)
Module Price	Rs 25/W_p	5.5
CAPEX	55,000/kW_p	10
Debt	70% of CAPEX	2.35
Interest Rate on Debt	12%	2
Degradation Rate of Output Power of Module	1% per annum	1.2
Debt Repayment Tenure	12 years	2.2
Capacity Utilisation Factor	16.5%	8.25
Useful Life of Power Plant	25 years	2.2
O&M Expense	2% of CAPEX	3.35
Escalation in O&M Expense	4% per annum	2

8.2 Business Models in Rooftop PV

Based on the learnings from chapters 3 to 6, it is clear that Kerala has a potential for at least 300 MW distributed among the various categories of consumers. Discussions in chapter 7 have emphasised on the importance of choice of appropriate ownership models and financial models for each category of consumers. Now it comes to the question, how to realise the potential in each segments of the market. The success of PV penetrating into all segments would depend on what business model is proposed to each of the sectors. A brief discussion on the potential business models which can be workable with different market segments in Kerala is given below:

8.2.1 Community Based Leased Rooftop Models for Colonies (Low Income Groups), where Government Welfare Funds can be Utilized

The case study of Chalayoor tribal hamlet has brought out the pros and cons of a community level rooftop PV project for low income groups of the society. If the flaws in the implementation (like not forming a local administrative mechanism with stakeholder participation, improper distribution of FiTs and other incentives etc., as discussed in chapter 7) can be rectified in this model, the model could be made successful in the field. In this model the government may have to invest (partly or fully) on the projects for financially lesser privileged people. Development loans with government providing guarantee for repayment can also make such projects into realities.

8.2.2 Build Own Operate and Transfer (BOOT) Model for Government Buildings

Third party developers can invest on the PV systems on the rooftop of government buildings and get the money back through the sales of electricity to the same building. The developers can offer slightly lesser amount per unit than what KSEB charges the offices. As already discussed in chapter 3, section 3.1.1, instead of KSEB supplying power at Rs. 5.87/kWh [35] for government departments, the government should initiate RESCO model projects at Rs. 3.97/kWh [70] and save KSEB from its burden. The issue of 'improper maintenance' of PV systems in government buildings, as identified in the All India Surveys (refer section 7.1.2 of this thesis) would also be solved in RESCO/BOOT model. Since the revenue of the companies would be dependent on the performance of the PV system, they would be proactively cleaning the panels and maintaining the systems. This becomes a win-win situation for the government departments, KSEB and the developers.

8.2.3 CAPEX Model with AD Benefit for Industries and Commercial Establishments

Profit making companies are encouraged by the government to invest in PV power plants, since they are offered the option of Accelerated Depreciation (AD) benefits. Most of the commercial and industrial users can go for CAPEX model and get the dual benefit of bill saving and tax saving. From financial year 2018-2019, the depreciation value has been revised to 40%. If a company can make an investment of Rs. 10 lakhs from their profit to build a PV plant, they can claim tax exemption for Rs. 4 lakhs in the first year and effectively save Rs. 1.2 lakh from tax paid (corporate taxes are approximately 30% [173] and the company have to pay income tax of 30% of 10 lakh profit as income tax otherwise). Another Rs. 2.4 lakhs can be depreciated (i.e. 40% of the remaining Rs. 6 lakh) in year two and so on. Industries in manufacturing sector with large roofs and high consumption of electricity can make use of this opportunity.

8.2.4 Flip Ownership Model for Educational Institutions which are Owned by 'Trusts'.

Many educational institutions in Kerala are run by managements which are registered as non-profit organisations. They are exempted from income taxes. These entities who cannot claim for AD benefit, can find an AD eligible partner (a for profit organisation) and ask them to invest a part of the CAPEX and become the co-owner of the system. The AD can be claimed on the books of the partner. After 3 years, when almost 100% of value can be depreciated in tax benefits, the partner can transfer the ownership of the plant to the trust/NGO who actually 'owns' the system with major share of CAPEX investment.

8.2.5 Leasing Rooftops to Private Investors of Open Access Projects

If the rooftop owner's consumption is very less as compared to the installation potential (in the case of auditoriums, warehouses, etc. which has large roofs but seasonal occupancy and sparse use of electricity as compared to their roof area and PV installation and generation potential), there is a possibility for project developers to take these roofs on lease, install and generate electricity through PV plants and sell it to the grid/private purchasers. This model is possible only in those states where FiTs and gross metering is possible. For open access, the PV plant size has to be more than 1 MW_p. Hence those roofs with more than 10,000 sq. m. (which can accommodate 1 MW_p) can be considered for such installations. Developers would save on land cost, civil foundation works, and structure cost as compared to ground mounted systems.

8.2.6 Clubbing Energy Efficiency and PV to Make Economics Viable for the Middle Income Class Domestic Customers

The case study in chapter 4, section 4.2 of this thesis had concluded with the fact that planning for a technology dissemination strategy which would club together PV and energy efficient equipments would be more appealing to the residential sector. For domestic consumers who are interested to 'go solar', an innovative package including both energy efficient equipments and PV systems can be proposed. The energy efficient equipments ensure a reduced energy bill, even if the PV system fails to work during monsoon and bad climatic conditions. Such a package will give the user a faster payback. Agencies like Energy Management Centre (EMC) who initiates energy efficiency and energy saving programmes in Kerala should work together with ANERT and KSEB to formulate and implement such schemes [176].

8.3 Role of Local Financial Institutions

It is evident from the case studies in chapters 3 to 7and from the financial models discussed in this chapter that role of a financing organisation is very important in the wider dissemination of PV. With respect to Kerala, this role can be taken up by the co-operative sector banks. There is a separate ministry and institutional mechanism for the control and working of co-operative banks. Compared to nationalised banks, the co-operative banks have better reach and better relationship with the customers especially in rural areas [177]. The co-operative banks have also played important role in the past for the dissemination of LPG stoves and connections through micro-credits to its customers [114]. It is reported that the number of primary co-operatives in Kerala are 1647, with a membership of 2.29 crore. The total deposits from the primary societies, the 14 district co-operative banks and the apex bank – Kerala State Co-operative Bank is Rs. 110,000 crore [178, 179]. Together this sector holds 30% of banking share of the state.

22.2% of the state's agricultural credits are advanced through co-operative banks [180]. They are familiar with the re-financing options of funds from NABARD for agricultural purposes. Counting on their prior experience, the government of Kerala has released a circular which basically asks the primary co-operative societies to extend loans at 9-10% interest for 36 months and for principal amounts from 3 to 5 lakhs for purchase of renewable energy systems [164]. This is a positive sign as far as the distributed PV sector is concerned.

8.4 Conclusions

Economic viability of PV systems is important while designing programmes for PV dissemination. Levelized Cost of Electricity (LCOE) is a good indicative variable to compare and evaluate the viability of PV projects with other power generation options. LCOE can be calculated using a complex function with multiple inputs. The most sensitive input cost for LCOE is the PV module cost which constitute as high as 66% of capital expense in rooftop PV projects. Economic viability can be attained in PV projects through various means. Decreasing the capital expense is one straight forward option, but there can be other means like increasing the debt investment and availing debts at lower interests, adopting technologies relatively affordable, but with better generation in the given geo-climatic regions (hence improving the CUF), adopting proven technologies with lesser degradation rates and hence ensuring long term performance and returns, controlling the O&M expenses etc. are other options.

Accelerated Depreciation is one of the major driving factors bringing in investments for PV plants among the private sector. Appropriate business models and financial models shall be used to different class of consumers so as to make the PV dissemination scheme attractive. Other than the currently prevailing CAPEX and RESCO (BOOT) models, other innovative models like the flip ownership models and solar-energy efficient product packages with loan facility shall be tried out.

Credit facility at low interest rates shall be a great accelerator for PV dissemination programmes. Banking sector has to support the government and the people by proactively offering retail banking services for adopting solar plants. In the context of Kerala, the primary credit societies and co-operative banking sector can also play a major role in offering financial services for purchasing PV systems.

Having understood the economics behind the success and failures of PV system dissemination models in this chapter, the next chapter looks into the different government policies in place in India at central and state level, which facilitates or limits the wider adoption of PV systems among the masses.

Chapter 9

Policy Framework and Facilitation: Comparison of State Solar Policies in India with Kerala Solar Energy Policy

Public policies and regulations do pl ay an important role in the large scale dissemination and adoption of any new technology in a country. The features of public policies and the different strategies used by various countries in popularising PV were already reviewed in section 2.3 of this thesis. In chapters 2 to 8, all major aspects regarding the dissemination of PV including the resource assessment, planning, technology packages and technology innovation needed, awareness creation, role of various institutions, the market potential, financial and institutional models, economic viability etc. were discussed. In this chapter, the policies and regulations issued by different states in India are being reviewed and compared with each other. Finally, the salient features of each of the state policies are compared with the Kerala's state solar policy. This gives an indication towards, how equipped is Kerala, in terms of legal and policy aspects to promote the PV sector.

Electricity is a concurrent list subject at entry 38 in list III of the seventh schedule of the constitution of India. In India's federal governance structure this means that both the central government and India's state government are involved in establishing policies and laws for its electricity sector. This principle motivates central government of India and individual state government to enter into memorandum of understanding to help expedite projects and reform electricity sector in respective state.

Electricity in India has a political dimension to it also. Many governments in India come to power with a promise to keep the electricity tariffs well within the reach of the residential and agricultural consumers. The system of cross subsidization where industrial and commercial consumers pay more, to subsidize the agricultural and residential consumers is prevalent in all states. We have been looking at the tariffs in Kerala in various chapters of this thesis, for a difference, Table 9.1 shows the category of consumers in Tamil Nadu who enjoys partial or full subsidy from government on their electricity bills. Most of the consumers either belongs to agricultural category or to the residential category because it forms the major vote base. Situations are not much different in other states as well.

Table 9.1: Categories of consumers who are partially or fully subsidized in Tamil Nadu [181].

Tariff Code	Category of Consumer	Tariff Fixed by TNERC (Rs/ kWh)	Tariff Paid by the Consumer (Rs/kWh)	Comments
HT-IV	Lift irrigation societies for agriculture registered under co-op societies	6.35	0	Fully subsidized
LT-IA Domestic	Consumption up to 100 uni ts bi-monthly	3.00	0	Partly subsidized
	Consumption above 100 uni ts and up to 200 units bi-monthly	3.25	0	

	0-100 units			
	101-200 units	3.25	1.50	
	Consumption above 200 uni ts and up to 500 units bi-monthly 0-100 units	3.50	0	
	101-200 units	3.50	2.00	
	201 to 500 units	4.60	3.00	
	Consumption above 500 uni ts bi-monthly 0-100 units	3.50	0	
	101-200 units	3.50	2.00	
	201-500 units	4.60	3.00	
	Above 500 units	6.60	6.60	
LT-IB	Huts in village panchayat	4.95	0	Fully subsidized
LT-IIC	Actual places of public worship	5.75	2.85	Partly subsidized
LT III-A	Power looms Up to 500 units	5.20	0	Partly subsidized
	501-750 units	5.75	0	
	751-1000 units	5.75	2.30	

	1001-1500 units	5.75	3.45	
	Above 1500 units	5.75	4.60	
LT IV	Agriculture, sericulture, floriculture, horticulture, fish/prawn culture etc.	3.22	0	Fully subsidized

Therefore with this backdrop, it is interesting to look at the structure at the state level which helps the dissemination of rooftop solar systems in the state and its interaction with the centre. Figure 9.1 shows the overall structure of power sector in India.

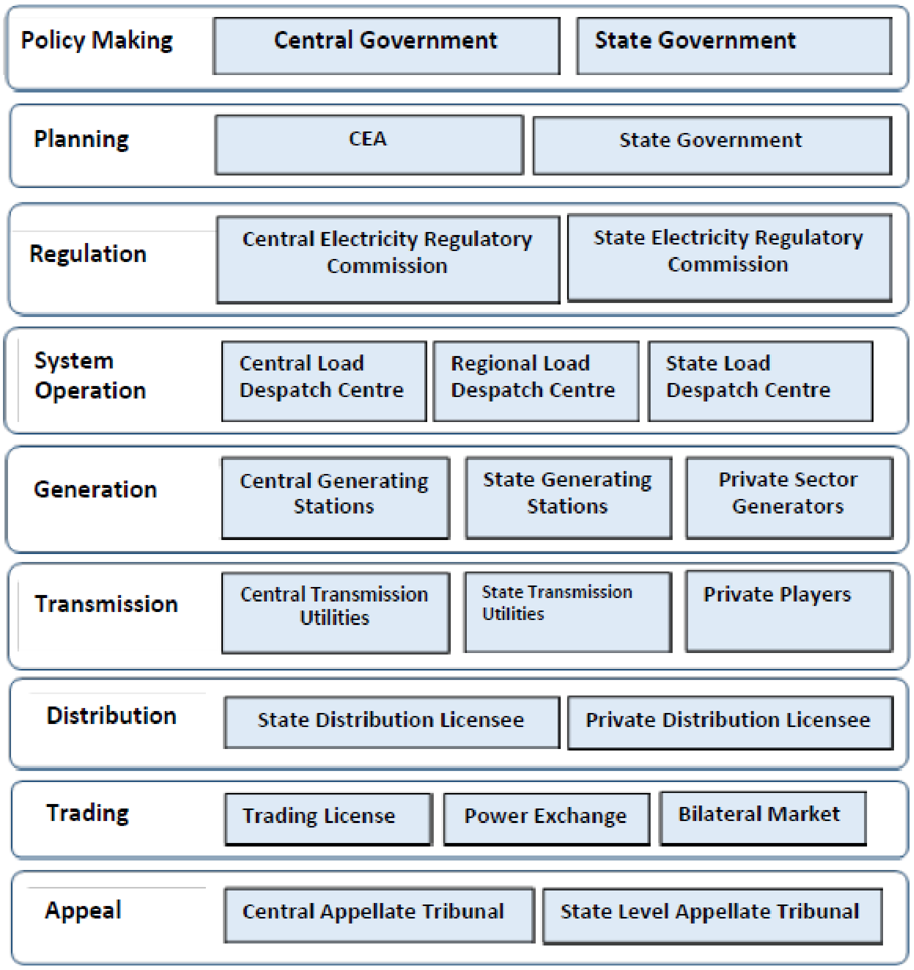

Figure 9.1: Structure of power sector in India [182].

It can be seen that for every function there is a body at the centre and state level which works closely in the direction to push electricity reforms in our country. With the impetus provided by the centre, almost every state in the country has now a state solar energy policy. Incentives like Generation Based Incentives (GBIs), Accelerated Depreciation (AD), Viability Gap Funding (VGF), Central Financial Assistance (CFA), and Feed-in-Tariffs (FiTs) at the federal and state level have helped increase India's total installed capacity by over 80% during 2016-2017 [14, 17].

The 100 GW solar target set by the government was distributed among the different states proportional to their power consumption. Maharashtra and Uttar Pradesh are expected to add higher capacities at 4,700 MW and 4,300 MW, respectively. Tamil Nadu and Gujarat have been given a target of 3,500 MW and 3,200 MW. Karnataka, Andhra Pradesh, Rajasthan, Madhya Pradesh, Punjab, Telangana and West Bengal are expected to add rooftop capacities between 2,000 MW and 2,300 MW. All other states will have to add capacities in the range of 50 MW to 1,600 MW. These capacities were expected to be built between fiscal years 2015-16 and 2021-22, according to an official document from MNRE [183].

The SECI (later renamed as RECI), DISCOMs of the respective states and the state nodal agencies of MNRE are the designated agencies for the implementation of the grid connected solar rooftop programme. The subsidy/Central Financial Assistance (CFA) for the programme, if any, will be provided through these implementing agencies. Grid connected solar rooftops can come up in a big way with supportive state government policies and SERC regulations. The importance of state level policies stems from the fact that electricity is in the concurrent list and to achieve the vision of the central government there needs to be a strong co-operation from the states.

9.1 Comparison of Policy Features across the States

An un-ambiguous policy framework for introducing, regulating and promoting roof mounted systems were not in place in most of the states till the beginning of 2016. In those states where the policies existed, the implementation of systems had not gathered momentum at the ground level [184]. The central government had released an indicative policy for the states in 2013 and specific year wise targets for individual states. Fifteen states were having their rooftop solar policy by June 2015 and only 11 of them had the State Electricity

Regulatory Commission's (SERC) directives on how to implement the policies. By January 2017, twenty states have solar policies supporting rooftop solar PV and state electricity regulatory commissions of 34 s tates / Union Territories (UTs) had issued guidelines and regulations for net or gross metering.

There are two major policy documents for every state as far as rooftop PV is concerned. The first one is the state solar policy or the rooftop policy document released by the ministry of power or electricity of the respective states and the second one is the State Electricity Regulatory Commission (SERC) directives which explains in detail on how to implement the state solar policy. The first document is most of the times an overview of target capacity to be installed in a stipulated timeline, RPOs for different customer segments, provision for open access, wheeling charges exemption, tax and duty holidays and subsidies by state. The SERC guidelines give clarity on tariff fixation, net metering/gross metering arrangements, technical details of interconnection, metering, billing and similar technicalities. The regulations by SERC are prerequisites for the DISCOMs to permit connectivity of PV systems to the distribution grid.

The State Solar Energy Policies of 17 s tates and Union Territories namely Andhra Pradesh, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Kerala, Manipur, Odisha, Rajasthan, Tamil Nadu, Telangana, Uttarkhand, West Bengal, Delhi and Puducherry have been reviewed in this chapter. The states like Punjab, Uttar Pradesh and Madhya Pradesh have dedicated solar rooftop PV policies released by respective state governments, which were also reviewed. The regulatory commission orders and amendments thereof of all states and seven union territories have been reviewed. The details of public consultations held by the SERCs, documentation of submission received and the responses of the SERC have also been studied to get a better understanding of the evolution of the policy. Table 9.2 summarises the types of documents reviewed.

Table 9.2: Types of policy documents reviewed.

Policy	Contents
State Renewable Energy Policy/ Solar Power Policy	Umbrella policies for renewable energy scale up in the states. It has sections regarding solar energy and rooftop PV segment. Specifies targets to be achieved, financial incentives etc. are discussed [185 – 193].
Regulations by State Electricity Regulatory Commissions	General conditions for installation of the rooftop PV system, obligation of the distribution licensee to provide connectivity, specifications, standards and safety, metering arrangement, procedure for granting connection to the solar energy system, accounting and settlement of energy, obligations, responsibilities and exemptions [59, 194 – 209].
State Rooftop Solar Policies	Year wise capacity targets, permissible metering arrangements, conditions for third party installations, metring arrangement, standards of interconnection, operation and maintenance, incentive structure, registration process and procedures [210, 211]
Submissions by Distribution Licensees, Consumers, other Stakeholders to SERCs and Response of SERCs	Grievances, suggestions to SERC Response of SERC to specific issues and related amendments in policy [71]
Official Memorandums, Guidelines from DISCOMs	Issued by Distribution Companies as directives to consumers [212 – 214]

Three sets of policy documents regarding technical and safety standards issued by the Central Electricity Authority (CEA) provide the basic procedural, technical and safety standards to rooftop solar PV systems and are used as benchmarks by many state policies.

1. Technical Standards for Connectivity of the Distributed Generation Resources 2013 [215].
2. Central Electricity Authority (Measures Relating to Safety and Electric Supply) Amendment Regulations 2015 [216].

3. Central Electricity Authority (Installation and Operation of meters) (Amendment) Regulations 2014 [217].

9.1.1 Attributes for Comparison of State Rooftop PV Policies

The policies and regulations in different states varied widely in terms of their focus areas and details that were specified. A set of attributes was developed for the systematic comparison of the policies. The attributes were developed considering the vantage point of a prospective consumer. The attributes were aimed at capturing

1. Relative quality of options available to a consumer.

2. Ease with which the consumer would be able to install, commission and operate such a system.

3. Other unique features of policies if any.

The initial list of attributes has been modified with inputs from the industry and academia. A final list of 36 qua ntitative and qualitative attributes have been used for comparison was prepared. They are presented in Table 9.3. The set of attributes have aimed to cover necessary details comprehensively. But the significant diversity in the policy documents of states meant that all attributes were not often specified in each of the state's policy documents. An attempt has been made to comprehend the implications of the policies in qualitative and quantitative terms. A discussion on t he results of the comparison is presented in the following sub sections of this thesis. Table 9.4 presents relevant information about policy initiatives of individual states that have not been mentioned in the general discussion.

Table 9.3: Attributes for comparison of state solar policies.

Basic Details of the Policy	Name of the policy
	Date of launch / last amendment
	Validity
	Capacity targets under the policy
Economic Parameters	Power purchase cost
	Pooled purchase cost of electricity in the state (Rs/kWh)
	Capital subsidy from State Government or other agencies

	Proposed escalations of tariff
	Banking facility for power
	Wheeling charges
	Exemptions from cross subsidy
	Applicability of RPO obligations
	Applicability of Renewable Energy Certificate Mechanism (REC)
	Applicability of benefits from Clean Development Mechanism (CDM)
	Initial charges for application and registration
	Other financial incentives
	Conditions for third party installations
Specifications of PV Systems	Type of metering (Net/Gross)
	Restriction in system capacity
	Individual capacity limits permitted
	Restriction in energy injection
	Connectivity voltages specified
	Restriction on capacity at Distribution Transformer (DT) or Feeder level
Metering Arrangement	Metering requirements
	Settlement period
	Annual update of capacity mandated (yes / no)
	Annual update of capacity to consumers (yes / no)
	Accounting procedure for ToD metered consumers
	Requirement of check meter
Registration Process	Procedure for obtaining connectivity
	Indicative net metering connection agreement / power purchase agreement
	Schematic diagram
	Initial charges
Remarks	Unique initiatives or any other relevant information

9.1.2 Eligibility Criteria for Consumers to Install Grid Connected Rooftop PV

All states and all union territories have allowed all categories of electricity consumers as 'eligible' for installing grid tied rooftop PV systems, except in Tamil Nadu and West Bengal. In Tamil Nadu, all LT and HT industries, places of public worship and power loom industries are not eligible for net metering arrangement under the "Order on LT Connectivity and Net-metering, in regard to Tamil Nadu Solar Energy Policy 2012" [203]. The West Bengal Electricity Regulatory Commission (Cogeneration and Generation of Electricity from Renewable Sources of Energy) Regulations, 2013 specifies that rooftop solar PV sources can be installed for injecting into the distribution system of a licensee only by institutional consumers [201]. Andhra Pradesh had amended the rules to include single phase consumers who had been excluded earlier [214]. Thus all the state policies are facilitative. Subject to technical feasibility and restrictions on capacity, all policies mandate the provision of grid connection to rooftop solar PV systems to interested consumers on non-discriminatory first come first serve basis. For most of the state policies, the metering arrangements are applicable to systems installed in the consumers "premises" which include rooftops or/and Open areas on the land, building or infrastructure or part or combination thereof.

9.1.3 Net Metering vs Gross Metering

This section has the comparative discussions on the features and attributes of different state policies with regards to the metering arrangement for PV plants.

Net Metering: In this metering arrangement, whoever installs a rooftop grid connected PV system, their existing energy meter will be replaced by a new bi-directional meter, which can account for flow of energy in both directions, i.e., from within the consumer premises to the grid and vice versa. Whenever the PV generation is less than the local loads from the premises, the additional energy is drawn from the grid. Whenever PV production is excess, it is pumped into the grid. Hence the priority here is to promote more local usage of energy from PV. The customers who produce more energy than what they consume in a month will be exempted from bill payment in that month and the excess energy produced will be carry forwarded for adjustment in the next month. Even after a year of billing cycle, if the consumer has some excess energy banked with the utility, in some states, they will be paid a fixed amount per unit of excess energy pumped into the grid. A customer who generates fewer units than what he actually consumes will have to pay for the additional consumption he has drawn from the grid. Some states policies keep a cap in the amount which can be fed back to the grid. The major fact in net metering is that the 'economic viability' is calculated at the customer's existing tariff.

Gross Metering: Here the entire PV generation is exported to the grid and accounted using a solar energy meter. The consumer who owns a rooftop PV continues to pay his electricity bills at his prevailing tariffs. The SERC fixes a "Feed in Tariff" for the energy he has fed into the grid and the utility pays the rooftop PV owners in a separate financial transaction at the FiT rates according to the generation. Here the financial viability is calculated at FiT rate.

Generally the FiT for gross metering is comparatively higher than the prevailing tariff for domestic sector consumers. So for them, gross metering is more attractive than net metering. Whereas for industries and commercial establishments, net metering is more attractive since they have higher tariffs for energy consumption.

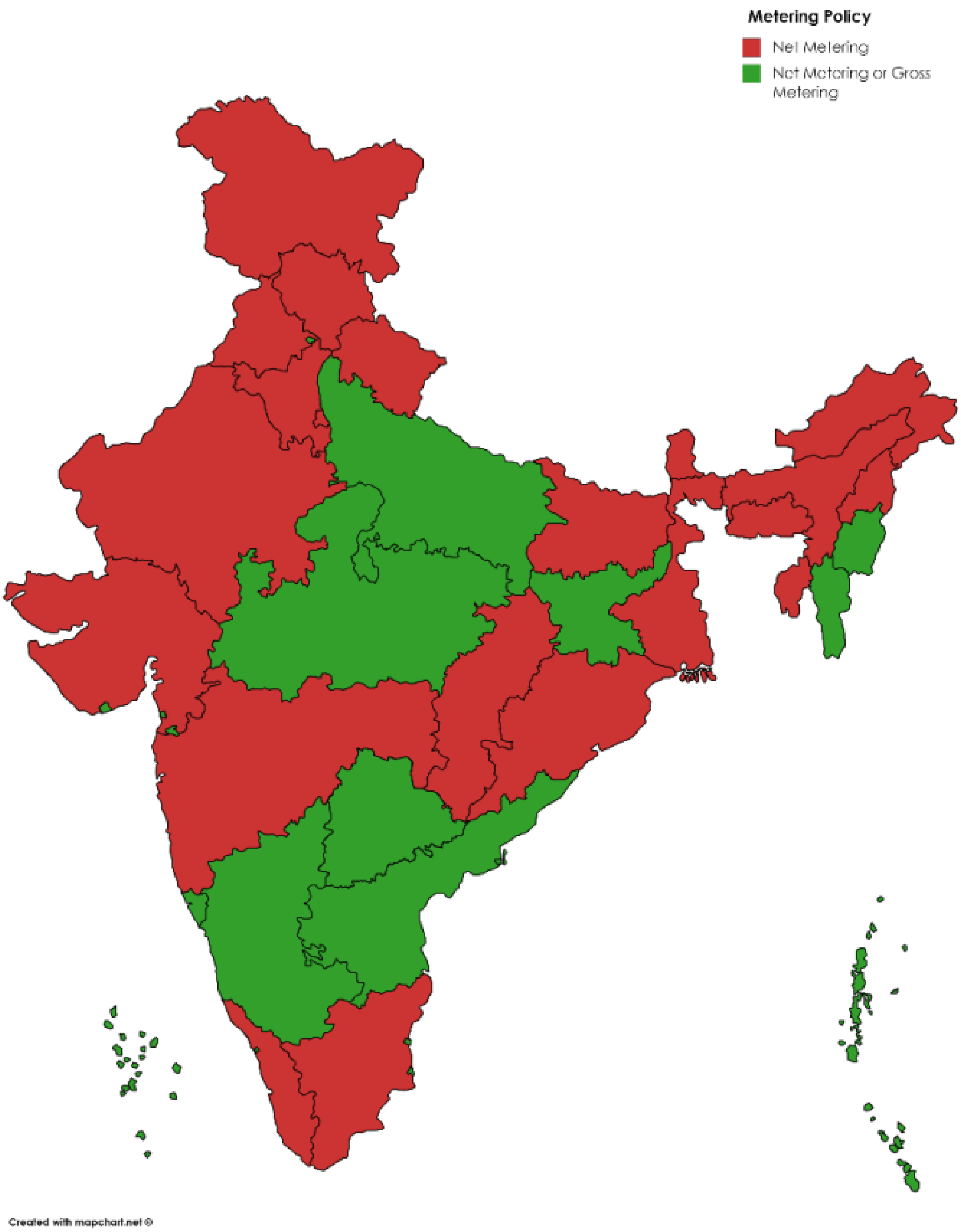

Figure 9.2: Adoption of net metering/ gross metering policies across the states and UTs in India.

22 states have adopted a net metering policy and 7 states and 7 union territories have given the customer an option of adopting either a net or gross metering agreement with the utility companies. Figure 9.2 depicts the status of policy support for grid connected rooftop PV systems from various states. Some states restrict the right of the customer to opt for a metering option and imposes the rule based on the category of customer. In Karnataka industrial and commercial customers are allowed for only net metering. For domestic

customers in Karnataka and for all types of customers in the UTs, the decision to go for net/gross metering has to be a one-time decision made by the customer and cannot be changed after the power purchase agreement is signed between the rooftop owner and the company. Table 9.4 shows the details of those states which have both net and gross metering options.

Table 9.4: Net metering/Gross metering options in certain states of India according to consumer category and PV capacity.

	Net Metering	**Gross Metering**
Goa, Mizoram, Jharkhand, Manipur, Andhra Pradesh and all Union Territories	As opted by the consumer	
Karnataka	Industrial and commercial	Applicable for houses, housing societies, institutions, hospitals. But they can also go for net metering, once decided; they cannot go back on the agreement.
Madhya Pradesh	Systems connected to < 11 kV (i.e. <100 kW)	Systems above 11 kV interconnection point have an option for Gross metering
Uttar Pradesh	Systems <50 kW	Systems > 50 kW

What happens if you generate more units at the end of bill settlement period in net metering?

11 states and 7 union territories allow their rooftop PV system owners to pump in excess energy to the grid without any limit. At the end of the billing cycle (mostly on a yearly basis) the excess energy will be purchased by the utility at either at Average Pooled Power Purchase Cost (APPC) or at a FiT fixed by SERC. 7 UTs and 2 states – Uttar Pradesh and Rajasthan pay the customer a FiT determined by SERC whereas 9 states pay at APPC rates.

Haryana, Bihar, J&K, Tamil Nadu, Orissa do not pay anything for the excess generation if still remains banked with the utility. Table 9.5 shows the restrictions imposed by different state policies on energy injection to the grid.

Table 9.5: Restrictions by different state policies on excess energy injection to the grid.

State	Restriction on Individual Energy Injection
Andhra Pradesh	Surplus energy injection above 20% of Plant Load Factor (PLF)
Bihar, Haryana, Jammu and Kashmir, Meghalaya, Nagaland, Odisha, Punjab, Tamil Nadu, West Bengal	Energy injection capped to 90% of annual energy consumption in the connection premises
Chhattisgarh	Excess energy injection capped at 49% of total generation
Tripura	Maximum billing for excess energy up to only 10% of total generated energy at the end of each financial year.

9.1.4 Individual Ceiling Limits for Rooftop PV System at User Premises

The restriction in the size of the system helps the distribution licensee to plan for changes in power flow patterns that may result from increased penetration of PV systems.

The restriction on installed capacity may take the form of

i) Absolute limits on permissible systems ratings.

ii) A restriction on system size relative to the connected load of the consumer.

iii) A restriction on system size at the level of the distribution transformer.

Absolute Limits on Permissible Systems Ratings

Most of the states have specified an upper limit of 1 MW_p and lower limit of 1kWp for PV systems that can be installed by a consumer in their premise. In terms of the rooftop space requirement, the limits would be approximately 10 m^2 for a 1 kW_p system and 20,000 m^2 (4.5 – 5 acres) for a 1 MW_p system. Chhattisgarh and Haryana have lower limits of 10 kW_p and 5 kW_p respectively. The minimum system size that can be installed in West Bengal is also 5 kW_p.

Uttarakhand differentiates between systems with battery backup and those without. For projects with battery backup, the permissible system size varies from 300 W_p to 100 kW_p. For systems without battery backup, system size of up to 500 kW_p are permissible. While the reason for such a differentiation is not explicitly mentioned, the underlying reason could be a concern of safety. A consumer is unlikely to opt for systems over 50 kW_p range with battery backup as the costs increase significantly (almost doubles), unless there is a very specific requirement. In any case, protection equipment that can prevent islanding and other negative effects of a large battery bank on the distribution system are available. The lower limit of 300W_p would mean a consumer can install a system with the minimal investment of Rs. 18,000 excluding subsidy.

Jammu and Kashmir has an upper limit on maximum capacity at 500 kW_p. Goa, Puducherry and other Union territories have a common policy capping the maximum system size at 500 kW_p but subject to system stability studies by the distribution licensee.

Restriction on System Size Relative to the Connected Load of the Consumer

The second method followed by many states is restriction on the capacity of the system with respect to connected load or contract demand of the consumer. Such restrictions indirectly ensure that the rooftop systems installed are in commensurate with the existing network infrastructure. It also makes the future injections of power from the prosumer more predictable. The recent policy amendment by Karnataka in 2016 has made the limit 150% of sanctioned load [209]. The restrictions imposed by the different states are mentioned in the Table 9.5.

With the lower bound of capacity decided at 1kW_p, restricting the capacity to 40% of connected load would effectively mean that consumers below sanctioned load of 2.5 kW are excluded from the process. It also impairs the ability of a consumer to offset a large portion of his energy consumption through installing a PV system, thereby making it less attractive economically. In a commercial establishment like a warehouse for instance where large rooftop area is available and sanctioned load may be low, such restrictions defeat the purpose of the policy – utilisation of idle rooftop space for energy generation. Table 9.6 summarises the restrictions on r ooftop PV pant capacities imposed based on t he sanctioned load of consumer, by different state policies.

Table 9.6: Restrictions by different state policies on PV system capacities based on consumer's sanctioned load.

State	Restriction on Capacity of Rooftop PV System
Assam	40% of connected load
Gujarat, Jammu and Kashmir	50% of sanctioned load
Rajasthan, Punjab, Sikkim	80% of sanctioned load
Himachal Pradesh	80% / 30% of sanctioned load for consumers under two part / one part tariff
Bihar, Jharkhand, Maharashtra, Odisha, Tripura, Uttar Pradesh, Manipur and Mizoram	100% of sanctioned load
Karnataka	150% of sanctioned load

Limiting the consumers at the 'sanctioned load' in a way balances the 'user's interest' to the 'equal opportunity' for consumers to go for PV. In most of the states, there is a limit in the PV penetration at the distribution transformer level. So a cap based on sanctioned load makes sure that the transformer capacity is not used up. If there are special cases where roof availability is plenty and sanctioned load is less and no one else under the same transformer is applying for PV connectivity, the DISCOM should be allowed to take a final call.

Distribution Transformer / Feeder Level Limit

Most states have kept a cap at the distribution transformer level to prevent over penetration of rooftop PV systems. In Kerala, Madhya Pradesh, Haryana, Bihar, Uttar Pradesh and Tripura, the limit is 15% of the Distribution Transformer (DT) capacity. It is 20% in Delhi and Jammu and Kashmir. Manipur, Rajasthan, Tamil Nadu, Goa and UTs have a cap of 30%. Maharashtra has 40%. Orissa is having highest provision in this regard at 75%.

The wide range of ceiling limits is indeed a pointer towards lack of data for a policy decision. Even in many policies, it is not clearly mentioned that whether the limit based on the transformer capacity is to be w.r.t. total connected inverter capacity (AC side). In different parts of the country, designers use different DC:AC ratio for improved performance of the system. It has almost become a standard practice to oversize the DC side by 1.1 to 1.4 times [129].

Table 9.7: Restrictions by different state policies on PV system capacities based on distribution transformer capacity to which they are evacuated.

State	Restriction on Capacity of PV Systems that can be Connected to a DT or Feeder	Provision in Policy for Higher Capacity
Goa and UTs	30% of rated DT capacity	Utility can allow higher capacity.
Gujarat	65% of rated DT capacity	Cost of capacity augmentation to be borne by the consumers.
Kerala	15% of rated DT capacity	Connection can be provided above 15% till cumulative capacity reaches average load of the feeder between 8 AM and 4 PM calculated for a period of seven days.
Madhya Pradesh	15% of rated DT capacity	Relocation to a nearby transformer preferred. Else, augmentation of capacity with incremental cost being borne by the consumers.
Maharashtra	40% of rated capacity of DT	Capacity can be added after detailed load study
Sikkim	Less than 80% of the average minimum daytime load on Feeder (between 8 AM and 4 PM)	Consumers can pay the incremental Service Line Cum Development (SLD) charges to obtain connections.
Telangana	50% of rated DT capacity for LT customers and 50% of rated Feeder Capacity for HT customers.	Can be exceeded after load study. Augmentation of capacity by distribution utility can be undertaken with the cost being borne by the consumer.
Delhi	20% of rated DT capacity	Connectivity for systems greater than 20% would be allowed based on assessments by independent agencies appointed by the SERC. Consumers can pay the incremental Service Line Cum Development (SLD) charges to obtain connections.

Table 9.7 shows the restriction in rooftop PV system capacities based on the distribution transformer ratings to which the consumers are connected, as imposed by different state policies. It also has the provisions, if provided by different policies to enhance the PV penetration limit. State policies can be modified to allow PV interconnections up to a threshold of 20-30%. The policies would have to evolve with the expansion of PV systems and be subjected to continuous review. It is important that these thresholds are not to be considered as ultimate limits of penetration but the threshold itself should be subjected to careful review. The policies of Maharashtra, Telangana, Goa and Union Territories specify that the limits could be revised after technical feasibility studies. Presently the CEA standards mandate that the utility should undertake an inter-connection study to determine the maximum net capacity of distributed generation system at a particular location. It should be ensured that the DISCOM has the necessary incentives and capacity to carry out such studies. Studies in the international and Indian context with guidelines on how the distribution utilities can proceed in formulating and conducting these studies are available [218, 219]. The Central Electricity Authority can also issue directives on the same to fasten such studies in high penetration pockets. Figure 9.3 has captured the different levels of penetration limits at distribution transformer level as directed by different state policies.

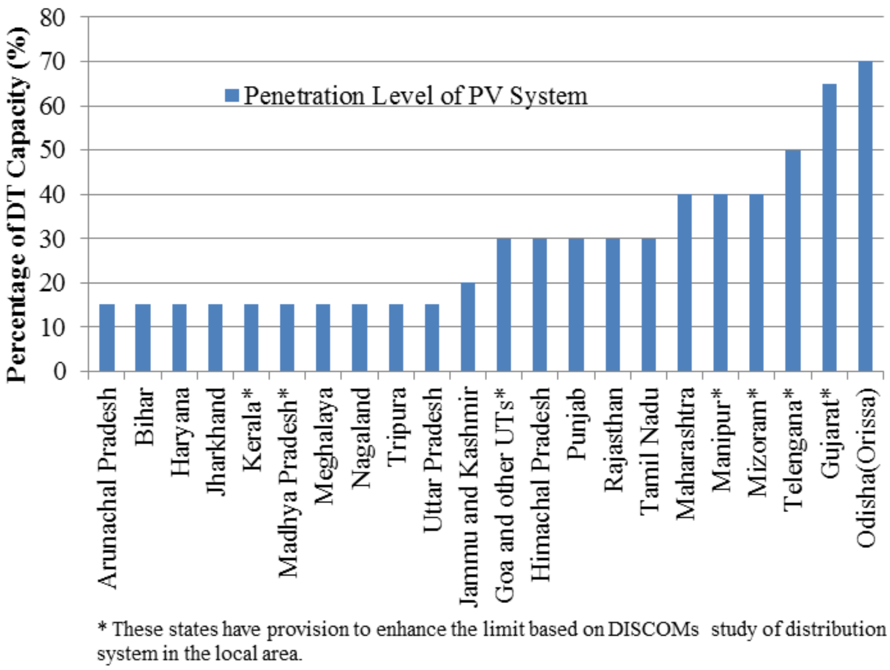

Figure 9.3: Restriction on capacity at DT or feeder level.

In case the transformer capacity has been exhausted, there is an option of the consumer paying the Line Development Charges to augment capacity for installing a PV system. This is the same procedure followed if a new connection is demanded in an area with limited transformer capacity available. Many states does not explicitly state the way forward in case the transformer capacity is exhausted. Such ambiguity would lead to difficulties for prospective consumers. Thus there has to be a uniform policy to make this information available in the public domain.

In states where there are such restrictions, it is important that the restrictions at specific locations are conveyed transparently to the commission and available to general public. Many state policies make note of this requirement and mandate updating available transformer capacity in the websites of distribution licensees. Maharashtra and Telangana mandates a quarterly update of capacity available to the SERC as well as in the web site of the distribution utility. Only 7 states (Madhya Pradesh, Delhi, Haryana, Bihar, Manipur, Rajasthan, Jammu and Kashmir) have mentioned in their policy that the remaining capacity at the transformer level need to be updated on a yearly basis and made available to the public. Maharashtra insists on an update every quarter.

9.1.5 Applicability of RPOs, CDM benefits

Renewable Purchase Obligations (RPOs), Renewable Energy Certificate (REC) Mechanism and benefits from Clean Development Mechanism (CDM) are aimed at incentivising migration to renewable energy generation by businesses including distribution companies. The RPO mechanism fixes a minimum quantum of energy that obligated entities have to purchase from renewable energy generators. There are specific Solar Renewable Purchase Obligations (Solar RPO) that mandate the purchase of a fixed percentage of solar energy. In line with the 8% solar RPO target for the country for March 2022, MNRE has allocated individual targets for states to set, but actual performance varies highly across states and enforcement is poor [81].

The Clean Development Mechanism (CDM) refers to a type of carbon credit developed under the Kyoto Protocol, issued under the United Nations Framework Convention on Climate Change (UNFCCC). A Carbon Emission Reduction (CER) credit operates as a tradable instrument, with each CER representing a ton of carbon dioxide generation abated annually. Upon earning credits, project developers may sell them to industrialized countries or other agencies for meeting their emission reduction targets under the Kyoto Protocol. The capacity of a rooftop solar PV project is generally small and a simplified methodology is in place for registering the CERs [220].

In most of the states the policy states that, if the consumer is an obligated entity as per Electricity Act 2013, the quantum of electricity consumed by eligible consumer would qualify towards compliance of Solar Renewable Purchase Obligation on the consumer. An "obligated entity" refers to any agency mandated under clause (e) of subsection (1) of section 86 of the Electricity Act, 2003 to fulfil the renewable purchase obligation [221]. In case the consumer is not an obligated entity, the benefits of renewable energy generation would be passed on to the RPO of the distribution utility. 7 UTs and in 9 state policies, it says that the PV generation from the rooftop systems can be accounted in the utilities RPOs. But in 19 other states, it is not clearly mentioned. Gujarat and Manipur has given the discretion to the user whether or not to share the RPO with the utility. In Gujarat, 100% of any benefits of the project accruing from CDM can be retained by the consumer while it would have to be shared between the consumer and the distribution licensee in Goa and UTs. Karnataka and Telangana follow a novel approach where the entire CDM benefits would be retained by the user in the first year. Starting from the second year, the share of the distribution licensee shall increase progressively by 10% till it reaches 50%. Rajasthan mandates that the entire benefits accrued to the DISCOM from CDM should be transferred to the consumers through annual return rate. Jammu and Kashmir, Manipur and Mizoram permit the distribution licensee to acquire the CDM benefits.

9.1.6 Other Financial Incentives

The capital subsidy by MNRE at 30% of the benchmark cost was a major incentive aimed at increased penetration of rooftop PV. The subsidy support had been removed for the rapidly growing commercial and industrial sectors in 2016 [222]. Now, the onus is upon the state governments to introduce possible financial packages to attract potential customers who have the potential to install PV plants. Most of the states have now standardised their policies to provide banking facility of power for grid connected PV plants, exempt them from charges for wheeling of power and cross subsidy surcharge.

A capital subsidy of Rs. 20,000 per kW_p has been provided by the Tamil Nadu state government and similar schemes exist in Gujarat and Chhattisgarh. Telangana provides a 20% capital subsidy in addition to the MNRE subsidy for systems up to 3 kW_p. Accelerated depreciation benefit of 40% is available for commercial and industrial consumers and all other profit making organisations liable for income tax. Haryana government provides a capital subsidy of 10%. Andhra Pradesh waives off charges for distribution losses from developers of grid connected rooftop PV systems. Chhattisgarh and Haryana provide exemption from electricity duty to energy generated and self-consumed from all PV projects. Madhya Pradesh specifies an exemption from Electricity Duty and Cess for a period of 10 years. The developers can also discount the area under PV for Floor Area Ratio (FAR) calculations which could lead to tax savings [185].

9.1.7 Metering Arrangements and Technical Standards

In this section, the technical and functional requirements of the meters and the scheme for installation are discussed.

Technical Specification of Meters

In case the consumer has opted for a net metering arrangement, the existing meter would have to be replaced by a bidirectional energy meter. In the case of a PV plant under the ambit of gross metering, a solar energy meter would have to be installed to monitor the injection of solar energy into the utility grid. In case RPO benefits are to be claimed, the obligated entity shall maintain a separate solar energy meter to monitor energy generation.

Most of the state policies are consistent with the CEA 'Installation and Operation of Meters' Regulation 2006 and amendments thereof [216]. The bidirectional meter shall have an accuracy of Class 1 and the solar energy meter shall have an accuracy of 0.2 and compliant with Meter Reading Instrument (MRI) or have wireless facility. Some states mandate additional facilities. The policy of Puducherry mandates all new service connections (from April 2016) meters to be configured for bidirectional energy recording and display for effecting solar energy net-metering at any time in future.

The policy of Goa mandates that the meter should have data storage capability of more than 45 days and meters for installations above 10kW should have a data communication port for real time information exchange with the distribution utility. If proper communication and data analysis framework could be developed, the information from these distributed systems can be used in predicting the generation from PV plants in a geographical region and it can help in effective scheduling operations. The policy of Chhattisgarh provides elaborate description on the type of metering and communication infrastructure. It mandates facilities such as supervisory control, set point editing, monitoring of module temperature, solar irradiation and a host of other features. While it may be beneficial to very large systems to help them monitor generation performance, it makes no s ense to small and medium installations to have any advanced monitoring or communication infrastructure. The availability and cost of metering infrastructure is a significant element of the capital cost [219]. The policies would have to be framed after considering the availability of such sophisticated systems in the market. While it is essential to "future-proof" the system to keep it in tune with the rapid advances in technology, it should not be at the cost of discouraging increased uptake of PV systems. Keeping the metering facility as an asset of the utility will help the consumers to avoid future hassles in maintaining and calibrating the meters.

Requirement of a Check Meter

State policies vary considerably in their requirement of a check meter for the installation. A check meter is an additional meter used to validate the reading of the primary meter and would be used as a back-up in case the primary meter fails. The conditions when a check meter is mandated by the state policy are described in Table 9.8.

When a check meter is mandated for a relatively small system of 20kW capacity, its impact on t he upfront capital expenditure has to be considered. The higher cost burden especially for systems of smaller capacity can significantly affect the increased uptake of PV systems by potential consumers.

Table 9.8: Requirement of check meter in rooftop PV systems.

State	Check Meter
Arunachal Pradesh, Assam, Bihar, Gujarat, Meghalaya, Nagaland, Tamil Nadu	Check meter mandatory above installed capacity of 20kW$_p$
Jharkhand, Uttar Pradesh	Check meter mandatory above installed capacity of 50kW$_p$
Jammu and Kashmir, Manipur, Mizoram, Rajasthan	Check meter mandatory above installed capacity of 250kW$_p$

9.1.8 Procedural Aspects for Connecting Rooftop PV Systems to the Grid

This section looks into the procedural aspects involved in the installation and commissioning of PV systems in various states.

The process for installing and commissioning a rooftop solar PV system is initiated by a consumer giving an application to the distribution utility. The utility acknowledges and verifies the application and determines the feasibility of the proposal after necessary technical parameters are evaluated. The distribution licensee is then required to inform the consumer of the approval or rejection of the application. While intimating the feasibility the license should also inform the consumer about the technical specifications and other particulars of the PV system to be installed. The consumer shall procure the system pertaining to the relevant standards and get it in stalled by a licensed contractor within a specified time period (six months in most of the states). Then the customer would require a certification from the Electrical Inspectorate of relevant jurisdiction to apply for testing and commissioning of the system by the distribution licensee. States like Kerala, Karnataka and Tamil Nadu have exempted systems less than 10 kW_p from inspectorate approval.

Many states mention specific timelines for each stage of the process which would avoid undue delays in approvals, certification, commissioning etc. of the system. But none of the state policies mention a redressal mechanism for cases where the timelines are not met or unduly delayed. The policies of twenty states and all union territories specify the exact procedure to be followed with indicative timelines.

Initial Charges

Initial charges considered in the study include application fee collected from the consumer and the registration fee charged for interconnection of the system. Some states combine these two charges to a single onetime payment. All states follow either slab rates for various connectivity voltages or a fixed amount per kilo watt of capacity. Rajasthan differentiates between prosumers and third party installations by doubling the security deposit for third party installations. Tamil Nadu mandates a 100% refund of the collected amount on successful commissioning of the project while the refund amount is 80% of the charges in Kerala if the project adheres to specified timelines.

A Sample Connection Agreement

A net metering connection agreement is a legal contract between the consumer and the distribution utility specifying various details such as financial principles, technical parameters, metering, billing and payment and responsibility of operation and maintenance. Without an indicative agreement to follow, it would be difficult for the client facing officials of the distribution utility to proceed. Such a standard agreement could be provided by individual distribution utilities specifying their concerns. Many states policies have an appended sample connection agreement that can be used directly by the agencies. The policies for fifteen states and all union territories have provided a sample net / gross metering connection agreement.

Schematic Connection Diagram

Multiple agents like system integrators, representatives of the utility, officials responsible for inspection, testing and commissioning etc. would be involved at various stages of installation of a PV system. It is important that a well-defined set of standards are available and enforced in installation of the system. Experience from the ground level suggests a deficit in the technical knowhow among the agencies mentioned above [118, 121]. Ten states have provided schematic connection diagrams for PV systems along with the policy documents. Arunachal Pradesh, Jammu and Kashmir, Manipur, Mizoram, Odisha, Rajasthan and Tamil Nadu have provided all the three details (procedural details and fees information, sample contract agreement, sample connection diagram) along with their respective policies.

The connection agreement of the consumer with distribution utility and other relevant provisions specify the authority for dispute redressal in case of a dispute between the interests of the consumer and the distribution utility. Some states have specifically mentioned the dispute redressal mechanism to be followed when a dispute arises related to the operation of a PV system. The administrative and technical capacity at the lowest level may have to be augmented to manage as the uptake of PV systems is gathering momentum. Testing and commissioning is a step at which the process can be expedited. Many policies mandate the certification of all systems irrespective of their capacity by the Electrical Inspectorate. Karnataka, Kerala and Tamil Nadu permit the certification of the systems under 10 kW_p by the distribution utility directly thereby avoiding an overlap of functions. The policies could allow self-certification of PV systems of lower capacities. The compliance can be ensured by random verifications and strict penal provisions in case of non-compliance.

9.2 Salient Features of Kerala's Rooftop PV Policy

- Only 'Net Metering' and no 'Gross Metering' is allowed. This might be a bit less encouraging for the domestic consumers, who pay at subsidised rates for their electricity consumption. In Karnataka, the domestic consumers have the option to do gross metering, where they can continue to pay their bills at lower tariff and they get a higher FiT from their rooftop PV generation.
- Unlike Tamil Nadu and Andhra Pradesh, Kerala has not kept any restriction in the eligibility of consumer categories for applying for net metering. All types of consumers including domestic, industrial, commercial and agricultural categories can apply for net metering.
- PV systems of cumulative capacity of up to 15% of Distribution Transformer capacity are allowed initially to get energised through net metering. This is one of the lowest limits when compared to other states. Even though there are provisions to enhance the capacity based on detailed load studies at the feeder levels, this restriction is the major stumbling block for faster and wider adoption of rooftop PV in the state. KSEB has no incentive for undertaking such a study and the number of technically equipped persons to do so is also a limiting factor.
- Requirement of a 'prior approval' on technical drawings of the PV system from Electrical Inspectorate was initially waived off for systems up to 5 kW_p. Recently this has been extended up to 10 kW_p and this has eased the procedural delays for the installation of smaller systems, especially among the domestic consumers who opt for such smaller systems.
- There are no restrictions on PV plant capacity based on the connected load of the customer.
- Linking the application fees with the system size (Rs. 1000/- per kW_p) and the provision to claim back 80% of this fees based on timely completion of the work incentivises the consumers for the completion of projects.

- KSEB can use and has the legal right to meet their RPO using the generation from their customer premises.
- Excess generation from one plant can be adjusted in the bills of other premises owned by the same owner.
- Metering arrangements, cost of transformers required as a part of grid extension etc. is clearly defined under customer's scope.

9.3 Conclusions

The policies at the state level to aid and encourage rooftop PV adoption have been reviewed and studied using a framework of 36 attributes. Net metering is the dominant metering arrangement for grid connected rooftop solar PV systems while seven states provide the flexibility of choosing net or gross metering. Keeping away certain categories of consumers as 'ineligible' users for net metering is not a positive sign, as in the case of Tamil Nadu and West Bengal. Restrictions on the size of the system to ensure smooth operation of the grid may discourage rapid adoption of PV systems. These restrictions could be introduced in a phased manner taking into consideration the growing stress on the distribution network due to increased penetration of PV. Curtailing the plant size based on the sanctioned load and transformer capacities should be based on sound technical analysis.

The financial incentives to adopt rooftop PV systems in the country include capital subsidy of 30% benchmark cost for residential and select institutional consumers from the central government and additional subsidies from a few state governments. PV installations have been exempted from wheeling and banking charges, cross subsidy surcharge, electricity duty etc. in many states. The metering arrangements mandated by the state policies are largely standardised with minor differences in the requirement of check meters and type of metering instrument to be used. Procedures for application, registration, installation and commissioning could be simplified and regulators should monitor if the processes are carried out in a time bound manner.

The increased penetration of a large number of supply points would be a challenge and an opportunity to all concerned stakeholders. The challenge lies in optimising the massive grid network to receive large number of PV systems and a simultaneous upgradation of institutional capacity. Varied experience in different states would provide valuable lessons to the global renewable energy commons. It is essential that the regulators at the central and state levels, DISCOMs and other stakeholders engage in periodic interactions to synergise the efforts. Proper documentation of details of implementation, challenges faced etc. are largely missing and needs to be created. A single and updated repository for all policies and other documentation related to rooftop PV would also aid future endeavours in this direction.

As far as Kerala's readiness in policy front for facilitating rooftop PV is concerned, the indications are positive. The state's solar policy, when compared to many other states in India is better in terms of enabling all categories of consumers for adopting PV. The state solar policy is well backed up with regulatory commission's directives and guidelines from KSEB. The provision for introducing gross metering and FiTs shall be considered and this can encourage more installation in the residential rooftop sector. KSERC shall also consider introducing a separate directive for third party ownership rooftop PV model, which can make the procedures clear and encourage investment in leased rooftop PV systems models. A few steps towards capacity building and incentivising KSEB in the process of project implementation could make the situations better at the ground level.

After covering almost all aspects related to large scale dissemination of PV systems, such as rooftop and market potential assessment, stakeholder involvement required, technology innovations required, institutional models preferred, cost and economics involved, failures and success stories from the past projects and the regulatory policies in the previous chapters, the next chapter tries to consolidate the learnings from the earlier chapters.

Chapter 10

Envisaging Wider Dissemination of Distributed PV in Kerala: Discussions Addressing the Research Questions and Meeting the Research Objectives

This thesis started off with a few research questions regarding the factors affecting the dissemination of distributed photovoltaic systems. In the previous chapters, most of the aspects related to dissemination of rooftop and distributed PV have been discussed in detail through literature review, case studies, sample surveys and analysis, and policy reviews. In this chapter, a few contemplations on the research questions, based on the findings, learnings and observations from the previous chapters is presented.

10.1 What are the Factors Affecting Large Scale Dissemination of Rooftop PV Systems?

An answer to this question was first found out from the literature review on 'adoption theory' by E.M. Rogers and later through the case studies, user interactions and surveys done in the field. The parameters are in plenty and some are often complex in nature. There are quantitative and tangible factors such as the price of PV systems and qualitative and intangible factors like the 'readiness' of the society to accept a technology. Various factors identified as linked with the dissemination of PV systems are listed and discussed in this section.

10.1.1 Knowledge and Awareness about PV among Potential Customers

'Adoption theory' could list out major factors which would affect the dissemination of any new technology introduced to the society. The product's characteristics (in terms of technology, usefulness, user-friendliness etc.), government initiatives (financial incentives and policies), supply ecosystem (quality and reliability of products, competitive pricing, availability of more options of vendors), financial facilitation by commercial banks, knowledge and awareness among the potential customers etc. were mentioned in the literature. Among all these factors, an emphasis was given to the knowledge and awareness of the potential customers about the technology. A typical example provided in chapter one was about the false information about the pricing of solar water heaters that prevented wider adoption of the technology.

Knowledge can be of basically of three levels as per the adoption theory, awareness, basic information (about the usefulness and how the technology is going to solve a problem for the end user, price and sources for purchase etc.) and principle knowledge (more of technical knowledge). The first two levels of knowledge are essential for dissemination of any new technology. As far as PV technology is concerned, the first two levels of knowledge have already been spread in the country through the JNNSM initiatives. MNRE had initiated demonstration projects in all the states and rolled out capital subsidy based schemes for encouraging 'early adopters' for PV. MNRE had also created a dedicated website for promoting rooftop PV systems called 'SPIN' [223]. The site has all relevant information about state nodal agencies, MNRE approved PV manufacturers and installers, and important announcements regarding rooftop PV sector. The site also has an option for posting enquiries and interest forms for rooftop PV installation. Such request forms would be shared with all empanelled channel partners in the state from which the enquiry originated and the channel partners would get in touch with the customers.

ANERT has also done extensive public awareness programmes and annual exhibitions in each district in Kerala for the promotion of rooftop PV [224]. Abundant information is being spread about PV in print, visual and the new social media, and the level of basic knowledge among the people has improved considerably in the recent years.

10.1.2 Presence of a Matured Market and Supply Eco System

Energy sector was highly regulated and monopolised by the government in the past. But the present scenario is very different. Most of the market failures such as inadequate information about the technological advances, lack of proper supply channels and logistics, lack of private investment and competitiveness etc. have been addressed in the present situation. MNRE has reported in August 2017 that there are 20 cell manufacturing companies and 117 module manufacturing companies in India with the total installed capacity for cell manufacturing of 3164 MW_p and 8398 MW_p for modules [225]. MNRE had listed around 89 system integrator companies in 2015 and another 35 companies in 2016 as channel partners for rooftop and distributed solar scheme [226, 227]. ENF Solar, a prominent global website which provides information about manufacturers and suppliers of PV components, has listed 104 sellers for PV modules, 127 sellers for inverters, 101 companies as suppliers for storage systems (batteries) and 69 companies as other BOS suppliers in their web site [228].

It should be noted that the demand forecasted as per the government policy is 14,000 to 18,000 MW_p per year (refer Figure1.4, chapter 1) between the years 2018-2022 and the in-house capacity of module production is only 50 – 60 % of the demand. Further it was brought into notice by Indian Solar Manufacturers Association (ISMA) that only 1.5 GW_p of cell production facility and 2 – 3 GW_p module production facility are operational in India due to the stiff competition in prices from imports [229]. Anti-dumping duties on imports, revision of domestic content requirement (which mandates the requirement of glass, EVA, back sheet, cells and junction boxes to be sourced from India), strict quality control on imports, and support from banks by considering PV manufacturing as a priority sector for lending are sought by the manufacturers in India. The government is currently working on a scheme to develop an end to end PV manufacturing facility in India and the draft policy is available for stakeholder's review [229].

The market for large scale PV power plants is controlled by the government policies. The state wise capacity allocation and reverse bidding process controls the demand in this market. But for rooftop PV segment to grow, it should develop a policy independent market. A study by TERI in 2016 shows that in Delhi, Maharashtra, Rajasthan, Andhra Pradesh, Karnataka, Punjab, Haryana and West Bengal, industrial and commercial PV plants are already economically viable [230]. The report also predicts that all states except Gujarat and Chhattisgarh, would find the payback period of less than 6 years by the year 2020. Hence the market has to pick up by itself without much policy support in terms of financial incentives. But from a legal and regulatory perspective, the government policies need to be facilitating to allow the market to grow. The market size and market potential of Kerala is discussed in detail in chapter 3, section 3.1. The minimum expected market size of 300 MW_p as calculated in that section is good enough for the 69 operational PV companies in Kerala to get good business [231].

10.1.3 Cost and Economic Viability of Projects and Presence of Financial Services

This topic was discussed in detail in chapter 8 and it was found that the PV module price is the most determining factor of the cost of PV projects. High upfront cost, irrespective of the continuing fall in the prices of PV systems remains as a major deterrent factor for large scale adoption of rooftop PV systems. The module degradation rates and the CUF also influence the long term economic viability of the projects. LCOE, IRRs and payback periods are the widely used indicators for the financial viability of PV projects. Reports from TERI, Bridge to India, and Climate Group, Nand & Jeet Khemka Foundation have shown that industrial and commercial consumers in almost all states would find it economically viable to adopt rooftop PV systems with the costs falling 10-12% year on year [231 – 233]. The growing market size is also helping to drive down the costs. The review of tariff rates and its comparison with cost of electricity from PV indicates that grid parity has already been achieved in commercial and industrial segments in Kerala. For residential consumers with less than 250 kWh/month consumption, the PV systems are not economically viable, as described in section 3.1.1 of chapter 3. Domestic users with 250 kWh and above consumption per month may find it attractive to own a PV system, if there are banks and financial institutions offering EMIs at 5% interest rate and for 10 years.

Lack of access to cheaper finance for developers and non-availability of loans to end users was often mentioned in literature as a major cause for slow adoption rates for PV systems. MNRE has requested the commercial banks in India to offer credit facility to their customers at attractive interest rates in order to purchase PV systems. Eight public sector banks (Bank of India, Syndicate Bank, State Bank of India, Dena Bank, Central Bank of India, Punjab National Bank, Allahabad Bank and Indian Overseas Bank) have responded to this call and have started offering loans for PV [234].

The government subsidies on capital cost for residential and non-profit institutions and accelerated depreciation benefits to commercial and industrial sector are two major fiscal incentives driving the market. Case study in chapter 4 of this thesis has proposed a new method to achieve economic viability for PV projects by integrating them with energy efficient equipments dissemination measures.

Detailed cash flow and financial modelling undertaken in chapter 8 shows that, with appropriate debt: equity ratio and interest rates on debts, net positive cash flows could be achieved from the first year of the project itself (net saving from energy bills could be made more that of the O&M expenses and loan repayment expenses). Such optimisations in financial modelling through negotiations with banks would help the interested customers to own PV systems.

Economic viability of solar water pumping was also established in section 5.5 of this thesis. Integrating PV into agriculture through farmer centric approaches could result in long term savings to the governments, who otherwise subsidises recurrently for the huge electricity needs for agriculture sector.

10.1.4 Presence of Institutional Models for Planning, Project Management, Principle Knowledge Dissemination and Training for Sustainable Operations

Planning for distributed PV schemes could be more decentralised, ground data based and with more stakeholder involvement. Review of past experiences in decentralised planning in energy sector in India is presented in section 2.4 of this thesis. A bottom up planning approach with user's need assessment and with adequate feedback from pilot projects was the missing element in the earlier failed projects. Chapters 3, 4 a nd 5 has presented wide range of case studies from Kerala which proposes a novel method of resource assessment and planning for dissemination of distributed solar systems. Assessing the rooftop potential through a mix of site surveys and satellite image based studies and understanding the perception of the potential adopters for planning appropriate installation targets and target groups was the highlight of these studies. Building of a local institutional mechanism with the involvement of local self-governments and local educational institutions was found successful and scalable across villages, towns and cities.

Procurement of components with quality checks and engineering works associated to the project needs to be undertaken by a knowledgeable entity with local presence. Section 6.2 of this thesis explains that the lack of such a lead organisation for engineering design, procurement and installation and post installation maintenance had left the Chendamangalam solar panchayat project unimplemented. Panchayat as an institution could create awareness and prepare the roadmaps for solarisation, but was handicapped in terms of project planning, project implementation and project management. The current organisational structure in all LSG Department offices accommodates a LSG Department engineer in the office. Conventionally, these engineers are with civil or mechanical engineering degree and primarily meant for handling civil works such as road, minor irrigation and land development works in the panchayat [235]. All electrical engineering related works are outsourced to the Public Works Department (PWD), electrical engineering division or PWD approved contractors through tenders. In order to initiate local planning and implementation of PV projects, LSG Department has to be strengthened with engineers who can take up electrical works.

Another model proposed in this thesis through the case study at Chalayoor tribal hamlet (chapter 6, section 5), field surveys and feasibility study for grid connected water pumping in Kole lands (chapter 5) and the review of Dhundi farmer co-operative society (chapter 7, section 2) is the co-operative model. The model propose a user group to come together to form a co-operative and formalise the design, procurement, installation and operations of the PV systems by establishing standard procedures and norms. In this case, even though the engineering works could be outsourced to any private or public sector company, there is a role to be played by a knowledgeable and trustworthy institution to draft the technical standards, designs and performance parameters. Ideally, KSEB as a major stakeholder in such projects shall be the best fit for such a role. Indian Institute of Management (IIM) Kozhikode has submitted a report to KSEB on how to enhance their service quality and organisational effectiveness. One of their recommendations is to form a consultancy wing in KSEB who can support LSG Department and other needy organisations on effective drafting of DPRs and ensuring quality of component and implementation of PV projects [236].

Principle knowledge dissemination and keeping up to date on the technology front is also important when popularising new technologies like PV. Knowledge dissemination and technical trainings have to be imparted to all stakeholders involved in the segment. The utilities, the customers and the regulators have to be educated in appropriate levels relevant to them. Government should also take initiatives to offer trainings to the EPC companies and practitioners in this field.

It was also discussed in chapter 7, section 7.1.2 about the requirement of trained technicians for the maintenance of PV systems. MNRE had initiated a few training programmes all over India through identification and accreditation of partner institutions. Solar Energy Training Network (SETNET) and 'Suryamitra' programmes are examples of such schemes. 35 centres (education and training institutes) were accredited by MNRE for conducting training programmes of different levels of technical and financial details (appropriate for diploma holders, graduate engineers, business administration graduates). Gujarat Energy Management Institute (GERMI), Global Sustainable Energy Solutions, Indian School of Petroleum and Energy (ISPEe), The Energy and Research Institute (TERI) and NCPRE are a few other prominent training and research institutes. Kerala has two accredited training centres under the SETNET programme, C-DIT, Thiruvananthapuram and Renewable Energy Centre, Mithradham, Eranakulam.

10.1.5 User Centric Designs of Products and Solutions

Products and solutions appropriate to cater to the needs of the end users are important for the acceptance of the same. The case study of peak load shifter project in chapter 4, section 2 has shown that the design of product with priority to utility's interest has resulted in poor adoption of the same. The study has also proposed a user-centric design of packages (including PV and energy efficient equipments) with detailed understanding of their tariff structures and monetary advantage on energy saving, but it was not considered during implementation. Similar need based package designing exercise was demonstrated in section 4.1.5 of this thesis where the equipment ownership data was used as a reference for design of packages. Proposal for community rooftop projects by grouping residential consumers with collective rooftop potential and connected from same distribution transformer was also proposed in this section. Supporting the day time loads of schools and offices with minimal battery backup was proposed in the section. Section 7.1 discussing the learnings from All India Surveys brings out the fact that the PV systems which are installed to meet the necessities are maintained well, since the end users are motivated enough to do so. Grid connected water pumping scheme executed in Dhundi village and proposed for the Kole lands is yet another example for user centric design of solutions.

10.1.6 Involvement and Support from DISCOMs

It is very important to transform the utilities from their current dormant mode to enablers of rooftop and distributed PV systems. They have to co-operate with other stakeholders in planning and executing PV projects by providing technical inputs, proactive actions for interconnection of PV systems to grid and management of the grid. In many cases, they are the buyers or bankers of excess energy generated from PV. How to incentivise the utilities to get involved in these activities is a challenge in front of the government.

Section 3.1.1 of this thesis has explained the advantages and disadvantages for KSEB in promoting distributed rooftop PV systems. Their attempts to propagate peak load shifter systems and community based PV systems in tribal hamlets were also analysed in chapters 4 and 6 respectively. The undue delays caused in the interconnection of rooftop PV systems in ANERT schemes due to non-coherent actions from KSEB and electrical inspectorate was identified through the analysis of electricity bills of beneficiaries in chapter 6, section 6.1.2.

MNRE came up with a detailed plan for performance based incentive scheme for the DISCOMs in 2016. The scheme proposed to bear 30% of the expenses incurred to the DISCOMs while promoting distributed and rooftop PV systems. The estimate for expenditure for activities like distribution transformer augmentation, purchase of net meters, introducing storage systems, development of information technology systems to manage distributed systems, capacity building of the engineers, installers and inspectors, consumer awareness campaigns, establishing call centres and helplines and rooftop PV cells in each division of distribution etc. was around Rs. 1.25 crores per MW [237]. MNRE was promising to fund Rs. 37.5 lakhs per MW of rooftop PV systems out of these Rs. 1.25 crores.

Another option given by MNRE is that the utilities themselves can invest on rooftop PV projects. Before the industrial and commercial consumers adopt PV systems for their captive use and causes loss of revenue to the DISCOM, the DISCOM can proactively offer a rooftop PV system on their roofs at slightly lesser tariff rates. This would prevent the entire revenue draining away. Utilities could also be incentivised by charging the rooftop PV owners a service charge of Rs 1/kWh (or appropriately fixed by the regulators) in the medium and long terms, once the owners have recovered their investment in the first 5-6 years. This would compensate the utilities for their revenue losses. But introducing such a charge in the initial years would make it unattractive for the roof owners and investors who intend to install a PV system. Analysis done on the economics of supply of energy to the domestic and agricultural sector by KSEB, in chapters 3, 4 and 5 of this thesis show that solarising these sectors in fact reduces the losses of KSEB.

MNRE has published a concept note for bringing the DISCOMs into more active role through the Sustainable Rooftop Implementation for Solar Transfiguration of India (SRISTI) programme in 2017 [238]. This is a sequel of the scheme proposed in 2016 and has much more clearer objectives and action plan. DISCOMs will be made single point of contact for the execution of rooftop PV projects. Since they are already in interaction with the consumers for their existing energy supply and billing, and have local offices, it will be convenient for the consumers to approach the nearest DISCOM office for initiating a rooftop PV project. DISCOMs will have to undertake the responsibilities of site assessment, technical design, bidding and purchase of components, installation, ensuring availability of net meters, commissioning, maintaining an online database management system of commissioned power plants and their performance. A financial outlay of Rs. 23,450 crores has been made by the government to operationalise the scheme.

10.1.7 Presence of Supportive Public Policies

The need for supportive policies for PV in deployment, manufacturing and R&D was discussed in the initial chapters of this thesis. Introduction, timely revision and withdrawal of support policies like capital subsidies and FiTs were instrumental in the wide adoption of rooftop PV systems in Germany and USA. The discussions in chapter 9 have brought out the salient features of rooftop PV policies in all the states in India. Major fiscal incentives in India for rooftop PV still remains as capital subsidies for residential customers and non-profit institutions. For industries and commercial consumers, accelerated depreciation is the major incentive. Analysis of the beneficiaries of capital subsidy scheme implemented through ANERT in chapter 6, section 6.1.1 points to the ineffectiveness and non-inclusive nature of capital subsidy schemes. Further, the learnings from All India Survey also supports the fact that incentivising the generation is a better option than incentivising the capital expense, as far as the long term performance of the PV plants are concerned. Accelerated depreciation tool also need to be reviewed, since it is not applicable for many non-profit institutions (who has huge rooftop potential for PV) and for those entities who are not making enough profit to claim the AD. Equal opportunity should be provided to those who cannot avail capital subsidies or AD benefits. Karnataka has come up with an innovative policy which allows the customer to claim higher FiTs, if they do not avail capital subsidy or AD benefit. Income tax holidays for the revenue from sales of electricity from PV plants, import duty exemptions (concessions) on PV modules and other components for power plant, exemption from wheeling and banking charges, cross subsidy surcharges, electricity duty etc. are other incentives in practice in India. Government has also initiated the issue of loans at affordable interest rates through nationalised banks for those who intent to implement rooftop and distributed PV projects at their homes and office spaces.

The restrictions in the size of the PV system based on t he sanctioned load and distribution transformer capacity of the customers is presently a bottleneck for the large scale adoption of rooftop PV systems in many states, which needs to be reviewed and revised. As discussed in section 9.3 of this thesis, these restrictions could be relaxed in a phased manner, reviewing the stress and manageability of the grid with increasing PV penetration.

10.2 How can We Plan for Better PV Dissemination Schemes?

Based on the learnings and experiences from the surveys and case studies and discussions in this thesis, a brief summary of the points to be considered while planning for distributed and rooftop PV dissemination schemes is presented in this section

Identify the ideal sized geographical region for planning and generate fine grain data of rooftop PV potential: Ideally, the planning process should start with the identification of an appropriate area or geographical region suitable for decentralised planning of distributed PV projects. Administrative limits of a village panchayat (as in the case of Chendamangalam), part of a township or a municipal corporation (as in the case of Thiruvananthapuram) or any such local self-government administrative units could be ideal for planning 'MW scale projects through kW scale systems'. The next step towards planning could be the identification of rooftop PV potential within the planned area. The innovative way of crowdsourcing the site surveys and questionnaire surveys to the students from local educational institutions was found successful in estimating the rooftop PV potential of such 'meso-scale' administrative areas. Such a methodology has the dual benefits of data generation and awareness creation (through the student community to the public). The methodology can be improved and scaled up by using freely available satellite map based and 3D modelling software based studies. An executive summary of the survey report of Mumbai using this improved methodology is presented in Annexure XII.

Involve stakeholders in the planning process: Involvement of the stakeholders in the planning process is very important, especially the end users. The expectations, needs and capabilities (financial as well as other capabilities such as knowledge and skill levels to undertake maintenance of systems by themselves) of the end users need to be understood before someone roll out a scheme on rooftop or distributed PV dissemination. The expected contribution from the end users, in terms of money (share on upfront investment, O&M charges), service (those who cannot offer money can offer service in terms of cleaning, fees collection, liaison with the banks, utility company etc.) , land (footprint of PV panels in case of PV pumping schemes in agricultural sector), roof area (in case of leased roof models) and their benefits in terms of money (FiT, rent to the roof), free energy or other incentives shall be clearly discussed and finalised. The roles and responsibilities of each stakeholder (local government, end user, DISCOM, other government departments involved, private investors if any, EPC contractors) and the incentives to each of them from a s uccessful project implementation shall be made clear. The stakeholders shall be accountable to each other for fulfilling their part in a time bound manner; else there shall be an effective and time bound dispute redressal mechanism.

User centric products and project designs: The technical and functional requirement of the PV based products which are introduced to the market shall be designed based on t he requirements of the end users. Rather than introducing them as just technological solutions and products, presenting them as complete 'techno-financial' packages would make it more attractive to the end users. For this to happen, an in depth study of the consumers' appliance ownership statistics, energy consumption statistics, existing tariff structures, alternate technologies which can be clubbed with PV (such as super-efficient equipments or even wind energy products, storage systems) etc. would be required.

Consideration of social aspects of target beneficiaries: Many top down approaches of technology dissemination have failed in the past due to the inability to understand the social aspects and the readiness of the society to accept a technology. Ignorance of the need for cleaning the panels leading to poor performance of PV systems, theft of batteries in off grid solar PV street light systems, theft and breakage of PV modules, energy theft in micro grid systems, lack of sense of ownership of PV systems in completely subsidised projects etc. have been reported as reasons for failures of distributed PV systems [150] [239 – 241]. Hence adequate importance shall be given to consider the ground realities and the possible social issues. Selection of beneficiaries and target groups shall be made based on consultation with the key persons in local administration. Capacity building and social engineering measures shall be considered as a part of planning.

Build regional institutional models for sustainable maintenance of the systems: Building local institutional models and hence ensuring organised maintenance of PV systems is a solution for long term sustainability of the systems. Proper organisational structure and representation from all sectors and classes of beneficiaries and bringing in accountability in the operations of the systems would be required.

Plan financial and cash flow models: Appropriate business models, financial models and cash flow models for different categories and classes of consumers shall be prepared as a part of the planning. Incentivising generation than incentivising upfront cost and hence ensuring proper maintenance and cash flows associated with the system would be appropriate.

Plan for an education and training element in programme: Other than basic awareness creation programs in the first stage of planning, regional level technical training and education programs shall be planned for better local availability of trained technicians.

Consider existing policies and request revisions if required: The policy aspects regulating the rooftop and distributed PV systems should be considered while planning for dissemination schemes. If any of the policies are found inhibitive, representations shall be made in front of the regulators and required amendments and revisions shall be demanded.

10.3 How Well Does Rooftop and Distributed PV Fit in Kerala?

This section answers the research question on the scope for rooftop PV in Kerala, and summarises the findings from this thesis regarding the same. Chapters 3 to 5 have very well presented the scope for rooftop and distributed PV in Kerala. Primary data from site surveys and secondary data from 2011 household census by Ministry of Home Affairs indicates the presence of large number of 'pukka' houses with strong roofs in Kerala. Even though quite a few of these buildings have the issue of shading due to the abundant vegetation in the state, Chendamangalam survey data shows that the total available shade free rooftops in a village panchayat would be more than enough to generate the total electricity requirement of that panchayat. A village panchayat with 10 sq.km. area was estimated of having 11 MW_p potential. Kerala has 941 village panchayats with smallest panchayat of area 2 sq.km. (Valapattanam) and largest being 815 sq. km. (Kumily) [242]. Other than this, there are 87 municipalities (towns) and 6 municipal corporations (large cities). Considering this fact, the physical potential for rooftop PV systems in Kerala is quite promising. MNRE has estimated a physical potential of 6110 MW_p in Kerala [243].

A well-developed power sector infrastructure with 100 percentage grid penetration in the state poses a challenge for promoting off-grid PV systems, but this can be seen as an opportunity for grid connected rooftop PV systems. Kerala's unique advantage of having 2104 MW hydroelectric power generation stations and the need for exploring this potential in complementing with distributed PV systems for grid management was also discussed in earlier.

As far as economics and financial viability is concerned, the calculations show that the domestic consumers with more than 250 kWh consumption a month would find it viable to adopt rooftop PV systems. Industrial and commercial customers will find it viable to adopt PV with current 40% AD benefit and 70% of CAPEX as debt with 12% interest. Even a conservative estimate based on KSEB's consumer statistics indicates an immediate potential of 317 MW_p. The process of awareness creation, consumer education and local manpower development on the technical front would be much easier in Kerala, due to its advancement in education sector and high literacy rates [244].

If we look at what Kerala has achieved in the past in realising this potential, we could see only three rounds of rooftop dissemination projects from ANERT (which were a part success), a few tender based installations from LSGD organisations, ANERT and KSEB and a few private installations adding up to 35 MW_p installed capacity as far as distributed PV is concerned [66]. This shows that there is still a lot of untapped potential to be exploited in the distributed PV segment. KSEB has announced a new scheme called 'Saura' in August 2018 with a target of 500 MW_p distributed PV systems to be realised by the year 2022 [245].

10.4 What need to be done for Wider Dissemination of Distributed PV in Kerala?

This section answers the final research question, which is 'what need to be done for wider dissemination of distributed PV in Kerala'. A generic review of the factors affecting the dissemination of PV in Indian context has been already presented in this chapter, section 8.1. One of the objectives of this thesis was to identify the necessary action points for PV dissemination in the Kerala context. This section focus on the findings and recommendation appropriate for distributed PV dissemination in Kerala.

10.4.1 Innovation in Technology

Innovation in technology, in terms of product design and package designs is very much needed to accelerate the adoption rate of distributed PV in Kerala. Peak load shifter was definitely an innovative product, which lacked financial package backing. A properly planned dissemination strategy of such products clubbed with energy efficient equipments would have attracted more buyers for the same. Another major area which needs to be explored is the possibility of hybrid systems (systems with both grid feeding capacity and battery backup). Conventional grid connected systems would shut down by themselves once the utility connection is lost. In such situation, the PV modules are unutilised. Considering the large number of potential domestic consumers who would like to adopt PV systems in Kerala, this will be a reason for customer dissatisfaction. After spending a reasonable amount on PV systems, they would be expecting uninterrupted power availability. Normal off-grid systems would make the system costs more expensive. In situations when the loads are not present and if the batteries are full, the generation from the panel would be lost. So an overlapping technical solution with optimal battery backup (to support basic domestic appliances during power outages) and grid feeding option (when there are no loads and if the batteries are full during day time, the generated power would be fed into the grid) is required. It was understood from the experiences from peak load shifter project and from the financial viability analysis of PV systems for domestic customers that monetary saving alone would not be a motivation for domestic users to adopt PV. An additional 'conveninence' of uninterrupted supply of power would only make PV look attractive for domestic consumers. It should be also noted that major share of 78% of consumers of KSEB and 51% of their total annual energy sales is from residential sector. Hence a technological innovation of this sort would open up oppo rtunities to attract considerable amount of adopters from this sector. ANERT has called for empanelment of system integrators who can offer such hybrid systems for their scheme in the financial year 2018-19 [246].

Another technology innovation needed is in the field of grid connected water pumps. Seasonal use of water pumps makes it more sensible to connect the PV based systems to the grid and feed the power to the grid. Unlike other states like Gujarat and Maharashtra, Kerala does not maintain separate feeders for agricultural connections. Hence during high energy consumption during agricultural season from these pumps, the tail end voltages of the grid also get affected. High inrush currents caused by the high capacity agricultural pumps can also result in frequent tripping of breaker at the output side of the distribution transformer and can cause power interruption to other consumers connected to the same transformer. Hence controlling the agricultural pumps always using VFDs as explained in chapter 5, section 3 would help in the soft starting of the motors and avoid inrush currents.

The current storage technology for distributed rooftop PV systems widely in use in Kerala is the lead-acid batteries. These kinds of batteries were promoted in ANERT's off grid schemes [107]. They offer comparatively lower nominal depth of discharge, surge handling capacities and useful life as compared to other new technologies such as Lithium Ferro Phosphate [247]. The sulphuric acid and lead plates used in these batteries need to be properly disposed off or recycled after its useful life. The cost of the batteries (which is a recurring cost after 5 years useful life of the batteries) is also a deterrent factor for the adopting of PV systems. An alternate storage mechanism which is more eco-friendly and cost effective shall be explored for better acceptance of PV systems.

More technical innovations at the power systems control level will be required to manage the grid with increasing penetration of PV and other renewables. Pumped storage and advanced automation of power systems control could be explored.

Generation prediction from distributed PV plants will be helpful in scheduling the generation stations once the level of PV penetration is considerably high. Gujarat has implemented such weather monitoring and performance prediction stations at major utility scale PV plants and they communicate to a central station and hence used in scheduling and dispatching.

MNRE had initiated geotagging of PV plants installed by their channel partners and the data about the installed capacity, cost of the power plant, installer details etc. are made available in public domain [248]. ANERT shall also make it mandatory for their empanelled agencies to geotag their installations within Kerala. In addition to the static data bout the system size and cost, if the generation data from these plants could also be monitored and displayed in this website, that can bring in a lot of valuable information about the performance of the systems. Such information would be helpful for those who are interested in adopting PV. They can evaluate the performance of PV systems in and around their locality (if already installed by some empanelled agencies) and compare between the plants of different system integrators. Such a step can enforce some sort of self-regulation among the players in the market.

10.4.2 Innovation in Financial Models

One major reform which needs to be done in the financial model of Kerala's rooftop PV dissemination strategy is to move towards performance based incentives like FiTs, rather than the present mode of capital subsidy. It was well established in chapter 6 that the current capital subsidy scheme is a failure in terms of benefiting the economically lesser privileged sector. Schemes should hence envisage regular cash flows associated with the PV systems, which was also a take away point from All India Surveys in chapter 7. Ensuring energy savings through energy efficient equipments and assured cash flows for debt repayment or EMIs through 'optimised' techno-financial packages would be beneficial for the residential consumers.

Even though a small state, Kerala has a well-established network of banks throughout the state. The State Bank group, other nationalised banks, private sector banks, co-operative banks and Regional Rural Banks (RRBs) together have 7312 operational branches in Kerala [249]. Offsetting the burden of capital expense on PV plants from the consumers through financial services from the banks should be operationalised in Kerala. Through proper optimised techno-financial models, if the system can ensure savings or income generation to the consumers, the banking sector should come forward to offer loans at attractive interest rates. The customers can also be convinced by showing the projected annual positive cash flows (as discussed in chapter 8, section 8.1), IRRs, payback period and lesser risk involved in the performance of the plants.

Reducing the transaction and vigilance costs involved in the operations of PV systems through co-operatives is also a proposed action, based on the studies in this thesis. Co-operatives would also get better access to finance than individual users. The co-operative banks also have a major role in providing loans to the customers interested in adopting PV, especially in the agriculture sector. Their prior experience in agricultural sector in re-financing the funds available from multi-lateral agencies shall be utilised in PV sector as well.

10.4.3 Institutional Model and Business Model Innovations

The concept of formation of co-operatives was already pointed out in this section under financial model innovations required. Co-operative model not only give better opportunity to benefit from the services of financial institutions but also provides opportunity for organised operation and maintenance practices. Kerala has successful history of co-operative institutions and the sector is well organised and matured. The Kerala co-operative societies act of 1969 and its amendments provide the legal and regulatory framework for the functioning of co-operatives in the state.

Finding niche areas for the application of solar PV systems and developing a business model around those needs is another requirement for wider dissemination of PV in the state. The case of dewatering in Kole lands using high capacity grid connected PV pumps is a typical example. Solar boats have started operating for the inland water transport in Kerala since January 2017, under the ownership of state water transport department [250]. Solar boats and charging stations also have good scope in the tourism sector of Kerala. Fisheries department give subsidy for kerosene for traditional fishermen who use kerosene engines to run their boats. There are about 15,000 engines run on diesel and the government spends Rs. 100 crores a year for providing them subsidy [251]. Solar based lightning and propulsion solutions for fishing boats can also help in saving the expenditure for government on subsidising kerosene. Aeration pumps for shrimp cultivation waterbodies, and other floating solar applications shall also be tested for viability. Hence a new project implementation strategy including the different government departments like transport, agriculture, fisheries etc., other than the power department shall be envisaged.

BOOT/RESCO model projects for government buildings is something which can be promoted through SECI, as discussed in section 3.1.1 of this thesis. Switched ownership model for institutions who cannot claim AD benefit was also discussed in section 8.2. KSEB themselves doing the aggregation of demands and implementing projects through 'Soura' scheme is also first of its kind among state owned utilities in India [245].

ANERT has opened a new web portal called 'buymysun' for online registration and purchase of renewable energy equipments in Kerala [252]. The portal also provides a mechanism for program monitoring and management of various schemes of ANERT. The system shows the status of implementation of various projects implemented under each programmes (like 'solar connect', solar smart' etc.) and various agencies (KSEB, Electrical Inspectorate, EPC company, ANERT) involved in the project can log into this portal and update the action from their side. This helps in tracing the project implementation status and the customer can approach whichever agency is delaying the project completion for corrective actions. Online market place also brings in transparency and competitiveness in the pricing of the PV systems.

10.4.4 Innovation in Policies

As discussed in section 2.2 of this thesis, framing policies for new technologies like PV is always challenging. Lack of enough data on cost, performance, technology forecast, and the presence of industrial lobbying always pose challenges to policy makers.

Now that the national solar mission has entered into the second phase, and more than 22 GW_p systems are installed in India, the issue of lack of information about the costs and performance of PV systems are solved to an extent [253]. Kerala has also crossed the cumulative installed capacity of 117 MW_p within the state by June 2018 [66]. Hence more data driven policies shall be formulated or the existing policies shall be revised based on the feedback from the field.

Kerala's solar policy has made provisions for mandatory installation of rooftop PV systems for domestic buildings with floor area 200 sq. m. and above. Similarly SPOs are imposed on LT and HT commercial and industrial consumers. Effective implementation of these mandates is often challenging. Making PV installation mandatory also does not motivate the consumers. This would lead to use of substandard components or improper system installation and poor maintenance (as discussed in the analysis of O&M activities and PV module degradation rates in chapter 7). Instead, if FiTs can be introduced, that would incentivise generation and motivate the system owners to take care of the systems. Currently the excess energy generated from rooftop PV systems are purchased by KSEB at the APPC rate (Rs. 3.26/kWh) [165]. An upfront subsidy of around Rs. 18,000/kW_p is provided for PV systems less than 10 kW_p (30% of bench mark cost of Rs. 60,000/kW_p). Annual expected generation from PV systems in Kerala is estimated as 1450 kWh/kW_p/year. If the system is maintained properly and the components are of good quality, then the generation for the first five years would be 7250 kWh. Instead of giving Rs. 18,000 as upfront subsidy, government can think of providing this as top up FiT of Rs. 2.48/kWh (18,000/7250 = 2.48) for the first 5 years. Then the total FiT could be Rs. 5.74/kWh (APPC of Rs. 3.26/kWh + Rs. 2.48/kWh). This FiT is more than enough to pay Rs. 636 per month (120 kWh/month * Rs. 5.74/kWh) as EMI for the first five years (Rs. 60,000 at 5% interest and for a 10 year tenure, as discussed in section 3.1.1 of this thesis). Similar kind of policy support which would incentivise generation shall be adopted. This FiT may be revised after the first control period and later may be withdrawn once the price of PV systems has become affordable without any incentives.

Upgradation of PV penetration limits based on the distribution transformer capacity on a timely basis after the review of power systems' performance with the existing penetration levels shall be required for future. Karnataka offers both gross and net metering opportunity for residential consumers and higher FiTs for those who do not opt for capital subsidy. Similar approach can motivate the residential sector users in Kerala. Orissa has made it mandatory to have real time communication of generation data from rooftop PV systems to a central station. With the cost of GSM (Global System for Mobile communication) based wireless communication in India becoming one of the cheapest in the world, this can be a good step to generate valuable data about the real performance of the PV plants in the field [254]. If this data can be used in geotagging the installations and the key statistics of this is made available in public, it can also bring a sort of self-regulation on the quality of components, installation practices and maintenance activities, as discussed in 'need for technology innovation' in this section.

Delay in disbursement of subsidy from ANERT was one of the issues came into notice while interacting with the stakeholders. In the past schemes of ANERT, customer was supposed to pay the amount after subsidy and the EPC company was credited by ANERT with the subsidy amount after successful project completion. The delays in subsidy payment often disturbed the cash flow management of the EPC companies and many stopped taking orders from customers. As an alternative to this, ANERT has announced 'direct transfer of subsidies to end user accounts' from the programmes starting in financial year 2018-19 onwards. This relieves the EPC from working on credit. Interest subsidy on loans was also announced by ANERT, which would encourage those customers who find it difficult to make high upfront investment and who would like to avail loans.

Regulatory bodies need to monitor the operationalization of policies and timely publishing of information from utilities on applications, time duration for approval and interconnections and transformer capacities available. A simple and faster process of interconnection approval with time bound actions is expected after ANERT start implementing their programmes through the online portal. Fast track grievance redressal mechanisms are also needed in distributed PV sector. Overlapping roles of KSEB and electrical inspectorate for on-site testing of systems may be avoided.

10.4.5 Address the Concerns of Stakeholders

KSEB – Grid management, inability of PV to contribute towards evening peak load management and loss of revenue from industrial and commercial customers are the major concerns of KSEB. It was discussed in section 3.1.1 of this thesis that neighbouring states like Tamil Nadu and Karnataka are managing as high as 40% renewable energy share in the grid using hydro power stations as peaking stations. Researches have found that 30% of feeder capacity penetration is the ideal penetration limit for minimising the transmission losses in LT network and beyond which, the losses would be more than that of a 'zero PV penetration' scenario [19]. There are studies which address the problems of voltage rise and harmonic injection in the LT network due to excess PV penetration, which indicates the voltage rise and THD would be within the limit of 5% of nominal voltage below 8% respectively at even 40% PV penetration [255 – 257]. But these studies were based on the load and load patterns of the local grids. Hence KSEB shall still take up a study in similar lines.

Regarding the financial front, KSEB cannot resort to cross subsidies for long term. The national tariff policy drafted by Ministry of Power, Government of India has proposed a gradual reduction of cross subsidy and limiting the tariffs of all categories of consumers within ±20% of the average cost of supply [258]. With more than 51% of total energy sales coming from residential sector, KSEB would find it difficult to manage their financials with these kinds of restrictions on cross subsidy. Hence they should see distributed PV systems as an opportunity to avail cheaper electricity at the consumer premises itself. Previously mentioned 'Saura' scheme is a positive move towards this direction.

KSEB should try to avail the infrastructure upgradation and training funds from the Central Government. MNRE has offered that they would pay Rs. 37.5 lakhs for every MW_p of rooftop PV systems realised in the state. KSEB can claim this fund from MNRE based on their performance in project completion. Long and medium term sharing of benefits of the customers with KSEB, such as levy of grid support charges of Rs. 1/kWh of energy self-generated from PV systems, after first five years after commissioning shall also be initiated. Some studies also propose that energy generated from rooftop PV systems shall be considered 1.3 times (or any appropriate value decided by regulatory commission) more valuable while calculating RPO compliance of the utilities as against generation from large ground mount systems [233]. As suggested by IIM Kozhikode study, KSEB shall constitute a consultancy wing for promoting renewable energy and can avail consultancy charges from LSG Department and other consumers who would like to adopt PV. This helps the consumers in ensuring quality of components and work execution and at the same time, helps KSEB in ensuring the quality of power injected to their grid. As discussed in section 6.2 of this thesis, there should be some organisation leading the efforts of rooftop PV dissemination in Kerala and taking the ownership and responsibility of the projects. KSEB can be a good fit to this role if they can translate themselves from their current dormant mode to a more active enabler for PV projects.

KSERC – The regulatory commission shall monitor timely enforcement of regulations and dispute redressal. They shall encourage more participation from the EPC companies and project developers, representatives from PV user forums, technical education institutions etc. in public hearing and formulation of policies. Timely revision of policies and directives through public consultation is required. KSERC can now rely on the data generated through the projects by ANERT, KSEB, LSG Department and other private players during the past 5 years for reviewing the policies and taking corrective measures.

ANERT – ANERT currently has a restricted image of a subsidy disbursement agency. Other than this, ANERT shall take more steps in ensuring the quality of components, develop their own component testing labs and facilities and create awareness among the public on t hese quality standards. ANERT shall also explore the possibility to promote technology innovations in the PV sector. They have introduced the provision to promote hybrid PV systems (with battery charging and grid feeding option) in their 2018-2019 programmes [246]. Administrative sanction and funds were approved by ANERT to develop prototypes of 50 HP grid connected PV pumps under their 2017-18 innovation schemes and RAIDCO was appointed as the implementation agency for this project [121].

Electrical Inspectorate – Instead of insisting on on-site testing of inverters and PV modules, inspectorate shall accept test certificates of components at some government approved third party labs as well (like ERTL Thiruvananthapuram, NISE Gurgaon, TUV Rhineland, UL etc.). Many states have issued regulations which exempt inspectorate approvals for smaller systems (less than 10 kW_p). Still, in order to ensure the quality and safety aspects of PV systems, they could continue to test some random installations and if they are found non-compliant, fine the EPC or system integrator heavily. In short, they should promote more self-certification by EPCs and system integrators and avoid the time delay incurred due to limited number of their trained staffs and equipments. At the same time, ensure quality through random checks and penalisation of the non-compliant cases.

System Integrators and Component Suppliers – They should restrain themselves from unhealthy price wars. They should rely to quality components, designs, installation practices and support in O&M. ANERT has given an option for quoting higher costs for PV systems using premium quality components and new technologies, in their scheme announced for year 2018-19 [246]. This shall be seen as an opportunity to the system integrators to promote newer technologies (such as Lithium based batteries, BIPV and flexible modules etc. as per user requirement).

Domestic Consumers – Upfront investment is the major concern of the domestic consumers. With the current existing subsidised rates, return on investment for PV are not attractive for majority of the consumers who use below 500 kW h a month. Lack of knowledge on the quality of components is another drawback in this segment. This can be overcome to an extent by relying on the instructions and directives from ANERT on how to choose a PV system based on their requirements. Once KSEB also gets on board through Saura scheme, it will be easier for the domestic users to approach them, since they are already in regular interaction with KSEB. Loan facility for buying PV systems is now available with 8 public sector banks and from the co-operative banks in Kerala and the residential users shall try to make use of this facility. The residential users can also take an initiative to monitor the generation from the PV plant and compare it with the expected benchmark generation (which can be obtained from ANERT). This simple step can give an indication towards any faults of underperformance from the system. Building 'solar ready roofs' for new constructions can also be encouraged among residential users. Housing co-operative societies shall invite private investors to implement RESCO models PV projects on their roofs and common areas and benefit from the savings on electricity bills.

Industrial and Commercial Consumers – Even though currently the investment on PV looks attractive to this segment in Kerala, it may become less attractive if the AD benefits are pulled back in a phased manner. Another hindrance from the business owners in this segment is that, whenever they have disposable additional funds, they would rather invest on their primary business (which they know very well), than investing on PV (which is a completely unknown technology to them).

Agriculture and Government Buildings - Government shall lead the PV dissemination activities in this areas by adopting rooftop PV on government buildings through RESCO models and by supporting the adoption of grid connected PV water pumps in agriculture sector.

10.5 Meeting the Research Objectives

This sub section of the thesis highlights how the research objectives listed out in the introductory chapter are being met in the process of research associated with this thesis. Each of the objectives are listed out here again and the way in which they were met is briefly explained.

- **To find out the factors affecting the acceptance and spread of rooftop PV**

The major factors affecting the dissemination of rooftop PV were identified through literature review, case studies, field surveys and stakeholder interactions, as explained in section 10.1. Seven major factors are listed out in the same section and the way in which each of the factors affect the adoption rate has also been explained.

- **To identify the stakeholders in this sector, their roles and responsibilities.**

Identification of stakeholders in PV dissemination sector is first presented in section 3.1.1 in a Kerala context. Major stakeholders including the utility company, the regulators, ministries and their nodal agencies, other government departments like the department of public works and electrical safety, system integrators and the end users were identified. The stake involved in the PV sector for each of these players, their roles and responsibilities were also explained in detail in section 3.1.1. Further discussion on how to address the concerns of these parties for wider dissemination of PV is explained in section 10.4.5.

- **To find out how well does the rooftop PV sector fit in the Kerala scenario.**

Chapters 3 to 6 discuss in length about the suitability of rooftop PV in Kerala. Chapters 3 to 5 first identified the stakeholders, study the availability of roof area in different types of buildings and does a basic economic viability analysis of each category of consumers.. Innovative schemes by promoting energy efficient equipments along with PV plant packages were proposed in this chapter. The scope for PV in irrigation sector in Kerala was also studied here. Chapter 6 looks into the performance and effectiveness of past PV dissemination schemes in Kerala and identifies scope for improvement in such efforts.

- **To develop a techno-financial evaluation tool for rooftop PV systems.**

Chapter 8 deals with the economics of rooftop PV systems. The factors affecting the cost and economic viability of PV was identified and their sensitivity towards levelised cost of electricity from PV was calculated through the evaluation tool developed.

- **To identify the underlying socio-cultural aspects which are related to the acceptance and proper ownership of distributed PV systems.**

The intangible factors and the socio cultural elements affecting the acceptance of PV systems were identified and elaborated first in chapter 2, through literature review. Later similar aspects were studied in chapter 6, section 6.5.4 where the social impact of PV project on a tribal hamlet was discussed. The most detailed study on these factors was done in chapter 7, where the interconnection between the ownership model and the performance of PV systems in field is discussed as a part of All India Survey of PV Module Reliablity.

- **To develop a p lanning and dissemination methodology considering all stakeholders, their priorities, and based on the learning from techno-economic, socio-cultural aspects related to dissemination of distributed PV.**

Section 10.2 has very well put down the proposal for a new planning and dissemination methodology for distributed PV systems, based on t he findings from the researches done as a part of this thesis. Identifying the right geographical size for project planning, involvement of stakeholders in the planning process, user centric product designs, consideration for the social aspects of the target consumers, building of regional institutional models and planning financial models and cash flows are mentioned in this section. Need for awareness creation, education and training and aligning the models with existing policies are also proposed. Need for innovation in technology, planning, financial models, institutional models and policies were identified.

- **To identify the policy and governance challenges and possible solutions for the above mentioned dissemination strategy.**

Chapter 9 has identified the policy challenges for the wider dissemination of distributed PV systems. Further, section 10.4. points out the innovations and improvements needed in the policy aspects controlling the PV adoption rate in the society.

With this critical analysis and consolidation of findings from the research, the next chapter is the general conclusion of the thesis.

Chapter 11

Conclusions

There is immense market potential for rooftop and distributed PV systems in Kerala. Considering the large number of 'pukka' houses with roofs suitable for PV installation, highly matured power sector in terms of infrastructure and the high acceptance levels of people of Kerala towards new technology (by virtue of their high levels of education, awareness and economic wellbeing), it is worth looking into the scope for large scale dissemination of grid connected rooftop PV systems in the state.

Considering the present status of in house generation by KSEB (~30% of the total needs), they need to adopt alternative mechanisms of power generation and PV can be one of the priority options. There need to be coherent efforts from the government sector organisations in the power department such as KSEB, Electrical Inspectorate, ANERT, EMC etc. to plan and implement PV projects in a time bound manner with mutual co-operation.

The felt needs and feedbacks from the end users need to be considered while planning policies and implementation schemes. Less successful past rooftop PV schemes from ANERT reiterates the importance of this fact. The department of power and it subsidiary organisations, i.e. KSEB, ANERT, Electrical Inspectorate has to be more 'responsible' in taking forward the solar PV sector in Kerala. There need to be more transparency and these departments should be held accountable for the undue delay of sanctions and approvals in the projects.

A Panchayat can be an ideal scale and geographical area for awareness creation and design of PV projects and schemes. But it cannot be a final implementing agency due to lack of technical expertise, technological know-how and prior experience. A public entity which can act as an implementation partner is important for the final rollout of projects.

Dissemination of rooftop PV can be made more effective by tying it up w ith the super-efficient equipment programs. Techno-Financial packages are to be designed for wider reach of costly renewable and energy efficient technologies.

Current subsidy schemes fail to reach the economically less privileged society and in fact the funds get diverted to the people who can afford to pay an upfront amount and has access to banks and financial mechanisms. A restructuring of subsidy programme and initiatives from banks to avail low interest loans to economically less privileged sections in society has to be planned for wider dissemination of PV.

Community based PV projects need participatory planning with multiple stakeholder involvement and need for clarity in terms of liabilities, responsibilities and incentives for each stakeholders associated with the project. If properly designed and implemented, community based PV projects were seen as the best performing systems during the field surveys.

Due diligence need to be done while selecting PV modules and other components for smaller sized systems, since the probability of receiving lower quality components are high in this case as indicated by the All India Survey of PV Module Reliability results. This also point towards the need of shift in strategy from the governments from a ‘target meeting’ approach to ‘target meeting with performance and quality’ approach. Not only meeting installation targets are important, but also the sustainability of installed systems is equally or more important.

PV has a good gap to fill in the irrigation sector, provided grid connectivity and net metering is available and if farmers can be actively involved in maintaining the system through incentivising them. Certain levels of technology and policy innovations are required in this sector. The need for grid export during non-farming season is not met by the presently available variable frequency drives in the market and this call for a new product development. Since the electricity tariffs in this sector are highly subsidised, a policy driven approach is required to increase solar uptake in this field.

Even though all the states in India have come up with their rooftop PV policies, there are still certain areas to be improved. Curtailing the plant size based on the sanctioned load and transformer capacities still need more data driven or scientific backup. The 15% limit of transformer capacity prevents the accelerated deployment of rooftop PV systems in Kerala. More clear directives should be given on the scope of work and cost sharing on the additional activities associated with grid and metering upgradation, which is an integral part of PV project. Procedures can still be simplified and regulators should monitor if the processes are carried out in a time bound manner. There need to be a grievance redressal mechanism in place to fast track the settlement of issues rising in the PV sector.

Ideally, KSEB should have headed the PV dissemination activities in Kerala, since they are the largest public sector company in the power sector of the state. Their wide presence in the state and access to public is incomparable. But due to bad financial shape and due to the need for technology and human resource upgradation to cope up with distributed PV, the company is restricting themselves from entering into solar EPC. At the same time, they are losing their cream industrial and commercial customers because most of them have already started adopting PV and other open access methods for power. ANERT schemes are not reaching the levels of success as expected because; the projects are executed mostly by companies outside Kerala through dealers. This result in improper after sales services and hike in project costings.

There is a felt need and a 'gap' to be filled by a pan Kerala public sector entity in distributed solar EPC business. Through their wide presence, the institution can do awareness creation, aggregation of demands, ensure effective implementation of policies through peer pressure and governmental level interventions, understand the real need of the public and formulate flexible solutions with financial facilitation. The entity can thus become a single point of contact for all 'procedures' to be met for distributed PV systems implementation. The organisation can also play the lead role in ensuring the quality in design, quality of components, quality in implementation of PV projects, and quality after sales service which is very much essential for the long term sustainability of the PV plants.

Publications from Thesis

Journal Publications

1. R. Dubey, S. Chattopadhyay, V. Kuthanazhi, A. Kottantharayil, C. S. Solanki, B. M. Arora, K.L. Narasimhan, J. Vasi, B. Bora, Y. K. Singh and O.S. Sastry, *"Comprehensive study of performance degradation of field-mounted PV modules in India,"* Energy Science and Engineering 5, 51 (2017)

2. S. Chattopadhyay, R. Dubey, Vivek K., J. John, C. S. Solanki, Anil K., B. M. Arora, K.L. Narsimhan, V. Kuber, J. Vasi, A. Kumar and O. S. Sastry, *"Visual Degradation in Field-Aged Crystalline Silicon PV Modules in India and Correlation With Electrical Degradation"*, IEEE Journal of Photovoltaics, 2014, 4, 1470-1476.

3. V. Kuthanazhi, A.K. Shibu, N.C. Narayanan, A. Kottantharayil, *"Replicability of Community Based Grid Connected Rooftop PV Systems: A case study in Chalayoor Tribal Hamlet, Kerala, India"*, submitted to – Energy Research and Social Science

Conference Publications

1. V. Kuthanazhi, S. Jois, K. Ramamritham, A. Kottantharayil, *"Meeting Mid-Day Peak Loads through Distributed Rooftop PV Systems: Tale of Two Cities"*, ACM e-Energy 2018, Karlsruhe, Germany

2. S. Bhaduri, S. Chattopadhyay, R. Dubey, S. Zachariah, V. Kuthanazhi, C. S. Solanki, B. M. Arora, K. L. Narsimhan, A. Kottantharayil, and J. Vasi, *"Correlating Infra-red Thermography with Electrical Degradation of Modules inspected in All India Survey of Photovoltaic Module Reliability 2016"*, Photovoltaic Reliability Workshop, Lakewood, CO, USA (2017)

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5. V. Kuthanazhi, A. Kottantharayil and N.C. Narayanan, *"Planning for integration of Solar Photovoltaics into the Energy Needs of Villages through Local Self Governments"*, Presented at 40th IEEE Photovoltaic Specialists Conference, Denver, Colorado, 1452 - 1457 , 2014

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7. R. Dubey, S. Chattopadhyay, V. Kuthanazhi, J. John, C. S. Solanki, A. Kottantharayil, B. M. Arora, K.L. Narsimhan and J. Vasi, *"Daylight Electroluminiscence Imaging of Photovoltaic Modules by Image Difference Technique"*, Presented at World Conference on Photovoltaic Energy Conversion , Kyoto, Nov. 2014

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9. S. Chattopadhyay, R. Dubey, V. Kuthanazhi, J. J. John, C. S. Solanki, A. Kottantharayil, B. M. Arora, K.L. Narasimhan, J. Vasi, A. Kumar, and O.S. Sastry, "*Visual Degradation in Field Aged Crystalline Silicon PV Modules and Correlation with Electrical Degradation*", presented in 40th IEEE PVSC, Denver, Colorado, 2014.

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1. V. Kuthanazhi, K. Augustine, A. Kottantharayil, N.C. Narayanan, *"Planning for Integration of Solar PV into the Energy Mix - Energy Survey Report, Chendamangalam Gram Panchayat, Kerala"*, June 2013.

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3. V. Kuthanazhi, S. Jois, P. Jadhav, K. Kumar, A. Magal. A. Pimpalkhare, J. Vasi, A. Kottantharayil, K. Ramamritham, N.C. Narayanan, V. Kotak, *"Estimating the Rooftop Solar Potential of Greater Mumbai"*, 2016

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Annexure I

Questionnaire for Studying Solar PV Power Integration Potential, Chendamangalam Gram Panchayat

Survey Questionnaire

Chendamangalam Gram Panchayat

Questionnaire for Studying Solar PV Power Integration Potential

(Conducted by C-DIT and IIT Bombay) **Form No:…**

1. Ward No		2. Building No	
3. Ownership Type	Private ☐ Government ☐ Others:		
4. Use of the building			
5. Owners Name			
6. Address		Pin Code:	
		Mobile No	
7. Is electricity connection available	Yes ☐ No ☐		

Details from Previous Bills			
8. Electrical section			
9. Transformer		10. Post No	
11. Consumer No			
12. Tarriff	☐ Single Phase	☐ 3 Phase	
13. Connected Load			
14. Average consumption	Monthly ☐ Bi-monthly ☐		
	Previous bill 1	Previous bill 2	Previous bill 3
Units consumed			
Amount			
15. For light/electricity			
(1) Do you use Diesel Generators/Kerosene Lamps?			
(2) Upfront Cost			
(3) Monthly Expenses			

16. Electrical Equipment Usage Patterns:

Appliances	Power Wt	Nos	Average operation Hours	6pm – 10pm				10pm – 7am				7am – 12 noon				12pm – 6pm			
				Summer	Rain	Critical		Summer	Rain	Critical		Summer	Rain	Critical		Summer	Rain	Critical	
				Nos	Nos	Nos	hours	Nos	Nos	Nos	No of hours	Nos	Nos	Nos	hours	Nos	Nos	Nos	No of hours
TV																			
Florescent Light (Tube)																			
Incandescent Bulb																			
CFL Lamps																			
Fan																			
AC																			
Geyser																			
Water Pump*																			
Washing Machine																			
Refrigerator																			
Mixer																			
Induction cooker																			
Computer																			
UPS																			

* 1Horse Power (HP)=746Watts

17. Do you use Inverters/ PV system already at home?	Inverter ☐	PV Unit ☐
(1) Equipment		
(2) Cost		
(3) KVA/KW rating		
(4) Battery rating(Ah)		
18. Building Type	Tile ☐ RCC ☐ Sheet ☐ Others :	
19. Roof Type	Sloped ☐ Flat ☐	Partially sloped ☐
20. Approx. area of Roof area (Sq.ft)		
21. Is the slanting of roof towards south?	Yes ☐ No ☐	Partial ☐
22. Is there any additional truss work (sheets) on rooftop to overcome rainwater leaking and to reduce heat?	Yes ☐ No ☐	If yes, what was the expense?
23. Regarding the rooftop/terrace		
(1) What is the approximate area over which there will be more or less continuous sunshine between 10 am to 4pm (sq.ft)?		
(2) How many hours of continuous direct sunshine?		
24. Regarding any open land associated with the building compounds		
(1) What is the approximate area over which there will be more or less continuous sunshine between 10 am to 4pm (sq.ft)?		
(2) How many hours of continuous direct sunshine?		

25. Wall type	☐ Strong (Brick, stone, Reinforced Concrete)	☐ Comparatively weak (Sun-burnt brick, lime mortar, mud)	☐ Weak	(2) Age (Years)
26. Are there any shading objects like trees, other higher building in the vicinity of the building?				
27. (1) Are you interested in solar PV?				
(2) How much money are you willing to pay on a per month basis for operating all the important equipment at your home (except heavy loads like AC, refrigerator, pump etc?)				

Details of Enumerator:

Name of Student: Class:	1) ………………………………… ……..	2) ………………………………… ……..
School:	……………………………………………………..………………………………………………………………	

TYPICAL POWER RATINGS OF HOUSEHOLD APPLIANCES

Appliance	Approximate Load (Watts)	Appliance	Approximate Load (Watts)
Lamps - Incandescent Bulb	40, 60, 100	Television- 19" Colour	90
Lamps – CFL	11, 22	Television- 25" Colour	150 - 200
Tube Lights	40	Television- Flat Screen/LED/LCD	120 - 200
Electric Iron	600 - 1000	CD Player	35
Immersion Heater	1500	Satellite Dish	30
Water Heater/ Geyser	1000 - 2000	Desktop Computer	150 - 200
Toaster	750	Laptop Computer	20 -50
Microwave Oven	600 - 1500	Printer	100
Induction Cooker	1000 - 1500	Mixer-Cum-Grinder	200
Refrigerator- 165 Litre	200	Water Pump- 1/2 HP	373
Window A/C- 1.5 ton	1500 - 2000	Water Pump- 1 HP	746
Desert Cooler - Medium	200	Water Pump- 1.5 HP	1119
Room Cooler	60 - 200	Vacuum Cleaner	700 - 1000
Table Fan	20 - 40	Electric Kettle	1000 - 1500
Ceiling Fan	40 - 60	Electric Sewing Machine	100
Exhaust Fan	150	Dish Washer	1200 - 1500
Washing Machine – Automatic	500 - 700	Hair Dryer	700 - 1000
Washing Machine - Manual	300 - 500	Portable Stereo/Home Theatre	20 - 30
Television-12" Black and White	20		

Annexure II

Questionnaire for Feasibility Study for Rooftop PV and Demand Side Management Program, Cantonment Section, Trivandrum

Feasibility Study for Rooftop PV and Demand Side Management Program
Cantonment Section, Trivandrum

Questionnaire Survey

Serial No:

Meter Reading:

1. Basic Information

1. Consumer Number		2. Ward & Building No		
3. Name of Respondent		4. Contact Number		
5. Type of building	□ Independent House □ Flat/Society	6. Building ownership	□ Own □ Rented	

2. Equipment Ownership and Usage Pattern

Equipment	Power Rating	Count	Details of the Equipment*		Age	Interest in** replacement	Average daily usage in hours:	Time of the Day Usage					
								6pm - 10pm		10pm-6am		6am-6pm	
								No	Hrs.	No.	Hrs.	No.	Hrs.
TV Brand/ Make: Cost:			□ C.R.Tube □ Flat Screen LCD □ Flat Screen LED □ Plasma	□ 20 inch or less □ Between 21 and 36″ □ 37″ or more		□ Yes □ No							
			When equipment is not in use □ Disconnect from mains □ Standby mode	Set top box/ DTH box connected? □Yes □ No									
Refrigerator Brand/ Make: Star Rating: .... Cost:			Capacity in litres: □ Direct Cooling □ Frost free	□ Two door with separate freezer unit □ Single door		□ Yes □ No							
AC ***Window type*** Brand/ Make:			Capacity in tons: Star Rating: Cost:	No of months when ACs are used almost every day: ………... Estimate days/year:		□ Yes □ No							

Split type Brand/ Make:			Capacity in tons: Star Rating: Cost:	No of months when ACs are used almost every day: ………... Estimate days/year:		□ Yes □ No							
Water Heater/ Geyser			Brand/ Make: Star Rating: Cost:	No of months when Geysers are used almost every day: ………... Estimate days/year:		□ Yes □ No							
Washing Machine			Brand/ Make: Cost:	□ Fully automatic □ Front Load □ Top Load		□ Yes □ No	Average **weekly** usage in hours: ………						
Wet Grinder			Brand/ Make: Cost:	□ Table top Capacity in litres:		□ Yes □ No	Average **weekly** usage in hours: ………						
Electric Iron			Brand/ Make: Cost:			□ Yes □ No	Average **weekly** usage in hours: ………						
Mixer			Brand/ Make: Cost:			□ Yes □ No							
Water Pump			Brand/ Make: Star Rating: Cost:			□ Yes □ No							
Ceiling Fan			Brand/ Make: Star Rating: Cost:	□ Resistive speed regulator □ TRIAC based speed regulator		□ Yes □ No							
Florescent	T5	28 W	Brand/ Make:	□ Electronic Choke		□ Yes							

Light (Tube)	T8	36 W	Star Rating:	□ Ballast Choke		□ No							
	T12	40 W											
CFL Lamps	11-15 W		Cost:			□ Yes □ No							
	22 W		Cost:										
	> 22 W		Cost:										
Incandescent Bulb	40 W		Place of Use:	Cost:		□ Yes □ No							
	60 W												
	100 W												
Computer			□ C.R.Tube □ Flat Screen LCD □ Flat Screen LED When equipment is not in use □ Monitor turned off □ Standby mode	□ 20 inch or less □ Between 21 and 25″ □ UPS always connected to mains □ UPS has auto cut off when fully charged		□ Yes □ No							
DVD Player			**When equipment is not in use:** □ Standby mode □ Disconnect from mains			□ Yes □ No							
Induction Cooker						□ Yes □ No							
Microwave Oven						□ Yes □ No							
Bread Toaster						□ Yes □ No							
Others						□ Yes □ No							

*Enter the details of the most used equipment in case of TV, Refrigerator, AC etc. if there are more than one equipments

* *Are you interested in replacing the current appliance with an energy efficient one, if the payback time of the incremental cost is up to 5 years?

1. Do you have power back up systems?		
☐ Inverter KVA/KW rating: Upfront Cost: Battery Bank Size: ....V …..Ah	Back up time (hrs): Make: Age: Rating: □ C10 □ C20 □NA	☐ Diesel Generators KVA/KW rating: Upfront Cost: Recurring Expenses (Monthly):	☐ Others (Please Specify)

UPS mode available: □Yes □ No		
2. Is there a segregation of wiring for high power appliances and low power appliances in domestic wiring?		□Yes □ No □ Partial
3. How old is the household wiring?		Years:
4. Type of wiring: □ Concealed □ Conduit Wiring □ Cleat Wiring		□ Others
5. Do you already own a rooftop PV system?		□Yes □ No
6. Would you like to convert/exchange the existing inverter system to a solar charged inverter at an additional investment which will pay back in less than 5 years?		□Yes □ No □NA
7. Would you like to buy a new solar charged inverter which will pay back in 5 years? Upfront cost : 10,000 and Monthly Payment approximately 300 Rs per month?		□Yes □ No
8. Is there a safe space for keeping an inverter and battery bank in your home? (possibly DC wiring requirement less than 5 m)		□Yes □ No
9. Do you own a solar water heater?		□Yes □ No

3. Building details and rooftop potential for PV installation

1. Building Roof Material	□ Tiled □ RCC □Sheet □ Truss work □ Others			
2. Roof Type	□ Sloped	□ Flat	□ Partially sloped	Is the slanting of roof towards south? □Yes □ No □ Partial
3. Are there any shading objects like trees, other high-rises etc. in the vicinity of the building?				□Yes □ No
4. Approx. area of Roof area (Sq. ft)	What is the approximate shade free area over which there will be more or less continuous sunshine between 10 am to 4pm (sq.ft)?			
5. Access to the rooftop	□ Easily Accessible □ Difficult			
6. (1) Wall type	□ Strong (Brick, stone, Reinforced Concrete)	□ Comparatively weak (Sunburnt brick, lime mortar, mud)	□ Weak	(2) Age (Years)

4. Details of Enumerator

Name of Student: Institution:	1) ………………………………………Class ………. ……………………………………………………..	2) …………………………………………Class ………..… ………………………………………………………………

Annexure III

Socio-Economic & System Level Checklist used in All India Survey of PV Module Reliability

Site No.: **SOCIO-ECONOMIC & SYSTEM LEVEL CHECKLIST (GROUP – B)**

1. **Year and month of** Procurement: ______________ Installation______________ Commissioning: _______________
2. **System Ownership**

☐ Private Individual ☐ Private Institution ☐ Community Ownership ☐ Govt/Semi-Govt Institutions

3. **Implementation Model**

☐ EPC Company /System Integrators ☐Supervised by NGOs ☐Supervised by MNRE Nodal Agency ☐Self (local electrician)

4. **Financial Model**: **Capital Investment:** Rs ___________

Did you avail any loans from banks? ☐ Yes ☐ No Bank: __________________

Loan Amount: Rs ___________________ Interest rate =__%

☐ Availed capital subsidy from MNRE ☐ Availed capital subsidy from State Govt

☐ Pending ☐ Pending

Percentage/Amount: ________________ Percentage/Amount: _________________

Year Received: ____ Year Received: ____

☐ Received funds from Govt/CSRs/Foreign Aids/NGOs

Amount: ______________

Year Received: ____

5. **O&M Expenses**

☐ Self ☐ Receive funds from Govt/Foreign Aids

☐ Generated by pay for service model

☐ Can be met from the savings in electricity bills

☐ Can be met from the replacement cost of previous power source (kerosene etc.)

6. **System Maintenance**

Comes from nearest town (___km away)

☐ **Preventive**

☐Daily ☐ Monthly ☐ Half Yearly ☐Yearly Other__________

Basic Trouble Shooting and Maintenance done by:

☐Self ☐Trained Technician Next Technician Visit Due on: ____________ After _________days/months/

☐ From same locality ☐Comes from nearest town (___km away)

☐ **Responsive**

No of times the system failed in a year: _____

Repair works when system is down done by

☐ Self (Owner is trained) ☐Trained Technician

☐ From same locality Response Time:_______________Mean repair time: __________

☐ Comes from nearest town (___km away), Response time: _____Mean repair time: _______

Average Expenses on operation and Maintenance: ___________Rs/ Year

7. **Skill Level of Technician**

☐High School ☐ Diploma ☐ Graduate ☐ Engineering Graduate ☐ Other: ________ ☐ Taken PV training at technical Institutes/ NGOs /Companies etc.

Years of Experience: __________

8. **What all maintenance services are done in a technician visit?**

Visual Inspection, Module Cleaning ☐ Checking the Junction boxes for tight wiring/ corrosion ☐Check battery terminal

☐ Check for shading issues ☐ Remove debris ☐ Adjust tilt ☐ Inspect mounting system ☐ Inspect Battery Enclosure

☐ Watering of battery ☐ Specific Gravity Measurement of electrolyte ☐ Charge Equalization ☐ Load Testing

☐ Capacity Testing ☐ Thermal inspection of Electrical equipment ☐ Disconnects, Fuses, Circuit breakers

☐ Strains in Wiring, Insulation damage

Comments: ____

____

Filled By: Page: 1 Date:

Site No.:

SOCIO-ECONOMIC & SYSTEM LEVEL CHECKLIST (GROUP – B)

List of Equipment: ____
____
____
____

Level of trouble shooting: ☐ System Level ☐ Subsystem Level ☐ Component level ☐ Element level

Most frequently replaced part of the system: ____

9. Motivation for installation of the system

☐ **Necessity:**

☐ ***Home Lighting System***

Impact of SHS: No of additional hours added to daily activities____

☐ Entertainment and Information form TV/Radio

☐ Extra income generation through small artisanal activities

☐ Reduced indoor pollution (kerosene fumes)

☐ Communication facility (Mobile phone charging)

☐ **Optional power back up**

☐ Grid is available, but high interruption rates

☐ Grid available, but with low interruption rates

☐ **PV for community**

☐ Provision of potable water

☐ Powering Health centers

☐ Powering of educational/community center

☐ Street lights

☐ Telecommunication (Towers/ Repeaters etc.)

☐ **Promotion of green energy**

☐ Even though the economies are not attractive, invested on PV for proving pro-green.

☐ Demonstrate the viability and scope (publicity)

Others_________________________________
____

☐ **Income generation/saving**

☐ ***Non-Agricultural productive Enterprises***

☐ Cottage industry (by powering small tools)

☐ Commercial Sector (Telephone Shops, Restaurant, Cinema etc.)

☐ Service Sector (Charging station, hiring of lamps, Power supplier, Communication services etc.)

☐ ***Agricultural and Animal Husbandry***

☐ Irrigation

☐ Aeration for Aquaculture/Fishing

☐ Electric Fencing

☐ ***Saving from electricity bill***/Previous electricity source, pay back in ____years

Cost of 1 unit of replaced electricity:______Rs/unit. LCOE of 1 unit of PV electricity: _____Rs/unit

☐ ***Income generation through sale of electricity***

☐ To Grid Rate: _____Rs/unit REC mechanism utilized: ☐ Yes ☐ No Years of PPA:____

☐ Microgrid Rate: _____Rs/unit REC mechanism utilized: ☐ Yes ☐ No Years of agreement:__

☐ **Tax Savings**: Accelerated depreciation of assets and associated tax savings, etc.

☐ **Research**

Comments: ____
____

Filled By: Page: 2 Date:

SOCIO-ECONOMIC & SYSTEM LEVEL CHECKLIST (GROUP – B)

10. Constrains faced while installation/ What delayed you getting into solar?

- ☐ High capital investment and Lack of Financial Model (Credit/ Soft loans/ EMIs/ FITs, PPAs)
- ☐ Lack of knowledge about technology (didn't get information about the possibilities of application of PV)
- ☐ Poor market infrastructure and supply chain (Didn't know where to buy and what to buy, quality assurance etc.)
- ☐ Lack of legal and regulatory framework, administrative delays
- ☐ Lack of standards, codes and certification for quality control
- ☐ Lack of trained man power/consultants
- ☐ Lack of infrastructure and grid connectivity

Inverter and Battery Bank

1. **Type of system:** ☐ Off Grid ☐ Grid tied, export ☐ Grid sharing (captive) ☐ Grid dependent (Battery+Grid)
2. **Inverter Details** **ϕ:** ☐ **1** ☐ **3** **Rated kVA ______**
   Max.Load:____ _ **Tripped at ______kVA**
   ☐ Connected ☐ Indoor ☐ Adequate ventilation ☐ Outdoor ☐ Vibration and Noise ☐ Properly Earthed
   MPPT available: ☐ Yes ☐ No
   MMPT Range: ________________V ____________________A
   IP Protection: ☐ 65 ☐ 64 ☐ Not Available

3. **Operation at maximum load**: **DC Side**: _____V, _____A , ____W
   AC Side: ____V, ____A, _____W Efficiency: ___%
   P.F=_____ T.H.D: ____% Operation Temperature:_____ Nominal Temperature:_____ Array Grounding:______

4. **Condition of Battery**
   ☐ Connected Manufacturer:_________ Single Unit: ____V, ____Ah Price per unit: _______ Parallel:___, Series:____
   Terminals Corroded: ☐ Yes ☐ No Terminal Lugs: ☐ Tight ☐ Loose ☐ Sulphation Observed
   Electrolyte levels above critical: ☐ Yes ☐ No ☐ NA
   Electrolyte levels equal in all cells: ☐ Yes ☐ No ☐ NA
   Difference in specific gravity of electrolyte among different cells >±0.004: ☐ Yes ☐ No ☐ NA
   How often batteries are changed:____________________

5. Module Transportation related issues
   What are the precautions done during transportation of modules?

____

____

Mode of transport: ____________________

Place from where the modules were shipped in: ____

Comments: ____

____

Filled By: Date:

Site No.: SOCIO-ECONOMIC & SYSTEM LEVEL CHECKLIST (GROUP – B)

System Layout Diagram

Comments: ____
____

Filled By: Page: 4 Date:

Annexure IV

Article on Chendamangalam Energy Survey in the News papers

Article on Chendamangalam Energy Survey in the News papers

THE HINDU

S & T » Environment

Published: January 17, 2013 19:27 IST | Updated: January 17, 2013 19:28 IST

SUNSHINE in Chendamangalam

DEEPA J.

School children conduct a survey as part of the ongoing solar power project at Chedamangalam panchayat. Photo: Special Arrangement

Chendamangalam is attempting to become Kerala's first solar powered panchayat.

The little panchayat of Chendamangalam in North Parur, a prominent site in the Muziris Heritage Project, boasts of rich history and the remnants of a glorious past. The whole panchayat now has another reason to celebrate. It is involved in a project that will make it the first completely solar-powered panchayat in the State, according to Centre for Development of Imaging Technology (CDIT) sources.

The initiative came from CDIT and the lucky break came with the decision of IIT Mumbai to support the project. The technological backing needed is being provided by these sources along with support from the KSEB, the panchayat, Agency for Non-conventional Energy and Rural Technology (ANERT), Energy Management Centre Kerala (EMC), and the State Planning Board. This has given the project a huge boost. "This project is a continuation of our attempts to promote Green Technology .CDIT had already undertaken the unique programme 'Green Kerala Express', a social reality show on television. Added to this was the implementation of 'Surya Keralam', an extensive solar power programme to harness 1000 MW in the coming two years. The Sainik School at Kazhakkoottam, Thiruvananthapuram, is now in the process of shifting to solar power. Legislator V. D.Satheesan and Mani Teacher, the Gram Panchayat President have been very encouraging," says K. Mohan Kumar, Deputy Director, CDIT.

Survey

The panchayat was bustling with activity and excitement the other day when the initial survey for data collection was held. It roped in around 140 first year engineering students from the Federal Institute of Science and Technology (FISAT), Angamaly, 65 students from Sree Narayana Guru Institute of Science and Technology (SNGIST), North Parur, Kudumbasree workers, and 2,000 students from Paliam HSS, Karimpadam DD Sabha High School, Chathedam St. Joseph's HS, and Gothuruthu St Sebastian's HSS.

They were formed into teams under a ward member or a teacher to collect data mainly on the current consumption of electricity. An energy survey undertaken of all houses, buildings, hospitals, government offices and similar places of an entire panchayat was the first of its kind in India. Electricity bills were made available to the children to peruse, householders answered their questions regarding the consumption of power, they located spacious areas to install the solar panels, queries about the difference in energy consumption during climate changes were answered, and all agreed that the concept was totally acceptable to them. This pilot project, they hope, will come up with a blueprint for a programme which will eventually turn every panchayat solar powered.

Dr. N. C.Narayan, IIT Mumbai, says: "Chendamangalam panchayat was an appropriate choice. The project is a combination of two things – of what technology can do to the power demand today and the supply options. So, we need a setting to meet the demand and hence it's not just a supply enhancing option alone. Demand management is the core of the project."

Encouraging factor

The most encouraging factor about the project is the general awareness it has created among the common man – awareness regarding the conservation of power and the need for producing more power. Dr. Narayan adds, "The project is more than just one to spread awareness, especially among the students. It is an educational project to learn about their environment. The data they have collected will be analysed to design appropriate solutions, and tap into alternative sources of power like solar panels."

What is encouraging for the panchayat is that a beginning has been made. With all the local enthusiasm, participation and technological backing, things are bound to see the light of day. Well begun is half done, they say. Dr. Anil Kottantharayil, asst. professor, Electrical and Engineering Dept, IIT Mumbai, agrees, "The National Centre for Photovoltaic Research and Education (NCPRE) at IIT Mumbai, has helped design this project. The shortage of power that stares us in the face has spurred this project. Things have had a head start at Chendamangalam. There is every promise of this pilot project meeting with the success expected."

When that happens, as it should, hopefully in one year, Chendamangalam will go down in history as a completely solar powered panchayat and will also have set the lead for the rest of the country.

Keywords: Chendamangalam, solar powered Panchayat, Muziris Heritage Project, Centre for Development of Imaging Technology, Green Kerala Express, power conservation awareness

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THE NEW INDIAN EXPRESS

A panchayat getting ready to swear by solar energy

Author: Reema Narendran

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- Last Updated: Jan 9, 2013 11:58 AM

If all goes well, Chendamangalam panchayat in Ernakulam may become the first power-cut free panchayat in the state in a not too distant future. As a first step towards popularising solar power in the panchayat, a complete energy audit of the panchayat will be done on January 12.

While the energy survey is a joint initiative of Centre for Digital Imaging Technology (C-DIT) and IIT Mumbai, the whole solar project at Chendamangalam panchayat will be supported in implementation by grama panchayat in collaboration with Kerala State Electricity Board (KSEB), Agency for Non-conventional Energy and Rural Technology (ANERT), Energy Management Centre and State Planning Board.

''The energy audit will give us an idea about the pattern of energy consumption in the panchayat, but more importantly, it will give us information about the available shadowless area in each house that can be used for generation of solar power,'' said C-Dit Deputy director K Mohankumar.

The questionnaire for the energy survey scheduled has questions on the type of roof, direction of the slope of the roof, whether the houses has additional rooftops in GI sheets, the area of free space around the constructed area, the presence of trees that might create shaded areas and the time at which the plot gets uninterrupted sunlight. Along with this, the survey also intends to optimise the utilisation of energy in public spaces such as primary health centres, schools, village offices, community halls and so on. ''We are also looking at ways by which energy consumption by street lights can be optimised looking at the height of the lamps, the time, whether LED can be used, whether the intensity can be cut down late in the night and so on,'' said Mohankumar.

Panchayat ward members, teachers, Kudumbashree workers, and thousands of school students from the four schools in the panchayat are all gearing up to conduct the survey that will start at 8 a.m on January 12 and conclude at 4 p.m. This is probably the first energy survey of its kind in the country.

At the end of it all, energy requirements of the panchayat and the potential of solar power production in about 9644 buildings of the panchayat will emerge, giving a clear data that can be used for the future planning.

''We are eagerly waiting for the results of the survey, which would give us some idea about the level of intervention needed. If it falls into the framework of what we are planning, we will think of possibilities of expanding it to other panchayats,'' said KSEB chairman M Sivasanker.

The survey tools have been modelled in such a way that it can be replicated in any panchayat in the state.

Annexure V

Expression of Interest Published by KSEB for Peak Load Shifter Project

Expression of Interest Published by KSEB for Empanelment of Vendor of ‘Peak Load Shifters’

KERALA STATE ELECTRICITY BOARD LTD.

Invitation of Expression of Interest for Supply of Offgrid Solar Inverter with peak load shifter

KSEB Ltd. invites Expression of Interest (EoI) from the suppliers/manufacturers of Solar inverters, for offgrid Solar inverters having peak load shifting features as per the specification of KSEB Ltd. for their tentative empanelment.

EoI document can be downloaded from the website http://www.kseb.in.

Last date and time of receipt of EoI documents-15-05-2014,3.00 p.m

Chief Engineer (Corporate Planning)
& Safety Commissioner
Vydyuthi Bhavanam,
Pattom
Thiruvananthapuram-695004
Phone :0471-2514421
E-mail : innovation@ksebnet.com

PRMC1 2741\1152|14

INVITATION OF EXPRESSION OF INTEREST FOR EMPANELMENT OF SUPPLIERS / MANUFACTURERS FOR THE SUPPLY OF SOLAR INVERTERS WITH PEAK LOAD SHIFTER AND SOLAR PANEL IN THE STATE OF KERALA

No.: KSEB/2014-15/ EoI/01 Dated 22-04-2014

1. **Objective :**

Due to the difficulty in meeting the peak demand, KSEB Ltd. sometimes resorts to load shedding during peak hours to tide over the crisis. During the period of load shedding, the inverters supply the essential loads of the consumers and once the feeders are charged after load shedding, the large number of inverters in the circuit turns to heavy charging mode there by defeating the purpose of load shedding. If the charging of the batteries can be postponed to a time period after the peak load hours, KSEB Ltd. can manage the demand during peak load time. KSEB Ltd. wishes to empanel suppliers / manufacturers of Backup solar inverters, which are not charged from the KSEB Ltd.grid during peak load hours. These inverters are to be charged from solar power during day time and should be able to provide backup power to essential loads during power failure and also meet a portion of the load of the consumers during peak hours.

Requisites:

2.1 Identified suppliers / manufacturers interested in supplying Solar Inverters with peak load shifter and solar panel as per KSEB Ltd.'s functional requirement will be empanelled through a process of pre-qualification.

2.2 The interested parties are expected to express their interest by submitting a technically viable proposal matching the Boards requirement.

2.3 Technologically competent and financially sound equipment manufacturers / suppliers who are experienced in the supply and installation of similar equipments are invited to submit their EoI in the specified date and time.

2.4 Interested suppliers / manufacturers shall submit a sample inverter with peakload shifter complete in all respect (without Solar PV panel and battery) at the Electrical Testing lab in College of Engineering, Thiruvananthapuram campus at their risk and cost for testing before the specified date and time. Submitted sample system / equipment will be returned after testing and performance evaluation.

2.5 Only firms and ventures that have been pre-qualified and empanelled under this process will be eligible to supply the proposed system / equipment.

3.1 **Solar Inverters with Solar Panel & Peak Load Shifter** :

3.1.1 Components:

a. Solar Inverter with integrated Peak Load Shifter
b. Charge Controller
c. Solar Panel

3.1.2 Functioning of the System:

Functions Expected from Peakload shifter:

Under normal conditions the battery shall be charged from solar source .The battery should not be charged during peak load hours from the KSEB Ltd. grid .Load shall normally be fed from KSEB Ltd. grid when KSEB Ltd. input supply is available except during peakload period. If the input supply fails while being fed from the KSEB Grid, the normal inverter function should commence.

During peak load period (06.00 Hrs to 09.00 Hrs and 18.00 Hrs to 23.00 Hrs), the load connected to the output of the inverter shall be fed from the battery, even if grid is available, till the battery charge drops to 50%. If the battery level has dropped to the above level or in the event of failure of inverter output, the load shall be fed from the KSEB Ltd. Grid after bypassing the inverter. The balance battery charge is retained to meet the load during power failure.

A detailed description of the functioning of the inverters is explained below :

The inverter basically should have 5 operational modes

1) Normal Inverter Mode: Whenever grid fails (irrespective of the real time) the inverter supplies power to the load by drawing energy from the battery. This process will continue until the battery terminal voltage drops below a threshold value, determined by the depth of discharge.

2) Evening Peak Load Shaving Mode: During this period (6 PM to 11 PM), the charging circuit from grid to the batteries is disconnected. This will avoid unnecessary phantom loads on the mains due to no-load losses of the battery charging circuit of the inverter. If the battery charge level of the inverter system is above a threshold value, (set as 50%),the loads are connected to the inverter output. Thus the inverter enters into Peak load shaving mode. The loads are transferred back to the grid once the battery levels drops below 50%.

3) Morning Peak Load Shaving Mode: During this period (6 AM to 9 AM), the charging circuit from grid to the batteries is disconnected. This will avoid unnecessary phantom loads on the mains due to no load losses of the battery charging circuit of the inverter. If the battery charge levels of the inverter system is above a threshold value, (set as 50%), the loads are connected to the inverter output. Thus the inverter enters into Peak load shaving mode. The loads are transferred back to the grid once the battery levels drops below 50%.

4) PV Energy Optimisation Mode: During day time, i.e. solar power is available and if the batteries are almost near full charge, (set as 95%), the loads are transferred to the inverter. This will prevent the batteries from over charging since the day time loads will consume the incoming solar power. This process will continue till the battery charge level drops to 85%. If there are no day time loads, the battery may get charged up to 100 % by solar power. Then the solar charging circuit should be cut off to prevent overcharging of the batteries at 100%.

5) Off Peak Hours Grid Charging mode: If the battery charge dips below a critical value (set as 50%), then the charging circuit from the grid can be reconnected during off peak hours (9 AM to 6 PM, 11 PM to 6 AM). Hence hybrid charging can be allowed till the battery charge level reaches the critical value of 50% during day time. This will increase the reliability of the power back up.

The time durations for entering into various modes shall be programmable by a super user (board staff, system integrator technician). The inverter should automatically switch from one mode to another, based on the time of the day and level of charge of the battery.

4.Instructions to the Participants:

4.1 Interested parties may submit their EoI along with the following:

a. company profile
b. details of the manufacturing facilities available to cater to the requirement.
c. financial capability
d. Major works undertaken particularly of similar nature etc.

The participants are free to add any additional information relevant to the project apart from the above.

4.2 **Last date of Submission of EoI and samples**:

i) Last date and time of receipt of EoI	:	15-05-2014; 3.00 p.m.
ii) Date and time of opening of EoI	:	15-05-2014; 4.00 p.m.
iii) Last date and time of submission of samples	:	02 -06-2014; 3.00 p.m.

4.3 The interested suppliers or manufacturers may obtain further details, if any, from office of the **Chief Engineer (Corporate Planning) & Safety Commissioner, KSEB, 9th Floor, Vydyuthi Bhavanam, Pattom, Thiruvananthapuram - 695 004.(Phone no.0471-2514421)**

4.4 All communications shall be addressed to the Chief Engineer (Corporate Planning) & Safety Commissioner only.

4.5 Expression of Interest documents may be downloaded from the website of KSEB Ltd www.kseb.in or obtained from the Office of Chief Engineer (Corporate Planning) & Safety Commissioner and should be submitted *in duplicate* by registered post/speed post/hand delivery only, at the address given below on or before 15-05-2014 at 3.00 p.m.

Chief Engineer (Corporate Planning) & Safety Commissioner,
KSEB Ltd., 9th Floor, Vydyuthi Bhavanam,
Pattom, Thiruvananthapuram-695 004.

4.6 Interested suppliers / manufacturers shall submit a sample inverter with peakload shifter complete in all respect (without Solar PV panel and battery) at the

Electrical Testing lab in College of Engineering, Thiruvananthapuram campus at their risk and cost for testing before the specified date and time. The testing fees of the suppliers/manufacturers who had earlier submitted their sample and remitted the testing fees at CET, Trivandrum will be borne by KSEB Ltd**.** The suppliers/manufacturers shall also furnish the complete guaranteed technical particulars of the equipment including the type / model no along with test reports and **a write-up describing the operational philosophy and working of the solar inverter during day time and peakload hours**. A schematic / wiring diagram of the equipment shall also be furnished. The equipment should be set up and programmed so that they are ready for testing.

4.7 The price bid is to be submitted in a separate sealed cover. The price for Solar panel, Inverter, battery, AMC etc. should be separately given in the following format.

Solar Panel -

Inverter with peak load shifter and charge controller–

Battery 12V,150 AH -

AMC (5 years) -

Total -

4.8 The application should be accompanied by a covering letter signed by a competent authority representing the participant organization.

4.9 KSEB Ltd. reserves the right to cancel /re-tender this empanelment process without assigning any reason.

4.10 KSEB Ltd. may instruct the suppliers/manufacturers to modify the product to suit the requirements of KSEB Ltd., and the instructions are to be complied with by the suppliers/manufacturers.

4.11 The empanelment does not in any way constitute any contract of agreement of any kind what so ever with the firms.

4.12 Empanelment will be valid for a period of six months

In subsequent periods new empanelment will be considered by KSEB Ltd.

Annexure - I

Technical Specification

Specification and Certification requirements for 650 VA Solar Inverter System

1. **SPV MODULES (200 Wp expandable upto 600Wp)**
   a) The solar PV module should have IEC 61215 / IS14286 qualification certification.
   b) PV modules must also qualify salt mist corrosion testing as per IEC 61701.
   c) The PV modules(s) shall contain crystalline silicon solar cells.
   d) Shading correction / bypass for optimizing array output is to be incorporated and shading optimization to be provided.
   e) Each PV module used in any solar power project must use a RF identification tag (RFID), which must contain the following information. The RFID can be inside or outside the module laminate as per MNRE conditions, but must be able to withstand harsh environmental conditions.
      i. Name of the manufacturer of PV Module
      ii. Name of the manufacturer of Solar cells
      iii. Month and year of the manufacture (separately for solar cells and module)
      iv. Country of origin (separately for solar cell and module)
      v. I-V curve for the module
      vi. Peak Wattage, Im, Vm and FF for the module
      vii. Unique Serial No. and Model No. of the module
      viii. Date and year of obtaining IEC PV module qualification certificate
      ix. Name of the test lab issuing IEC certificate
      x. Other relevant information on traceability of solar cells and module as per ISO 9000 series
   f) The PV modules must be tested and approved by one of the MNRE authorised test centres for IEC/ IS certification. Test certificates can be from any of the NABL/ BIS accredited Testing / Calibration Laboratories.
   g) The power output of the module(s) under STC should be a minimum of 200 Wp (as per panel rating)

h) PV modules used in solar power plants/ systems must be warranted for their output peak watt capacity, which should not be less than 90% at the end of 10 years and 80% at the end of 25 years.

i) Operating voltage for the output shall be suitable for 12 volt DC applications

j) If multiple solar modules are connected in parallel, blocking diodes should also be provided.

2. PEAK LOAD SHIFTER:

1. Peak load shifter should be integrated with the solar inverter or a separate unit .
2. Should not draw supply from the KSEB grid from 6pm to 11 pm and 06.00 a.m to 09.00 a.m unless extreme emergency condition like discharge of battery beyond safe operating limit occurs.
3. The peakload shifter should function as mentioned in 3.1 above

3. CHARGE CONTROLLER

To prevent the batteries from over charging through solar power, a charge controller should be provided. It should have an MPPT algorithm to ensure optimum utilisation of solar energy.

1. The charge controller should confirm to applicable standards for requisite AC/DC inputs
2. Operational Voltage Range: 12 volt
3. Controlling element: IGBTs or MOSFET
4. Current rating as required for panel array and inverter/battery used
5. Electronic protection (if charge controller is separate from inverter) for
   i. Short circuit
   ii. Overload
   iii. Electronic over current protection
6. LCD Digital display with back lighting and continue display of
   i. Battery voltage
   ii. DC charge/ discharge current
   iii. LED/LCD indications for state of charge

4. INVERTER

Rating-650 VA

Type-IGBT/MOSFET BASED

Input AC; 230 ±-5%

DC Voltage-12V

Output Voltage at rated load - 230±5%

Output Waveform : Pure Sine wave

Total Harmonic Distortion: Less than (<) 5% at 12Volt and Full load

MPPT charge controller

Efficiency: 75% or above at full load and at Unity P.F

Output Frequeny:50 Hz±3%

Ambient temperature: 0 to 50°C

Cooling : Forced Air cooled

Tolerances as per relevant IS

Protections:

a. Short circuit (circuit breaker & electronic protection against sustained fault)
b. Automatic shutdown for Over-load , Surge and under Voltage of Battery
c. Auto re-connect shall be attempted for 3 times and if fault sustains it shall go to shutdown mode and reconnect shall be manual.
d. A manual inverter ON/OFF switch is to be provided in front panel of inverter.
e. Battery overcharge protection.
f. All indications & switches shall be clearly and permanently labeled.

2. Indicators / Displays / Alarms :

a. DC SPV Charging Indicator
b. AC Load Indicator to indicate Grid/Inverter

c. LED lamp for inverter ON/OFF indications
d. Battery Low indicator
e. Beep for load greater than 550VA
f. Overload Alarm / cut off
g. System Cut off Indicator
h. System reset button

5. Battery

12V,150 AH,C10,Tubular (Deep Discharge)

6.WARRANTY AND AMC

1. 5 years warranty and AMC for the entire system should be provided by the supplier as per the conditions of the contract.
2. PV modules used in solar power plants/ systems must be warranted for their output peak watt capacity, which should not be less than 90% at the end of 10 years and 80 % at the end of 25 years

7. FACTORY TESTING

1. A Factory Test Report (FTR) shall be supplied with the unit after all tests. The FTR shall include detailed description of all parameters tested qualified and warranted.
2. Factory testing shall include measurement of phase currents, efficiencies, harmonic content and power factor. All tests shall be performed at 25, 50, 75 and 100 percent of the rated nominal power.

8. OPERATION MANUAL

1. An Operation, Instruction and Maintenance Manual, in English and Malayalam, should be provided with the system.
2. The following minimum details must be provided in the manual:
   i. About PV module supplied
   ii. About battery supplied
   iii. About electronics supplied
   iv. About charging and significance of indicators
   v. DO's and DON'T's
   vi. Clear instructions on regular maintenance and trouble shooting of solar power system

vii. Name and address of the contact person in case of non-functionality of the solar power system.
viii. Service centre.
ix. Warranty details.

DETAILS TO BE FURNISHED BY MANUFACTURER (To be submitted with the EoI documents and also at the Testing Lab)

1.Name of the firm -

2.Address -

3.E.mail id -

4.Telephone nos. -

5.Fax no. -

6.Name of contact person -

<u>DETAILS OF INVERTER WITH PEAKLOAD SHIFTER</u>

1.Capacity -

2.Efficiency -

3.Whether battery charging from KSEB Grid is cutoff during 18.00 to 23.00 hrs-

4.Whether battery charging from KSEB Grid is cutoff during 06.00 to 09.00 hrs-

5.Operational philosophy of peakload shifter(in detail)

Annexure VI

Results of Peak Load Shifter Implementation

Results of Implementation of Peak Load Shifter Project

As a response to the Expression of Interest (EoI) invited by KSEB (see Annexure II), 14 system integrators submitted their products to KSEB. The products were sent for testing to the department of electrical engineering, college of engineering, Thiruvananthapuram. Products from seven out of these 14 companies qualified in the testing procedure. They were empanelled by KSEB as partner institutions in the PLS project implementation. After lab testing, the prototypes were installed for a month in a few houses in Cantonment section. It was found the system could save 1 to 1.5 units a day.

The Sun shift Project was officially launched on 3rd March 2015 with 7 “Empanelled Vendors”. The price details and technical details of the package was published in KSEB’s official website.

Instead of channelizing the capital subsidy to the cost of SEE equipments, the implementation scheme resorted to upfront distribution of subsidy as cash. The cost of the kit from various empanelled vendors varied from Rs. 43,000 to Rs, 53,000. Capital subsidy of Rs. 5000 was offered to the first 2750 consumers registering for the scheme.

The response from the consumers was not very exciting. Only 17 people registered in the program and availed subsidy in the first 6 months of programme. There are various reasons for the mild response from the public. Another parallel programme was being run by the MNRE nodal agency, ANERT (Agency for Non-Conventional Energy and Rural Technology) which offered 1 kW off grid system for Rs. 1,00,000. So those people who could really afford for Rs. 53,000 for a PLS kit might have been attracted to this scheme. Another programme run by ANERT offered 1 kW grid tied systems for Rs.80,000. These two programs may be the major reason people were not involving in the sun shift programme. Lack of EMI schemes can also be stated as a reason. Now, KSEB is trying to tackle the issue of inverters (uninterrupted power supply systems/ UPS) charging from grid through policy level initiatives. They have released a new order on the behalf of government of Kerala that all the inverter based systems within the state should be charged primarily through PV. The deadline for changing the existing inverter systems to solar inverter systems was June 30, 2016.

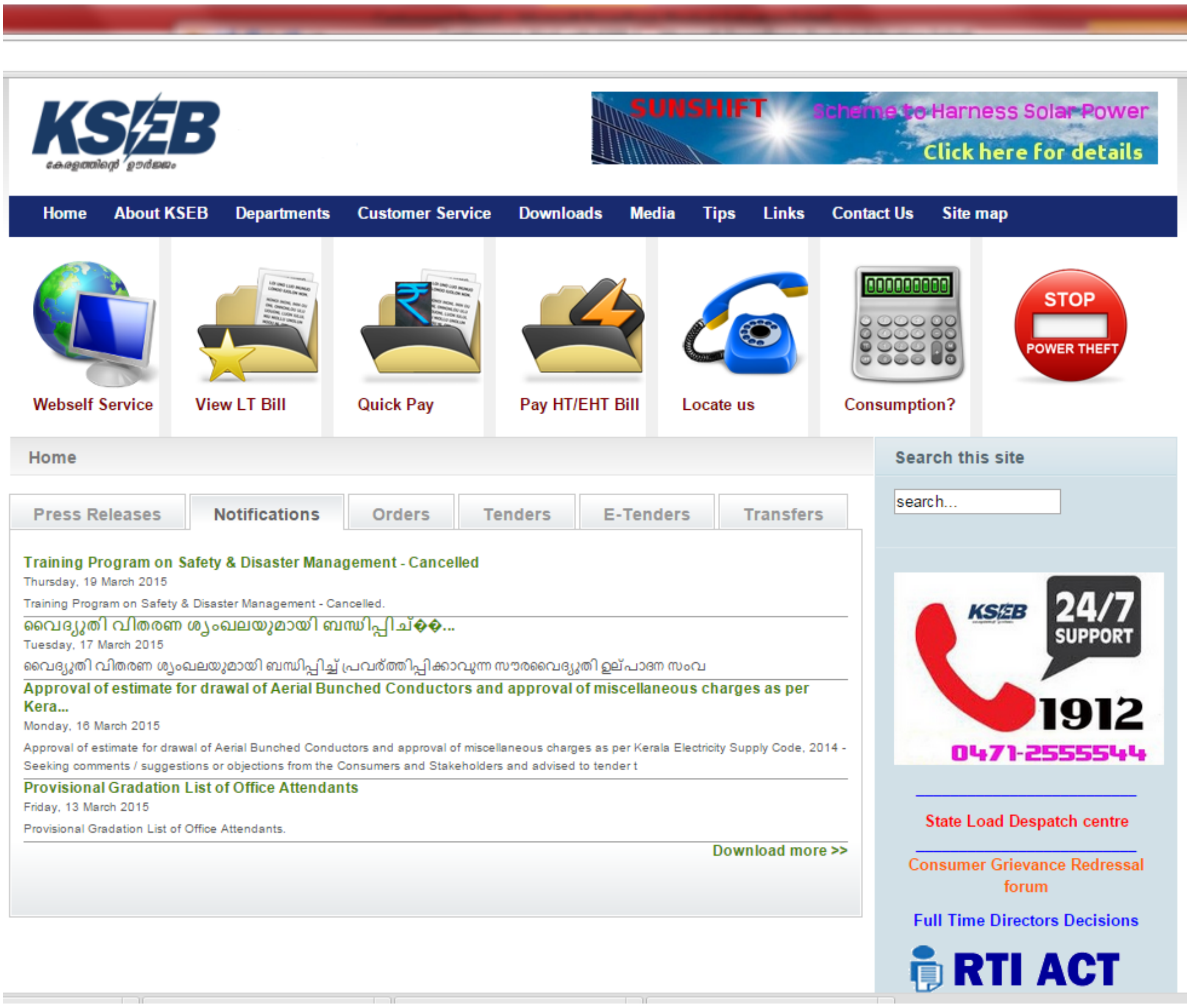


Figure VI.1: Official website of KSEB with the link to register in sun shift programme

Printed from
THE TIMES OF INDIA

KSEB bid to promote solar inverters finds few takers

TNN | Feb 6, 2016, 09.59 AM IST

Thiruvananthapuram: The efforts of the state electricity board (KSEB) to promote intelligent power inverters have failed to impress consumers. There were not many takers for a subsidy programme introduced in this connection. The board had introduced the subsidy programme, Sun Shift, to promote solar-based intelligent inverters and ease pressure on the KSEB grid during peak hours besides helping consumers to save on their power bills. In early 2015, it announced a subsidy of Rs 5,000 for the first 2,750 consumers installing the recommended solar power packs, the price of which ranged from Rs 43,000 to Rs 53,000. The data with the renewable energy cell of KSEB show that only 17 people have availed the subsidy.
Conventional inverters draw considerable amount of grid energy even while not in use, thereby putting pressure on the KSEB distribution grid during peak hours (5-9am and 6-10pm) The board had engaged a committee headed by non-conventional energy expert R V G Menon to prescribe specifications for the intelligent solar inverters that draw power from solar power units during the day. It had empanelled seven firms for producing the solar power packs based on the committee's recommendations.

Studies show that common inverters consume about 30-50 watt power even when they are on idle mode. As a result, consumers are forced to pay for the unutilized power and the inverters remain a permanent load connected to the system. These inverters supply power for essential needs during loadshedding but they shift to heavy charge mode once it is over, thereby defeating the purpose of loadshedding itself.

The deadline for availing the subsidy is over but the board will be introducing fresh initiatives to sensitize the public on the benefits of solar-based intelligent inverters before promoting the scheme afresh.

Figure VI.2: Newspaper report on the poor acceptance of Peak Load Shifters

Annexure VII

Costing Sheets for Conversion of Existing High Capacity Motor Pumps to PV Driven Systems

Costing Sheets for Conversion of Existing High Capacity Motor Pumps to PV Driven Systems

Table 1: Direct costs involved for materials and installation labour charges for 7.5 HP systems.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9520	/module	30	2,85,600
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	2	2,00,000
3	VFD controller	10 HP, variable frequency drive controller for existing AC motors, with 1 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	94,035	/controller	1	94,035
4	Grid tied PV inverter	8 kW, 3 phase	1,54,370	/inverter	1	1,54,370
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	2	2,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30000	/housing (including civil work)	1	30000

7	DC wiring	1C, 6 sq.mm solar DC cable	60	/m	70	4200
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter	170	/m	35	5950
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	2	180
10	AC wiring	4 Core x 16 sq.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel	566	/m	26	14716
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	19981	/housing (depends on HP rating also)	1	19981
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14000
		GI earthing strip for structure and panel frame earthing	70	/m	35	2450
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	36	/m	6	216
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	2	5000
14	Miscellaneous	Lights, sign boards etc.				1000

15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour + 18% GST	2360	/pole	2	4720
	Total					**9,69,778**

Table 2: Direct costs involved for materials and installation labour charges for 10 HP systems.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9520	/module	30	2,85,600
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	2	2,00,000
3	VFD controller	10 HP, variable frequency drive controller for existing AC motors, with 1 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	1,05,816	/controller	1	1,05,816
4	Grid tied PV inverter	8 kW, 3 phase	1,54,370	/inverter	1	1,54,370
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	2	2,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30000	/housing (including civil work)	1	30000
7	DC wiring	1C, 6 sq.mm solar DC cable	60	/m	70	4200
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter	170	/m	35	5950
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	2	180

10	AC wiring	4 Core x 16 sq.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel	566	/m	26	14716
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	19981	/housing (depends on HP rating also)	1	19981
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14000
		GI earthing strip for structure and panel frame earthing	70	/m	35	2450
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	36	/m	6	216
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	2	5000
14	Miscellaneous	Lights, sign boards etc.				1000
15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour + 18% GST	2360	/pole	2	4720
	Total					**10,48,199**

Table 3: Direct costs involved for materials and installation labour charges for 15 HP systems.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9520	/module	45	4,28,400
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	3	3,00,000
3	VFD controller	15 HP, variable frequency drive controller for existing AC motors, with 2 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	1,35,804	/controller	1	1,35,804
4	Grid tied PV inverter	12 kW, 3 phase	1,54,370	/inverter	1	1,54,370
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	3	3,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30000	/housing (including civil work)	1	30000
7	DC wiring	1C, 6 sq.mm solar DC cable	60	/m	100	6000
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter	170	/m	50	8500
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	3	270

10	AC wiring	4 Core x 16 sq.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel	566	/m	32	18112
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	21194	/housing (depends on HP rating also)	1	21194
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14000
		GI earthing strip for structure and panel frame earthing	70	/m	50	3500
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	36	/m	9	324
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	3	7500
14	Miscellaneous	Lights, sign boards etc.				1000
15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour + 18% GST	2360	/pole	3	7080
	Total					**14,36,054**

Table 4: Direct costs involved for materials and installation labour charges for 20 HP systems.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9520	/module	59	5,61,680
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	4	4,00,000
3	VFD controller	20 HP, variable frequency drive controller for existing AC motors, with 2 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	1,48,656	/controller	1	1,48,656
4	Grid tied PV inverter	15 kW, 3 phase	1,99,224	/inverter	1	1,99,224
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	4	4,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30000	/housing (including civil work)	1	30000
7	DC wiring	1C, 6 sq.mm solar DC cable	60	/m	130	7800
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter	170	/m	65	11050
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	4	360

10	AC wiring	4 Core x 16 sq.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel - for 8 kW inverter	566	/m	38	21508
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	22408	/housing (depends on HP rating also)	1	22408
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14000
		GI earthing strip for structure and panel frame earthing	70	/m	65	4550
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	36	/m	12	432
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	4	10000
14	Miscellaneous	Lights, sign boards etc.				1000
15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour + 18% GST	2360	/pole	4	9440
	Total					**18,42,108**

Table 5: Direct costs involved for materials and installation labour charges for 30 HP systems.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9520	/module	89	8,47,280
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	6	6,00,000
3	VFD controller	30 HP, variable frequency drive controller for existing AC motors, with 2 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	182928	/controller	1	1,82,928
4	Grid tied PV inverter	25 kW, 3 phase	2,25,505	/inverter	1	2,25,505
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	6	6,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30000	/housing (including civil work)	1	30000
7	DC wiring	1C, 6 sq.mm solar DC cable	60	/m	190	11400
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter	170	/m	95	16150
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	6	540

10	AC wiring	4 Core x 16 sq.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel - for 8 kW inverter	566	/m	50	28300
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	24836	/housing (depends on HP rating also)	1	24836
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14000
		GI earthing strip for structure and panel frame earthing	70	/m	95	6650
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	36	/m	18	648
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	6	15000
14	Miscellaneous	Lights, sign boards etc.				1000
15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour + 18% GST	2360	/pole	6	14160
	Total					**26,18,397**

Table 6: Direct costs involved for materials and installation labour charges for 40 HP systems.

Sl. No	Item	Specification	Rate (Rs)	Unit	Quantity	Total (Rs)
1	Solar PV module	340 W_p	9520	/module	118	11,23,360
2	Module mounting structure	5 m x 6 m frame for mounting 15 modules, single pole support with seasonal tracking	1,00,000	/pole	8	8,00,000
3	VFD controller	40 HP, variable frequency drive controller for existing AC motors, with 2 channel MPPT, pure sine wave for both voltage and current, dual stacked IGBT and remote monitoring	240762	/controller	1	2,40,762
4	Grid tied PV inverter	15 kW, 3 phase	1,99,224	/inverter	2	3,98,448
5	Civil work	Piling and concrete work for structure	1,00,000	/pole	8	8,00,000
6	Housing for inverter, controller and protection devices	Inverters, controllers and change over switches and meters can be housed in a cubicle	30000	/housing (including civil work)	1	30000
7	DC wiring	1C, 6 sq.mm solar DC cable	60	/m	250	15000
8	Cable conduits	For laying DC cables from tables to inverter - 2 inch diameter	170	/m	125	21250
9	MC4 (Multi Contact) connectors	1Core, 6 sq.mm	90	/pair	8	720

10	AC wiring	4 Core x 16 sq.mm, flexible Copper. Cable for 1.1 kV, inverter to AC distribution box panel - for 8 kW inverter	566	/m	62	35092
11	Balance of System	Change overs, combiners, solar meters, net meter, SPDs, DC distribution box	106710	/housing (depends on HP rating also)	1	106710
12	Earthing kit	Maintenance free chemical earthing electrodes	3500	/electrode	4	14000
		GI earthing strip for structure and panel frame earthing	70	/m	125	8750
		2.5 sq. mm copper cable, single core for inter module earthing connection, with nuts and lugs (3 m per pole)	36	/m	24	864
13	Lightning arrestor	Lightning arrester pole, 2" diameter, 5 meters, hot dip GI 25x5mm GI flat, hot dip GI earthing strips with ceramic insulators	2500	/ pole	8	20000
14	Miscellaneous	Lights, sign boards etc.				1000
15	Labour	16 man hours/pole installation + wiring. 125 Rs/man hour + 18% GST	2360	/pole	8	18880
	Total					**36,34,836**

Annexure VIII

LCOE Calculation for the Project for Solarising 67 Motor Pumps in Thrissur-Ponnani Kole Lands

Net Returns to Consumer (INR mn)	**260.75**	Capacity of the Project	MW	2.252	Current grid cost	INR/unit	4.64	AD Available	0%	Plant Life	25 years
Total Savings for Consumer (INR mn)	**595.38**	Cost of Project	INR mn/MW	110.00	Expected escalation	% p.a.	5%	Corporate tax rate	33.99%	Loan Period	13 years
Pre-Tax IRR	**6.0%**	% of cost by AD Investor		30%	O&M Fees		1%			Generation	1.50 Mn units/MW
Total generation from the plant in life time	69.80	Interest Payment to Bank		5.0%	O&M Escalation offered	% p.a.	1.5%			Deration	1.00% p.a.
Cost of the Plant (Initial +O&M+Interest+Principal)	(364.88)	**LCOE**	**5.23 INR/kWh**							First Year Dera	1.50%
	29.77										

Financial Year		Mar-17	Mar-17	Mar-18	Mar-19	Mar-20	Mar-21	Mar-22	Mar-23	Mar-24	Mar-25	Mar-26	Mar-27	Mar-28
Year count		0	1	2	3	4	5	6	7	8	9	10	11	12
Generation from plant	Mn units		3.327330	3.28	3.23	3.18	3.13	3.09	3.04	2.99	2.95	2.90	2.86	2.82
Grid tariff trend	INR/unit		4.64	4.87	5.12	5.37	5.64	5.92	6.22	6.53	6.86	7.20	7.56	7.94
Savings for Power Consumer	**INR mn**		**15.44**	**15.97**	**16.51**	**17.08**	**17.67**	**18.27**	**18.90**	**19.54**	**20.21**	**20.90**	**21.62**	**22.36**
Cashflow for Consumer														
Tax Benefit to AD Investor/Consumer	INR mn		2.83	2.61	2.38	2.15	1.93	1.70	1.47	1.25	1.02	0.79	0.57	0.34
Initial Investment	INR mn	(74.32)	-	-	-	-	-	-	-	-	-	(24.77)	-	-
Savings from Solar PV	INR mn		15.44	15.97	16.51	17.08	17.67	18.27	18.90	19.54	20.21	20.90	21.62	22.36
O&M Fees	INR mn		(2.48)	(2.51)	(2.55)	(2.59)	(2.63)	(2.67)	(2.71)	(2.75)	(2.79)	(2.83)	(2.87)	(2.92)
Net Cash Flows	INR mn	(74.32)	**(5.88)**	**(4.95)**	**(4.00)**	**(3.03)**	**(2.04)**	**(1.04)**	**(0.01)**	**1.03**	**2.10**	**(21.58)**	**4.31**	**5.44**
Cumulative Cash Flows		(74.32)	-80.20	-85.14	-89.14	-92.17	-94.22	-95.26	-95.27	-94.24	-92.14	-113.72	-109.41	-103.97
Adjustment of Generation Revenue:														
Interest Payment	INR mn		(8.34)	(7.67)	(7.00)	(6.34)	(5.67)	(5.00)	(4.34)	(3.67)	(3.00)	(2.33)	(1.67)	(1.00)
Principle Payment	INR mn		(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)	(13.34)
Total Generation revenue paid by Consumer	**INR mn**		**(21.68)**	**(21.01)**	**(20.34)**	**(19.67)**	**(19.01)**	**(18.34)**	**(17.67)**	**(17.01)**	**(16.34)**	**(15.67)**	**(15.01)**	**(14.34)**
Bank Credit Schedule														
Bank Credit extended			173.40	-	-	-	-	-	-	-	-	-	-	-
Opening Balance	INR mn		-	160.07	146.73	133.39	120.05	106.71	93.37	80.03	66.69	53.36	40.02	26.68
(-) AD benefit Sharing	INR mn		-	-	-	-	-	-	-	-	-	-	-	-
(-) Bank Credit repayment	INR mn		13.34	13.34	13.34	13.34	13.34	13.34	13.34	13.34	13.34	13.34	13.34	13.34
Closing Balance	INR mn		160.07	146.73	133.39	120.05	106.71	93.37	80.03	66.69	53.36	40.02	26.68	13.34
Interest On Bank Credit	INR mn		8.34	7.67	7.00	6.34	5.67	5.00	4.34	3.67	3.00	2.33	1.67	1.00
Depreciation and Tax Schedule														
Opening asset block	INR mn		-	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7
(+) Addtion	INR mn		247.7	-	-	-	-	-	-	-	-	-	-	-
(-) Tax depreciated	INR mn		-	-	-	-	-	-	-	-	-	-	-	-
Closing Balance	INR mn		247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7
TAX BENEFIT via AD	INR mn		-	-	-	-	-	-	-	-	-	-	-	-
TAX BENEFIT via Interest	INR mn		2.8	2.6	2.4	2.2	1.9	1.7	1.5	1.2	1.0	0.8	0.6	0.3
Total Tax Benefit	INR mn		**2.8**	**2.61**	**2.4**	**2.2**	**1.9**	**1.7**	**1.5**	**1.2468**	**1.0**	**0.8**	**0.5667**	**0.3**

Financial Year	Mar-29	Mar-30	Mar-31	Mar-32	Mar-33	Mar-34	Mar-35	Mar-36	Mar-37	Mar-38	Mar-39	Mar-40	Mar-41
Year count	13	14	15	16	17	18	19	20	21	22	23	24	25
Generation from plant	2.78	2.73	2.69	2.65	2.61	2.57	2.53	2.50	2.46	2.42	2.39	2.35	2.32
Grid tariff trend	8.33	8.75	9.19	9.65	10.13	10.63	11.17	11.73	12.31	12.93	13.57	14.25	14.96
Savings for Power Consumer	**23.13**	**23.92**	**24.74**	**25.59**	**26.46**	**27.37**	**28.31**	**29.28**	**30.28**	**31.31**	**32.39**	**33.50**	**34.64**
Cashflow for Consumer													
Tax Benefit to AD Investor/Consumer	0.11	-	-	-	-	-	-	-	-	-	-	-	-
Initial Investment	-	-	-	-	-	-	-	(24.77)	-	-	-	-	-
Savings from Solar PV	23.13	23.92	24.74	25.59	26.46	27.37	28.31	29.28	30.28	31.31	32.39	33.50	34.64
O&M Fees	(2.96)	(3.01)	(3.05)	(3.10)	(3.14)	(3.19)	(3.24)	(3.29)	(3.34)	(3.39)	(3.44)	(3.49)	(3.54)
Net Cash Flows	**6.61**	**20.91**	**21.69**	**22.49**	**23.32**	**24.18**	**25.07**	**1.22**	**26.94**	**27.93**	**28.95**	**30.01**	**31.10**
Cumulative Cash Flows	-97.36	-76.45	-54.76	-32.27	-8.95	15.23	40.29	41.51	68.45	96.38	125.33	155.34	186.44
Adjustment of Generation Revenue:													
Interest Payment	(0.33)	-	-	-	-	-	-	-	-	-	-	-	-
Principle Payment	(13.34)	-	-	-	-	-	-	-	-	-	-	-	-
Total Generation revenue paid by Consumer	**(13.67)**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Bank Credit Schedule													
Bank Credit extended	-	-	-	-	-	-	-	-	-	-	-	-	-
Opening Balance	13.34	-	-	-	-	-	-	-	-	-	-	-	-
(-) AD benefit Sharing	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) Bank Credit repayment	13.34	-	-	-	-	-	-	-	-	-	-	-	-
Closing Balance	-	-	-	-	-	-	-	-	-	-	-	-	-
Interest On Bank Credit	0.33	-	-	-	-	-	-	-	-	-	-	-	-
Depreciation and Tax Schedule													
Opening asset block	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7
(+) Addtion	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) Tax depreciated	-	-	-	-	-	-	-	-	-	-	-	-	-
Closing Balance	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7	247.7
TAX BENEFIT via AD	-	-	-	-	-	-	-	-	-	-	-	-	-
TAX BENEFIT via Interest	0.1	-	-	-	-	-	-	-	-	-	-	-	-
Total Tax Benefit	**0.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Annexure IX

Questionnaires Used for Evaluating SPICE Model Solar Irrigation in Dhundi, Anand District Gujarat

Questionnaires Used for Evaluating SPICE Model Solar Irrigation in Dhundi, Anand District Gujarat

Questionnaire I – For Farmers:

Full Name :
Age :
Adress :
Phone number:

1. What crops do you grow?
    - Cropping cycle of each crop (no. of days)
    - Pumping requirement for each crop
2. How much money do you invest for each crop?
3. Revenue for each crop? (descriptive)

4. Where are you getting water from?

5. Which type of pumps are you using?
    - ❏ Submersible
    - ❏ Surface
    - ❏ Floating

6. What is the elevation between water source and the storage tank?

7. Prior to the solar pumps, what have you used?

8. Expenses on previous pumps?
    - Initial?
    - Recurring?

9. Expense on putting a solar pump? (number)
    - Initial
        i. Cost of components - panel, inverter, structure, wiring
        ii. Installation
        iii. Procedures, permissions and other logistics
    - Recurring

- ❑ Is there a local trained technician available at call?

iv. Cost of technician

v. How often the maintenance is done

vi. Cost of components replaced

10. How much percent of initial cost are you investing?
    - ❑ Is it 90 percent as mentioned in the papers ?

- How are you managing the remaining costs if the subsidy provided are less than above ?

11. How much money have you earned for the past two times by feeding power to the grid ?

- Is it of roughly same amount all the time ?
  - ❑ Yes
  - ❑ No
- If no, :
  - ❑ Sunlight
  - ❑ Irregular efficiency of the pump
  - ❑ Seasonal crops (more water requirements)
  - ❑ Other **:**

12. How would you generally spend the money that you've earned by connecting power to the grid?
    - ❑ Invest them in other crops
    - ❑ Savings in Bank
    - ❑ Personal Use
    - ❑ Others **:**

13. Would you rather invest the money on the next crop or installing additional solar pumps?

- ❏ Next crop
- Reason **:**

- ❏ Installing additional Solar pumps?
- Reason **:**

14. Familiar with cooperative/ In any cooperative?

- ❏ Yes
- ❏ No
- If Yes
  - i. How did the cooperative model help you?
    - ❏ Could reduce the individual efforts of going around to different vendors, suppliers, DISCOM offices for permission
    - ❏ Could hire a knowledgeable person to design and execute the project
    - ❏ Could get the components at a better price due to bulk purchase
    - ❏ Others:
- If No, why?
    - ❏ Cooperatives are unproductive
    - ❏ Members uncooperative
    - ❏ Trust issues with the cooperative
    - ❏ Have very less information about cooperatives
    - ❏ Other disadvantages

15. Structure of the cooperative?

16. Suggestions regarding cooperatives

17. Changing over of solar power between grid export and pumping, how is it done?

- ❑ Manual
- ❑ Automatic

18. What is your preference?

- ❑ Manual
- ❑ Automatic

19. Are you going to switch to alternate crops because you have more water now?

- ❑ Yes
- ❑ No, due to feed in tariff
- ❑ No, other reason

- Reason **:**

20. If yes,

- Which crop?
- It's water requirement?
- Revenue?

21. What are the things that made you happy about the solar pumps?

- ❑ No pollution

- ❏ No recurring costs eg. Diesel for diesel pumps
- ❏ More water pumping efficiency
- ❏ I get Feed in tariff
- ❏ Prevents crop failure
- ❏ Other **:**

22. What are the things that made you unhappy about the solar pumps?
    - ❏ Initial cost is high
    - ❏ Performance is not as good as previous pumps(can be quantified?)
    - ❏ Maintenance issues - cannot be locally maintained??
    - ❏ Doesn't work on cloudy days
    - ❏ Other

23. Would you go back to those Pumps? (later)

24. If yes, Why?
    - ❏ Installation(High costs)
    - ❏ Recurring (High Costs)
    - ❏ Maintenance
    - ❏ Efficiency of Solar pump
    - ❏ Any other reason:

25. Do you get timely revenue from the DISCOM?
    - ❏ Yes
    - ❏ No
    - ❏ If no,Do you know why ?

26. How can government help you?
    - ❏ More Information about solar pumps (creating public awareness)
    - ❏ More loans/subsidies

- ❑ Simplifying procedures for grid connections
- ❑ Others

Questionnaire II – For DISCOMS (MGVCL Authorities)

Full Name : **Age :** **Adress :**   **Phone number:**

1. Do you find this model attractive?
    - ❑ Yes
        - ❑ Single point feed-in at HT level
        - ❑ Lesser transaction and vigilance costs
    - ❑ No
        - ❑ Financial burden
        - ❑ Technical reasons
            - ❑ Harmonic Injection
            - ❑ Voltage rise at the tail end
            - ❑ Other Reasons ________________
        - ❑ Manpower
        - ❑ We need more trained manpower to handle such PV projects
        - ❑ Lack of infrastructure
            - ❑ Bidirectional meters
            - ❑ Transformers with adequate capacity
            - ❑ Other **:**

2. Any other Technical Challenges?

3. Suggestions?

4. What are the conditions on which they would take in power?
    - Bidirectional meters\
    - HT feed-in
    - Timely revision of FiT(downwards)
    - No more subsidies

5. Can the government help in anyway?

Questionnaire III – For Facilitating NGO (IWMI Project Co-Ordinators)

Full Name : **Age :** **Adress :**   **Phone number:**

1. What was the original objective of this project?

2. Basis for Technical Design
   - ❑ MNRE guidelines
   - ❑ Own research, field study
   - ❑ If yes, what are your findings?

3. Do you give training for the technicians?
   - ❑ Yes
   - ❑ No

   - How **:**

4. Difficulties faced while getting grid connectivity.
    - ❑ Poor response from DISCOMS
    - ❑ Lack of infrastructure
    - ❑ Policy limitations (cannot connect beyond a limit on transformers, other reasons)
    - ❑ Others (Explain)

5. Are there any constraints for replicability of similar model?
    - ❑ Forming cooperatives is difficult
    - ❑ Funds/ subsidies cannot be available everywhere
    - ❑ Other **:**

6. Are there any constraints for scalability?
    a) Technical
        - ❑ Larger HP VFDs are not available
        - ❑ Other **:**

b) Funds and Finance:

Amount	Source

7. Suggestions for improving

a) Technical Design
- One device(inverter/VFD) possible?
  - ❑ Yes
  - ❑ No

❑ Automatic/remote controlled change-over
Any ideas :

b) Institutional design/ Business model
❑ Bring in Banks/Financial institutions

8. In your opinion, what are the indicators of ‘success’ of this project?
- ❑ Farmers getting regular FiT and making an additional revenue
- ❑ ‘Sales’ of water and unnecessary pumping have stopped
- ❑ Pumps and PV systems are maintained properly
- ❑ Farmers are sticking to the same crops even after water availability is not a problem now for ‘cash crops’

Annexure X

PV Syst Simulation Result for Dhundi, Gujarat

Grid-Connected System: Simulation parameters

Project : **Dhundi Simulation for Thesis**

Geographical Site	**Dhundi**		Country	**India**
Situation	Latitude	22.80° N	Longitude	73.19° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	5 m
	Albedo	0.20		
Meteo data:	**Dhundi**	Meteonorm 7.1 (1981-2010), Sat=25% - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 27/11/18 00h17

Simulation parameters

Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Arrays Characteristics (6 kinds of array defined)

Sub-array "Sub-array #1"	Si-poly	Model	**Poly 250 Wp 60 cells**		
Original PVsyst database		Manufacturer	Goldi Green		
Number of PV modules		In series	16 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	32	Unit Nom. Power	250 Wp
Array global power		Nominal (STC)	**8.00 kWp**	At operating cond.	7.04 kWp (50°C)
Array operating characteristics (50°C)		U mpp	428 V	I mpp	16 A
Sub-array "Sub-array #2"	Si-poly	Model	**Poly 250 Wp 60 cells**		
Original PVsyst database		Manufacturer	Goldi Green		
Number of PV modules		In series	16 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	32	Unit Nom. Power	250 Wp
Array global power		Nominal (STC)	**8.00 kWp**	At operating cond.	7.04 kWp (50°C)
Array operating characteristics (50°C)		U mpp	428 V	I mpp	16 A
Sub-array "Sub-array #3"	Si-poly	Model	**Poly 250 Wp 60 cells**		
Original PVsyst database		Manufacturer	Goldi Green		
Number of PV modules		In series	16 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	32	Unit Nom. Power	250 Wp
Array global power		Nominal (STC)	**8.00 kWp**	At operating cond.	7.04 kWp (50°C)
Array operating characteristics (50°C)		U mpp	428 V	I mpp	16 A
Sub-array "Sub-array #4"	Si-poly	Model	**Poly 300 Wp 72 cells**		
Original PVsyst database		Manufacturer	Goldi Green		
Number of PV modules		In series	18 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	36	Unit Nom. Power	300 Wp
Array global power		Nominal (STC)	**10.80 kWp**	At operating cond.	9.40 kWp (50°C)
Array operating characteristics (50°C)		U mpp	575 V	I mpp	16 A
Sub-array "Sub-array #5"	Si-poly	Model	**Poly 300 Wp 72 cells**		
Original PVsyst database		Manufacturer	Goldi Green		
Number of PV modules		In series	18 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	36	Unit Nom. Power	300 Wp
Array global power		Nominal (STC)	**10.80 kWp**	At operating cond.	9.40 kWp (50°C)
Array operating characteristics (50°C)		U mpp	575 V	I mpp	16 A

Grid-Connected System: Simulation parameters (continued)

Sub-array "Sub-array #6"	Si-poly	Model	**Poly 300 Wp 72 cells**		
Original PVsyst database		Manufacturer	Goldi Green		
Number of PV modules		In series	18 modules	In parallel	2 strings
Total number of PV modules		Nb. modules	36	Unit Nom. Power	300 Wp
Array global power		Nominal (STC)	**10.80 kWp**	At operating cond.	9.40 kWp (50°C)
Array operating characteristics (50°C)		U mpp	575 V	I mpp	16 A
Total	Arrays global power	Nominal (STC)	**56 kWp**	Total	204 modules
		Module area	**368 m²**		

Sub-array "Sub-array #1" : Inverter	Model	**Solar Inverter RPI M10A**		
Custom parameters definition	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	10.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 0.40	Total Power	8.5 kWac
Sub-array "Sub-array #2" : Inverter	Model	**Solar Inverter RPI M10A**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	10.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 0.40	Total Power	8.5 kWac
Sub-array "Sub-array #3" : Inverter	Model	**Solar Inverter RPI M10A**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	10.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 0.40	Total Power	8.5 kWac
Sub-array "Sub-array #4" : Inverter	Model	**Solar Inverter RPI M10A**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	10.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 0.60	Total Power	11.5 kWac
Sub-array "Sub-array #5" : Inverter	Model	**Solar Inverter RPI M10A**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	10.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 0.60	Total Power	11.5 kWac
Sub-array "Sub-array #6" : Inverter	Model	**Solar Inverter RPI M10A**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	10.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 0.60	Total Power	11.5 kWac
Total	Nb. of inverters	6	Total Power	60 kWac

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	456 mOhm	Loss Fraction	1.5 % at STC
	Array#2	456 mOhm	Loss Fraction	1.5 % at STC
	Array#3	456 mOhm	Loss Fraction	1.5 % at STC
	Array#4	615 mOhm	Loss Fraction	1.5 % at STC
	Array#5	615 mOhm	Loss Fraction	1.5 % at STC
	Array#6	615 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	1.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

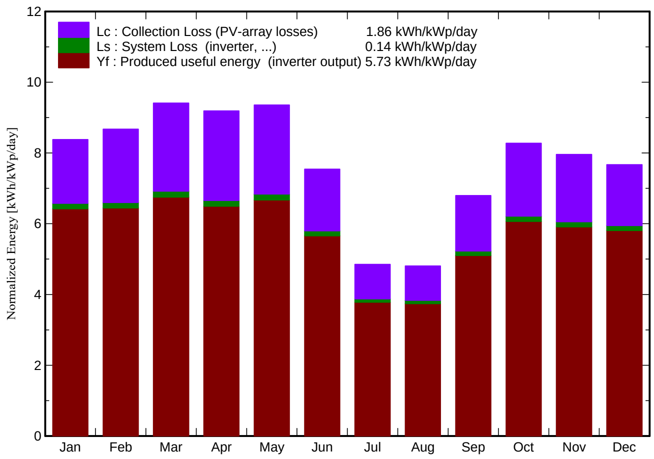
Project : **Dhundi Simulation for Thesis**

Simulation variant : **New simulation variant**

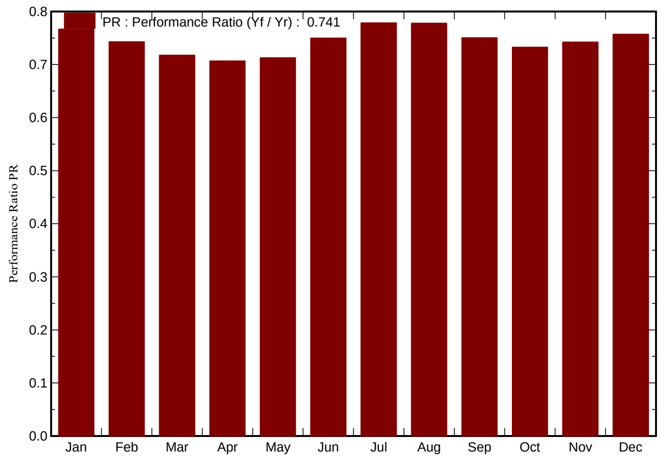
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Tracking two axis			
PV modules	Model	Poly 250 Wp 60 cells	Pnom	250 Wp
PV modules	Model	Poly 300 Wp 72 cells	Pnom	300 Wp
PV Array	Nb. of modules	204	Pnom total	**56.4 kWp**
Inverter	Model	Solar Inverter RPI M10A	Pnom	10.00 kW ac
Inverter	Model	Solar Inverter RPI M10A	Pnom	10.00 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**60.0 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**118.0 MWh/year**	Specific prod.	2092 kWh/kWp/year
	Performance Ratio PR	74.09 %		

Normalized productions (per installed kWp): Nominal power 56.4 kWp



Performance Ratio PR



New simulation variant
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	146.4	19.91	259.8	257.6	11.49	11.23	12.01	11.73
February	155.4	22.76	242.9	240.6	10.42	10.18	11.65	11.37
March	201.6	27.87	291.7	288.9	12.10	11.81	11.26	10.99
April	209.2	31.36	275.7	272.4	11.27	10.99	11.09	10.82
May	219.4	33.05	290.1	286.2	11.95	11.66	11.18	10.91
June	182.3	31.40	226.4	222.3	9.81	9.58	11.76	11.48
July	134.4	29.13	150.5	146.8	6.78	6.61	12.23	11.92
August	129.3	28.07	149.1	145.7	6.71	6.54	12.21	11.91
September	158.8	28.81	203.9	200.6	8.84	8.63	11.77	11.49
October	169.5	28.26	256.5	253.6	10.86	10.60	11.49	11.22
November	144.3	24.26	238.8	236.5	10.24	10.00	11.64	11.36
December	136.0	21.23	237.7	235.5	10.40	10.15	11.87	11.59
Year	1986.6	27.19	2823.0	2786.7	120.88	117.97	11.62	11.34

Legends:	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

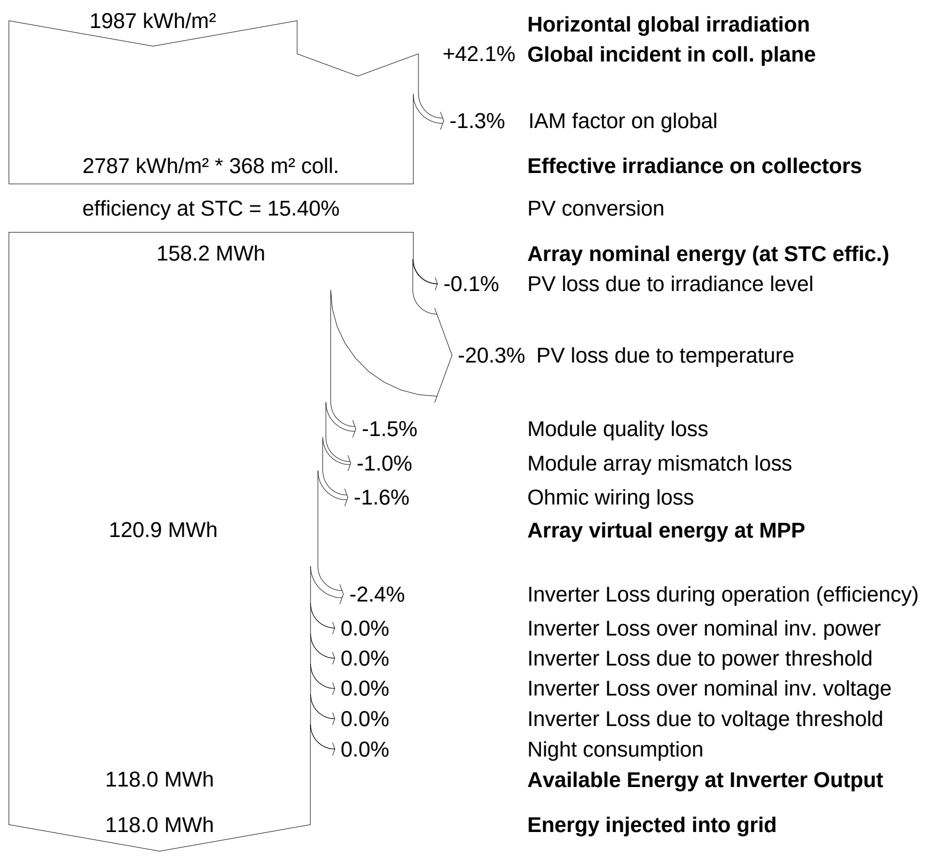
Grid-Connected System: Loss diagram

Project : **Dhundi Simulation for Thesis**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Tracking two axis			
PV modules	Model	Poly 250 Wp 60 cells	Pnom	250 Wp
PV modules	Model	Poly 300 Wp 72 cells	Pnom	300 Wp
PV Array	Nb. of modules	204	Pnom total	**56.4 kWp**
Inverter	Model	Solar Inverter RPI M10A	Pnom	10.00 kW ac
Inverter	Model	Solar Inverter RPI M10A	Pnom	10.00 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**60.0 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Annexure XI

Algorithm for Calculation of Levelized Cost of Electricity (LCOE)

Algorithm for Calculation of Levelized Cost of Electricity (LCOE)

Label		Action	Sample Code and Comments
	Step 1	Define function LCOE with input variables 'Plant Size (kW_p)', 'Capital Expenditure (Rs/kW_p)', 'Debt (percentage of CAPEX)', 'Interest (percentage)', 'Loan Tenure (years)', 'Capacity Utilisation Factor (percentage)', 'Modules Output Power Degradation for First Year (percentage)', 'Modules Output Power Degradation for Further Project Life (percentage/year)', 'Project Life (years)', Operation and Maintenance Expense for First Year (percentage of CAPEX), Annual Escalation Rate of O&M Expense (percentage/year)	**FUNCTION LCOE**(PLANTSIZE, CAPEXKWP, DEBTPERCENT, INTEREST, TENURE, CUF, DEGRADATIONFIRSTYEAR, DEGRADATION,PROJECTLIFE, OM, OMESC)
	Step 2	Calculate Total Capital Expense of the project using variables Capital Expenditure (Rs/kW_p) and Plant size	CAPEX = CAPEXKWP * PLANTSIZE
	Step 3	Calculate Equity and Debt (Loan Principal Amount) amount using Total Capital Expense and Debt percentage	EQUITY = CAPEX * (1 - DEBTPERCENT / 100) Principal = CAPEX - EQUITY
	Step 4	Calculate yearly principal repayment amount using Debt and Loan Tenure	Termpay = Principal / TENURE
	Step 5	Initiate 'outstanding loan amount' with principal value calculated in step 3	Loan = Principal

	Step 6	Calculate present year interest on loan using Principal and Interest rate	INTERESTThisyear = Loan * INTEREST / 100
	Step 7	Initiate cumulative interest repayment variable as first year interest amount	LifetimeINTERESTAmount = INTERESTThisyear
	Step 8	Calculate first year O&M expense using CAPEX and O&M percentage	OMInitial = CAPEX * OM/ 100
	Step 9	Initiate lifetime O&M Expense by adding first year's O&M expenses	LifetimeOMExpense = OMInitial
	Step 10	Calculate first year energy generation by uisng input variables 'Plant Size', 'CUF', 'Modules Output Power Degradation for First Year	Firstyeargeneration = PLANTSIZE * CUF / 100 * 24 * 365 * (1 - DEGRADATIONFIRSTYEAR / 100)
	Step 11	Initiate a continuously updating variable 'Total Generation' with first year energy generation	Totalgeneration = Firstyeargeneration
	Step 12	Initiate a variable 'Last Year Generation' with First year energy generation	Lastyeargeneration = Firstyeargeneration
LOOP	Step 13	Initiate loop control variable 'Year' as 1	Year = 1
	Step 14	Calculate present year energy generation using Lastyaer generation and 'Modules Output Power Degradation for First Year	Thisyeargeneration = Lastyeargeneration * (1 - DEGRADATION / 100)
	Step 15	Update Total generation by adding this year's generation	Totalgeneraation = Totalgeneration + Thisyeargeneration
	Step 16	Update the variable 'Last year generation' with present year generation value for using in the next iteration	Lastyeargeneration = Thisyeargeneration

	Step 17	Calculate present year O&M expense using previous year's O&M expense and O&M escalation rate	OMThisyear = OMInitial * (1 + OMESC / 100)
	Step 18	Update lifetime O&M expense by adding present year's O&M expense	LifetimeOMExpense = LifetimeOMExpense + OMThisyear
	Step 19	Update the variable Initial value of O&M expense with present year O&M expense value for using in the next iteration	OMInitial = OMThisyear
	Step 20	Calculate 'present year outstanading loan amount' using previous year's loan amount and annual loan repayment vlaue	Loan = Loan - Termpay
	Step 21	Calculate present year interest on loan using updated outstanding loan amout and Interest rate	INTERESTThisyear = Loan * INTEREST / 100
	Step 22	Update lifetime interest payment by adding present year's interest amount	LifetimeINTERESTAmount = LifetimeINTERESTAmount + INTERESTThisyear
	Step 23	Check if Year < PROJECT Life	IF(Year <PROJECTLIFE)
	Step 24	If YES, Go to Step , Else Go to Step	THEN Year = Year +1 GOTO: Loop, ELSE GOTO Final Step
Final Step	Step 25	Calculate LCOE by dividing the Lifetime Expense of the Plant (i.e. CAPEX + Lifetime Cumulative O&M Expense + Lifetime Cumulative Interest on Debt) with Lifetime Cumulative Generation	LCOE = (CAPEX + LifetimeOMExpense + LifetimeINTERESTAmount) / Totalgeneration, Return Value of LCOE

Annexure XII

Estimating the Rooftop PV Potential of Greater Mumbai

ESTIMATING THE ROOFTOP SOLAR POTENTIAL OF GREATER MUMBAI

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

NATIONAL CENTRE FOR PHOTOVOLTAIC RESEARCH AND EDUCATION, IIT BOMBAY

CENTRE FOR URBAN SCIENCE & ENGINEERING, IIT BOMBAY

IEEE BOMBAY SECTION

OBSERVER RESEARCH FOUNDATION MUMBAI

BRIDGE TO INDIA

Published in November, 2016

THE PROJECT TEAM

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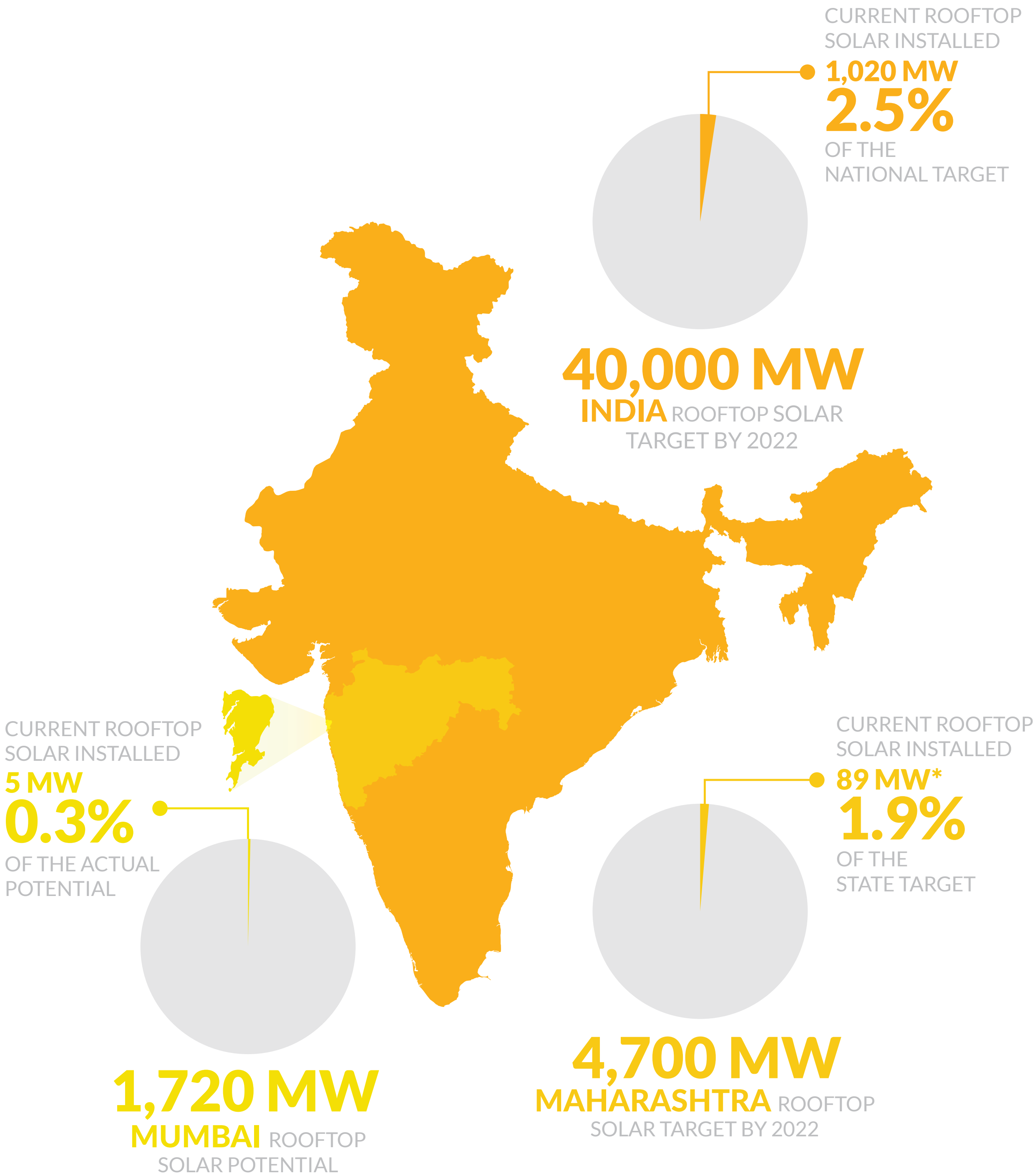
8	Prof. Vinit Kotak	Secretary, IEEE Bombay Section	IEEE Bombay Section
9	Vivek Kuthanazhi	Sr. Research Associate, National Centre for Photovoltaic Research and Education	IIT Bombay

THE INDIAN **ROOFTOP SOLAR** OPPORTUNITY



Source: *MNRE Website, Bridge to India Website (As of September 2016)*
**Excluding Residential Solar Installations*

FOREWORD

Jawaharlal Nehru National Solar Mission (JNNSM) has set an ambitious target of 40 GW capacity to be achieved by the year 2022 through decentralised and roof top scale solar projects. In this context, Municipal Corporation of Greater Mumbai in collaboration with Observer Research Foundation Mumbai and other stake holders had launched a discussion, which I had the opportunity to chair, sometime in 2014 on taking up an ambitious Mumbai Solar Mission. Several aspects of establishing roof top PV installations in Mumbai were discussed at length. Estimating the roof top solar potential in Mumbai was one of them. IIT Bombay had come forward to take up this task in the right earnest. I must compliment NCPRE and CUSE of IIT Bombay and their partners, IEEE Bombay Section, Bridge to India and ORF to have systematically completed this task.

Quite apart from bringing out some key findings, the study is also an important attempt to evolve scalable methodologies for assessment of rooftop potential in our cities. Involvement of students has been an important aspect of this effort. The study has concluded that the total potential for rooftop PV installations in Greater Mumbai is around 1.72 GWp. An assessment of the load profile of the city and the expected generation profile from PV installations indicates that grid management may not be a difficult task even if the entire 1.72 GWp potential becomes a reality. The study has also identified the need to look at major load centres in the city and potential of roof top PV sources in proximity for their effective use in feeding the needs of nearest load centres. Industrial and commercial buildings offer special attraction in this context as there is a significant tariff advantage. The study does bring out potential of different categories of buildings in various wards. One can expect fuller use of available potential in commercial and industrial buildings.

Potential for decentralised generation located close to loads is one of the important feature of solar energy. Roof top installations form an important component of this mode of generation that is free from issues of land use conflict.

I do hope that this study would lead to the much-needed impetus to required actions as well as further policy evolution by concerned agencies in realising the dream of Mumbai Solar Mission.

Nov. 16, 2016

Anil Kakodkar

Dr. Anil Kakodkar
Former Chairman, Atomic Energy Commission
INAE Satish Dhawan Chair of Engineering Eminence

CONTENTS

EXECUTIVE SUMMARY

Renewable energy is being seen as a transformative solution to meet energy as well as climate challenges, both globally and nationally. There is an increasing focus on the development of solar energy in India for a variety of reasons, including our limited conventional energy reserves, their local environment and social impacts, energy security issues, energy access and tackling the challenge of climate change. Solar photovoltaics (PV) technology is emerging as an extremely attractive option, particularly with abundantly available solar resource, modular technology and zero fuel costs over 25 years of the project life.

Considering this, the Government of India, through the Jawaharlal Nehru National Solar Mission (JNNSM) has recently expressed its intent to achieve 100 GW of solar capacity in the country by 2022, of which 40 GW is expected to be achieved through decentralised and rooftop-scale solar projects. Rooftop solar PV would play a prominent role in meeting energy demands across different consumption segments. It has already achieved grid parity for commercial and industrial users and is fast becoming attractive for residential consumers as well.

As the first step towards achieving the 40 GW target we undertook a study to assess the potential of solar rooftop PV in various urban, semi-urban and rural areas to help prioritise and target several infrastructure segments for deployment of the technology. The goal of this study was to estimate the potential of solar rooftop PV for the city of Mumbai. Mumbai has an average power demand of about 3 GW, one of the highest in India.

An equally important objective of this study was to establish a quick, yet accurate, methodology to estimate the rooftop solar potential of India's urban centres. One of the biggest challenges in deploying a large capacity of rooftop solar PV system is the availability of shadow free rooftop area. Additionally, most of India's cities have witnessed unplanned urbanization in the last decade. Such unplanned urbanization shows lack of clearly demarcated areas for different usages. For instance, residential areas also cater to commercial activities (small shops that sell daily supplies); slums coexist with industries; schools and colleges weave themselves around residential complexes, etc. Managing to categorise buildings by type of usage is indeed a challenge in most Indian cities.

Satellite based assessments using open source tools such as Google Earth and Google Maps can help estimate a fairly accurate potential of rooftop solar PV area. However, since Google Maps is not capable of categorizing areas as per usage (residential, commercial, educational, etc.), the methodology adopted in this study uses a three-step approach. In the first step, we estimate, category-wise, the potential rooftop area available in Mumbai by solely relying on freely available satellite imagery (Google Maps, Google Earth, Wikimapia and WoNoBo) along with the Existing Land Use (ELU) Maps provided by the Municipal Corporation of Greater Mumbai (MCGM). In the second step, we refine these results by making site visits to carefully selected sample sites (one each in residential, commercial, industrial, etc.) and ascertain use-type. Site visits also help corroborate satellite data and check for accuracy. We found, in most cases, that satellite data varied from actual ground data by a maximum of 12%, while in most cases, the average variation was only 5%. This shows that open source tools are adequate for estimating rooftop potential of cities without the need for expensive satellite imagery or time-consuming and complicated image processing algorithms. In the third step, we further refined the estimate using 3D modelling and shading analysis of building clusters to come up with discounting factors which account for inter-building shading,

This study estimates the total rooftop solar PV potential of Greater Mumbai to be 1.72 GW with residential buildings making up nearly 1.3 GW_p or nearly 75% of the total rooftop solar PV potential in Greater Mumbai. The second largest potential is contributed by industries - 223 MW_p, followed by educational institutions - 72 MW_p and commercial buildings - 56 MW_p. Mumbai's transportation sector holds some potential with the railways (stations and offices) contributing 26 MW_p and bus depots contributing 4 MW_p.

This potential only indicates the maximum amount of solar PV installation capacity that Greater Mumbai's rooftops can accommodate. It does not take into account the adoption rate of solar rooftop systems, which is difficult to estimate, being dependent on various factors such as affordability, system price trends, electricity rates and incentives from the State and Central Government and finally policy support.

The geographic boundary of this study was Greater Mumbai which includes all areas that fall under the jurisdiction of the Municipal Corporation of Greater Mumbai (MCGM) within an expanse of 437 sq. km. This study area covers all of the 24 wards (administrative zones) that fall under the MGCM.

We hope that this report will help the government and the solar industry to tap this vast potential of rooftop solar PV in the city of Mumbai and in other urban areas of India. The study will also help policy makers in taking appropriate steps to come up with schemes helping the proliferation of rooftop solar. We believe that the methodology which we have developed can readily be adopted by various stakeholders across other cities in India so as to ensure a speedy assessment of the solar potential of India's urban centres.

Acknowledgement

First and foremost, I wish to express my utmost gratitude and heartfelt appreciation to both my research advisors, Prof. Anil Kottantharayil and Prof. N.C. Narayanan for their guidance, continuous support, motivation and discussions throughout the course of my research work. Without my supervisors' advice this thesis would not have been possible. I thank Prof. Juzer Vasi and Prof. K. Narayanan for their valuable comments as my research progress committee members that helped to improve my research work. I thank Prof. Chetan Singh Solanki and Prof. B.G. Fernandes, Principal Investigators of NCPRE Phase I and Phase II for financially supporting me through the project and allowing me to pursue research of interdisciplinary nature. I acknowledge the financial assistance I have received from Ministry of New and Renewable Energy, Government of India through NCPRE for pursuing my PhD.

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Akhilesh Magal from Bridge to India, Ameya Pimpalkhare from Observer Research Foundation were excellent in giving their support to me for executing one of the biggest survey exercise I have undertaken, to estimate the rooftop PV potential of Greater Mumbai. Thanks to IEEE Bombay Chapter for allowing mobilising their students for doing rooftop surveys in Mumbai.

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