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Factors influencing the success of decentralised solar power systems in remote villages

A case study in Chhattisgarh, India

Master of Science Thesis in the Master Degree Programme Industrial Ecology

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Cover:
A solar photovoltaic power plant in a remote village in Chhattisgarh, India

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Abstract

This study investigates organisation and design factors of decentralised rural electrification through solar power in light of views from the World Bank, the Millennium Development Goals, Indian Governmental Policy and some additional complementary views. Choice and design of the technology as well as organisation of Operation & Maintenance (O&M) are crucial factors, but illiteracy, poverty and remoteness add to the difficulties. In the state of Chhattisgarh, India, some interesting ways of O&M have been developed and are investigated in this study. Solar Home Systems (SHS) and photovoltaic micro-grids (SPVPP) are also compared. As basis for the investigations and assessments a field survey in eleven villages with 168 respondents was conducted.

For SPVPPs, the O&M structure was found to work regarding the upkeep of batteries as the plants generally did not degrade over time. However, as fluorescent lights (CFLs) were normally replaced by incandescent lights, the hours of light and reliability decreased and users were found to no longer be able to rely on the supply. Provision of CFLs is therefore proposed to be included in the sphere of responsibilities of the implementing agency. Quality of installation for SPVPPs has been found to make a very large difference for the output, and an investment in better inverters is advised on both social and economical grounds. Technical problems were found to create social conflicts especially for the operators in the villages, and maintenance costs were large due to failed inverters. Efficiency of the SPVPPs was found to have been overestimated, and thus too little capacity installed, which contributed to the social problems.

SHSs are cheaper per kWh, and a more suitable solution for villages with low homogeneity and social cohesion as no cooperation is required. The level of trust within the village and whether there is a presence of minorities is proposed to be investigated when choosing which type of system to install.

Keywords: Rural electrification, Photovoltaic microgrid, Solar home system, India, Chhattisgarh, CREDA

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Contents

Abbreviation list

AC	Alternating Current
ACDB	Alternating Current Distribution Box
AE	Assistance Engineer
Ah	Ampere hours
AJB	Array Junction Box
BOS	Balance Of System
BPL	Below Poverty Line
BPP	Battery Protection Panel
c-Si	crystalline Silicon cells
CFL	Compact Fluorescent lamp
CREDA	Chhattisgarh State Renewable Energy Development Agency
CSM	Cluster Service Model
DC	Direct Current
DCDB	Direct Current Distribution Box
DO	District Office
EE	Executive Engineer
hh	Household
HLS	Home Light System
HO	Head Office
HoH	Head of Household
JE	Junior Engineer
JNNSM	Jawaharlal Nehru National Solar Mission
kWh	Kilo Watt hour
MDG	Millennium Development Goal
MJB	Multi Junction Box
MNRE	Ministry of New and Renewable Energy
O&M	Operation and Maintenance
OSP	Outsourced Service Provider
PCU	Power Conditioning Unit
PDN	Power Distribution Network
PV	Photovoltaic
RO	Regional Office
Rs	Rupees
RVE	Remote Village Electrification
SHS	Solar Home System
SPV	Solar Photovoltaic
SPVPP	Solar Photovoltaic Power Plant
STC	Standard Test Conditions
VEC	Village Electricity Committee
W	Watt
Wp	Watt peak
WTP	Willingness To Pay

1 Introduction

Access to energy in general and electricity in particular has potential to contribute to benefits in health, education, income and environment, and correlations with Gross Domestic Product and Human Development Index are strong (Kanagawa and Nakata, 2008). Electricity can free time for education or productive uses by reducing the time for collecting water and providing lighting during dark hours. It can give access to clean drinking water through the use of electric pumps. Health centres can be electrified and thus medicines can be refrigerated and operations can occur at night. The potential for communication through radio, TV and mobile phones can be enhanced along with increased commercial and economic opportunities.

1.4 billion people or one fifth of the world's population live without access to electricity, of which 400 million people live in India (IEA, 2010b). In the rural areas of India, almost half of the population lives without electricity (IEA, 2009).

Solar power is a promising solution for electrifying rural areas, for several reasons. For the Indian context, solar power is especially suitable as solar radiation is strong. Solar power is also clean and silent, thereby not disturbing the environment which in rural contexts is especially sensitive. Also, a decentralized power generation may be the only option for remote and protected areas. The sun is deeply rooted in many religions, also in Hindu mythology where the sun God is called Surya. This may lead to a larger acceptability of the technology, as the source is visible to the eye and can be felt every day.

However, electrification is not without problems. Systems need to be dimensioned in a way that they meet demands of output and reliability at the same time as finding a balance between needs and economical costs and benefits. Where this balance lies is a political question. Systems also need to be cleaned, batteries refilled and broken components replaced. As remote areas are also far from the markets, components and knowledge are not readily available. This calls for an operation and maintenance (O&M) structure. How best to find the mentioned balance and keep the systems working is the topic of this thesis.

1.1 Background

Chhattisgarh is a state in India, with a population of 26 million people on an area of 135191 km^2 (Census India, 2011). 44 % of Chhattisgarh is covered by forest. One third of the population lives in tribes in the forests in the northern and southern parts of the state (Government of Chhattisgarh, 2011a), and a total of 80 % of the population is rural. A large part of the population therefore cannot be reached by the main electricity network, why decentralized solutions are required. In the 1991 census about 25 % of the rural households had access to electricity, compared to 61 % of urban households, which had grown to 46 % and 83 % respectively in 2001. Access to safe drinking water was in 1991 45 % in the rural areas, compared to 80 % in the urban areas. The life expectancy difference between rural and urban areas was as high as 10 years (60 in rural areas, 70 in urban). Literacy rates in rural areas were 52 % for men and 21 % for women (Government of Chhattisgarh, 2011b) (At the time of writing, the data from the 2011 census was not yet available). Therefore there is large potential for the electricity systems to improve the standard of living in several ways.

The Chhattisgarh State Renewable Energy Development Agency (CREDA) is a nodal agency from the government of India, which implements governmental schemes in Chhattisgarh (CREDA, 2011). According to a presentation held by the director of CREDA during a conference in Kolkata in 2010, CREDA have in parallel to building new small scale solar systems also created an O&M system that is interesting for other implementing agencies in the field.

The idea for this study came forth through the Solar Transitions project, lead from the Dept. of Sociology and Human Geography at Oslo University, Norway. It is a four year collaborative research project which is funded by the Research Council of Norway and lead from the Department of Sociology and Human Geography at Oslo's University. The research aims to learn "how to implement and socially organise local energy supply with solar energy in ways that benefit people, including marginalised groups, and embeds the technology in local communities and climates", and to initiate and analyse "a process of South-South transfer of social and technological innovations between India and Kenya" (Solar Transitions, 2010). Thus the focus for this study has been on the users in the villages.

1.2 Purpose

The purpose of this study has been to identify crucial factors regarding organization and design of village-scale Solar Photovoltaic Power Plant (SPVPP) systems and Solar Home systems (SHS). A case study on solar power systems installed by Chhattisgarh State Renewable Energy Development Agency (CREDA) in the state of Chhattisgarh, India serves as basis for the thesis. The study attempts to answer the following questions:

1. What defines "success" of electrification according to the United Nations, the World Bank and Indian Governmental Electrification Policy?
2. What factors have affected the success of CREDA's electrification by solar power of remote villages?

The findings in this study can be useful for several actors. Decision makers involved in establishing or working in similar organizations in other countries can get valuable guidelines in how to prepare, design and organise similar projects. Policy makers can learn about the effects an implemented program can have and use this knowledge in future program implementations. Other actors working with electrification of remote villages can learn what benefits and problems that might occur and how these problems can possibly be solved.

1.3 Limitations

The scope of this study has been limited to only focusing on decentralized autonomous solar photovoltaic power in remote and rural villages in Chhattisgarh, India. Other technology solutions for electrifying remote areas have not been considered. Only currently installed systems and the socio-technological effects they have had in the villages have been analysed. Environmental aspects have not been in focus.

1.4 Disposition

Section 2 describes the method used during this study where information is given of how the organization CREDA has been evaluated, how the survey was designed and how data was collected and analysed. An introduction to the organization CREDA is given in *Section 3* by describing their role, strategy, structure, competences and achievements within the Rural Village Electrification (RVE) program. *Section 4* gives a brief overview of how solar power has been implemented worldwide with related important factors along with the basics in photovoltaic. *Section 5* elaborates different views on success from the World Bank, the United Nations, the Indian Government along with other viewpoints. *Section 6* presents the first results found from field study by introducing how CREDA works. The section covers CREDA staff's views on electrification, what occurs during preparations, installations and operation & maintenance (O&M) of the solar photovoltaic (SPV) systems and some technical and financial aspects. *Section 7* gives an overview of the field study by briefly presenting information about the visited villages and statistics from the conducted survey. *Section 8* presents the main results and findings with related analysis in a process order. Initially the CREDA organization and their preparation process are covered followed by an analysis about technical considerations. CREDA's installation and O&M process is analysed followed by an analysis of some economical aspects. Finally the CREDA approach is analysed in relation to success factors. A discussion about the chosen method is featured in *Section 9*. *Section 10* presents the main conclusions drawn from this study and ends with recommendations to CREDA. Factors that influence the success of decentralized solar power systems in remote villages have been identified within two areas, technical longevity and organizational functionality.

2 Method

This section describes the method used during the study. Information about how the organization and electrification procedures were mapped and evaluated, how the survey was designed, how data was collected and finally how data was analyzed are presented. Several sources served to define success to provide a way to assess how well the electrification has satisfied the various criteria that need to be considered. Further in order to find aspects that affects the success of decentralized solar power systems in remote villages it has been important to investigate how the organization works. Qualitative interviews were conducted with CREDA personnel to map how the organization works concerning preparations, installation and O&M. The interviews were carried out both before and after the field study. Technical and process documents was also studied. The obtained results were verified through field visits to villages by conducting qualitative interviews with key people in the villages concerning the running of the plants along with quantitative interviews with women based on a surveys.

2.1 Evaluating the organization

The procedures by which CREDA has implemented solar power in remote villages were identified mainly through interviews with the Director and the Executive Engineer at the Head Office (EEHO) at the CREDA Head Office in Raipur and Executive Engineers (EEs) in the Regional Offices (ROs) of Bilaspur and Jagdalpur. The interviews were semi-structured, with the intentions to obtain knowledge about O&M in the villages, outsourcing, tender procedures, finances, design and choice of systems and the general process for village electrification. Interviews were conducted at site. Additional information was gathered through e-mails to mainly the EEHO, from the CREDA website and from official documents used during the electrification process.

2.2 Survey design

In planning and designing the survey, mainly two sources were found useful: For the general planning and design Glewwe was used (Glewwe, 2005), and for the time allocation questions Harvey and Taylor (Harvey and Taylor, 2000).

As women play a crucial role in development it was decided to interview women specifically and to investigate in what ways the electrification of remote villages in Chhattisgarh has benefited women and children. Another aspect which was deemed important to evaluate was how the electrification was perceived by the women, as well as their involvement in the procedures. To connect social capital to the well-being and freedom in terms of women's empowerment, a larger detail in who were present at the gatherings was asked, in hoping to investigate if women's societies were prevalent, and if possible connect that to social trust.

A first survey was designed after a first field visit to a village in the area Barnavapara, near Raipur. The field visit was guided by CREDA personnel. A household visited there was found to have several TVs, which lead the authors to focus more on appliances in the beginning. During the pilot study, it was found that appliances were not common in the villages visited, and the questions were adapted accordingly. Mobile phones seemed a solution for many problems of accessibility, and businesses for charging mobile phones have elsewhere emerged in similar contexts, why this was also asked about.

During the pilot study, a clearer picture of the reality in the villages was obtained, as well as the respondents understanding of the questions. Too complex questions[1] and time-consuming questions[2] were reformulated and distilled or removed. For example, from having

[1] Example: People here look out mainly for the welfare of their own families and they are not much concerned with community welfare, (Disagree/Disagree partially/Agree partially/Agree)

[2] Example: In your view, what kind of improvements has/can electrification provide for the overall well-being of the household?

six difficult questions about trust[3], in the final version simply *"are all people in this village honest and trustworthy? (YES/NO)"* was asked, which was much easier to comprehend by the respondents (and to translate by the translators), and hence was deemed to provide a more reliable answer, albeit more limited. A reduction in focus on this was also decided as it was observed that no community buildings had been electrified in those villages visited during the pilot study.

Since changes in habits were sought and no prior data was available, the respondents were asked about their habits prior to electrification and at the time of interviewing. Although no watches were seen in the villages, the answers to the time questions were relatively consistent. As sunrise and sunset fluctuations are relatively small over the year in Chhattisgarh, the answers were judged as sufficiently accurate.

As operation and maintenance was observed not to be as punctual as the impression given by CREDA people, questions related to that were also included.

Initially, the questions judged as most important were placed in the beginning of the survey sheet. As questions about economy appeared sensitive, they were put in the end, as the respondents became more comfortable and open with their answers during the course of the interview. Also the more time-consuming open-ended questions were put towards the end. They were not all excluded, as it was judged that open questions would open up for new directions and findings unthought of by the authors.

The answers from the pilot study were deemed of sufficient quality to use among the rest of the analyzed data, as only minor changes were made, and most questions remaining in the final version corresponded highly to questions in the beginning. An example would be the questions about trust, where the answers were translated from the former questions to the latter.

For the final version of the surveys, the interviews took between $20 - 40$ minutes, from an initial hour in the beginning (including instructing the interpreters) and covered questions about general household information, energy, time, productive use, social capital, own perception and economy. As there are always trade-offs between quality and quantity, this was judged as a good balance where most of the important questions were investigated.

The final version of the survey can be viewed in Appendix C.

2.3 Data collection

Quantitative data about electricity output, installed capacity and number of households has been obtained from reports monitoring energy output to assess the power output for the SPVPP systems and analyse trends. As no energy output is recorded for the SHSs, these could not be analyzed in the same way. Some financial data for the villages installed prior to 2007 was obtained from the CREDA website. Financial documents for the later installed villages were not obtained, as they had been "filed".

Surveys were conducted in Bilaspur and Jagdalpur areas, in villages $2 - 3$ hours by jeep from the main cities, into the jungles. The villages were chosen through recommendation from CREDA in the cases of Sarsoha, Babutola, Shantipur and Dhudwadongri in the Bilaspur district, and Tiriya, Mardaya and Nagalsar in the Jagdalpur district. The other four villages were chosen with the intent to find villages where there had been problems. In total, 11 villages were visited and 158 women were interviewed with the survey, during the period between 20110310 to 20110331. In parallel to this, qualitative interviews were conducted with key people in villages, namely technicians, operators, village chiefs, Village Electricity Committee (VEC) members, teachers, medical staff and other prominent people.

Villages with SHSs were largely inaccessible to the authors, due to their location in remote areas affected by Maoist guerrillas called Naxalites, prevalent in southern and northern Chhattisgarh, as well as in many other states. Hence, villages that had had SHS installed for

[3]A combination of the questions about trust from the General Social Survey (National Opinion Research Center, University of Chicago, www.norc.org) and the World Bank's Social Capital Measurement Tool from (Janssens, 2010)

five years or more could not be examined, as would have been ideal. As no SHS plant in the surveyed villages was older than 27 months, when comparing SHS and SPVPP no plants older than 27 months were chosen, as the bias in choosing villages where the output had decreased since installation would have affected the results heavily.

2.4 Data analysis

As the survey was designed for analytical rather than descriptive reasons, more sophisticated statistical tools than mere descriptives were necessary. In general, the first step when conducting a statistical analysis is to create a scatter plot, to be able to visualize the patterns. This would show whether there is a relationship, and if so of what kind (linear, exponential, curvilinear etc.) Also, outliers can then be spotted which tweak the results and would give a false negative contribution to the correlation if not considered.

There are basically two different types of tests for correlations with distributions, namely metric and non-parametric. Non-parametric tests do not (in contrast to metric tests) require a normal distribution of the data, which is good for instance if the pattern is skewed. Also, ordinal, categorical and rank data can be analyzed. However, cause should be used when selecting non-parametric methods over metric ones, as the power (the ability of a test to find a difference when there really is one) is lower. (Plonsky, 2009). As the patterns in many cases were skewed (i.e. median and mean were dissimilar), non-parametric methods were however chosen in most cases, as the requirements for metric tests were thus not met.

Comparisons between virtually all not trivially negligible factors were made between type of system installed (SPVPP or SHS). The sample for this analysis was limited to villages with plants younger than 27 months, as no villages with SHSs older than that were surveyed (due to political instability and safety issues), and the time factor was assumed to make a large difference for the results. Changes over time were assessed both for the larger sample from the monitoring reports, as well as for the smaller sample of all visited villages. Differences between factors found interesting, such as minority/majority belonging, perceived benefit (YES/NO), and trust (YES/NO) were also tested.

For distribution comparisons the Mann-Whitney U test (non-parametric) was used, which shows if two distributions differ significantly (i.e. in a non-random manner). The significance of the result has been denoted by p and a significance level of the normal $p = 0.05$ was chosen as limit for significance. p-values under $p = 0.05$ allow for a rejection of the null hypothesis, i.e. the differences in distribution are significantly different. For correlations either Pearson's (metric) or Spearman's (non-parametric) method was used. For both, p again denotes the significance, but for Pearson's r and for Spearman's ρ denote the correlations. In describing the correlations, the following (arbitrary) definitions were applied for the terms used:

0.0 to 0.3: Weak to negligible correlation
0.3 to 0.5: Moderate correlation
0.5 to 0.7: Strong correlation
0.7 to 1.0: Very strong correlation

When several parameters were correlated at least moderately to another parameter, the correlations were further analyzed by multiple regression analysis to assess the effects of cross-correlations. The results are declared with b denoting the contribution from a variable to the sought parameter and again p denoting the significance of that contribution.

For comparison between categorical variables (i.e. variables where the answers are not numerical or ordinal of nature, and cannot be ranked, e.g. where the alternatives for the answers are COFFEE or TEA), Fischer's Exact Test was used (as Chi-square would require five or more answers in each category). Again, p denotes significance. YES/NO-questions are categorical, but can be written as 1 (one) and 0 (zero), and thereby the answers can be used in correlations as well.

The program Statistical Package for Social Sciences, SPSS 19 was used for data input and analysis.

3 Solar Power

The following section gives a brief introduction to how rural electrification has been implemented worldwide and the main factors that have been important to consider. The current PV market is thereafter outlined briefly. Finally, the basics in PVs, main PV technologies that presently exist on the market and the main stand-alone PV systems are covered.

3.1 Rural electrification

Providing electricity for poor people is thought to bring both social and economical development. The basic human needs can be fulfilled and productivity can increase, hence it is seen as a crucial factor to fulfil many of the Millennium Development Goals (GNESD, 2007). Governments around the world have for around three decades implemented renewable energy technologies as a means to poverty prevention and meeting the basic needs of people (Bhattacharya and Jana, 2009) and PV technology was one of the first renewable energy technologies that was implemented in the world (REN21, 2009).

There are several experiences and lessons that can be learned from implemented national governmental schemes and programs along with regional initiatives concerning PV technology. Except from techno-economical aspects there are also barriers and challenges concerning marketing and dissemination, institutional and financial approaches and productive and economic applications (Chaurey and Kandpal, 2010).

Techno-economic aspects are several and varied. The system performance aspects depend on many things where technology and social adoption goes hand in hand. Aspects influencing technology performance are technical, managerial, psychological, geographical, demographic, socio-cultural and economical (Chaurey and Kandpal, 2010). One techno-economic study showed that SPVPP are in general a more economical option if the village is on flat terrain, has more then 500 households lying close to each other and each using three to four low power appliances for an average of 4 hours per day (Chaurey and Kandpal, 2010). Batteries have in several studies been identified as the weakest link in a PV system. A study made in Mexico on 555 lead-acid batteries showed that undersized storage capacity was one of the main features contributing to battery capacity degradation, hence affecting the overall performance of a PV system. Also found to influence the lifetime of the batteries has been improper O&M due to socio-cultural factors and inferior staff training. Furthermore, it is important to have spare batteries available (Lambert et al., 2000). Overall it is recommended to choose components that are reliable and easy to maintain and it can be effective to standardise designs when implementing rural electrification projects (Chaurey and Kandpal, 2010).

Some of the main marketing barriers in developing countries have been found to be lack of investments and financing, high transaction costs, subsidies to conventional fuels and lack of awareness about PV systems at all levels in society (Muntasser et al., 2000). Actions that have been identified as having a positive affect on adoption of PV systems are information meetings, technical support meetings and social networks (Jager, 2006).

Different, broad and vague institutional approaches can make it problematic for implementing PV technologies, in the sense that clear goals could be difficult to define and implement (Urmee and Harries, 2009). The functionality of the local legal and financial institutions have a large impact on project success. If a country has a developed and functional legal institution but a non-functioning financial institution (e.g. Zambia), a ”fee-for service SHS” can work as people would otherwise not be able to acquire any financial help. Then there is a need of a strong judiciary body that ensures that fees are paid regularly and that contracts are respected. On the other hand, if a country has a functioning private market where informal or formal micro-credits exist, but no established functioning legal institution (e.g. Kenya), a ”modular cash purchase” model can work. However it has shown that the model only works for purchasing smaller PV systems (Lemaire, 2009). Subsidies on other energy sources are also important to consider when discussing institutional barriers. Subsidies on e.g. kerosene are a critical factor when it comes to the Willingness to Pay (WTP) for PV electricity. WTP increases with the cost of the alternative energy sources (Bhandari and Jana, 2010).

Several productive uses and economic applications have erupted from usage of PV electricity. For example radio and TV educates people and can stimulate business advertisers. PV light stimulates rural education by giving children the chance to study longer during evening times (Jacobson, 2007), and small and micro enterprises can be stimulated because electrical equipment and tools can be used (Kirubi et al., 2009). Therefore, it is important for local governments and international donors to co-operate with different development schemes such as health, education and community welfare schemes (Chaurey and Kandpal, 2010).

3.2 Photovoltaic market

The PV market has increased dramatically globally in the last decades, from 0,1 GW in 1992 to 14 GW in 2008 (see Figure 1). Up until the mid 1990's the most common systems were stand-alone PV systems. Since then grid-connected systems have increased and today only 10 % of the market share is stand-alone PV systems, although they play an important role in remote areas in developing countries (IEA, 2010a). There are four countries that account for 80 % of the total installed global capacity, Germany, Spain, Japan and the USA. Other countries start to have an expanding PV market such as Australia, China, France, Greece, India, Korea and Portugal and this is due to changed and supportive policies and governmental schemes. The investment cost for PV technology is still relatively high but decreasing fast due to technology and production improvements along with economy of scale (IEA, 2010a).

India is an area with one of the best solar resources in the world, with solar irradiation ranging between 1900-2200 kWh/m^2 (Malaviya, 2010). In addition, the central and state government of India have put high priority on rural electrification. Hence there is potential for the PV market to grow (Malaviya, 2010). The total installed power capacity in India in April 2006 was 124 GW, where power produced from decentralized SPV systems such as SPVPP, SHS, SPV street lights and solar lanterns accounted for approximately 1,9 ‰.

There are several factors that influence when decentralized renewable systems are more economically feasible to install compared to extending the grid to rural villages. India has five interconnected grids with national average transmission and distribution (T&D) losses of 33 % in 2005 (Nouni et al., 2009).

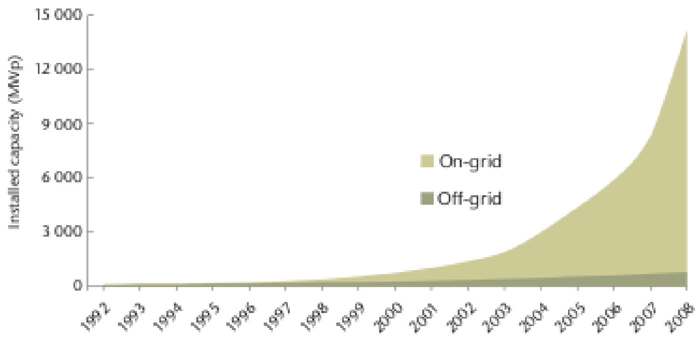


Figure 1: Installed PV capacity measured in MWp globally (IEA, 2010a)

3.3 Photovoltaic technology

Below follows the basics in PV technology and stand-alone PV systems.

3.3.1 Photovoltaics

The sun emits a spectrum of electromagnetic wavelengths which can be utilized in several ways. One way is to use materials that have, on the atom level, the ability to absorb photons and release electrons when light hits them. If these free electrons are captured, an electric current can be created. This property of a material is called the photoelectric effect. The PV effect is different in the sense that the released electrons are transferred between different bands in the material, which creates a voltage between the two electrodes. Thus a PV cell is a semiconductor device that converts the solar energy into DC electricity. The first PV component was built by Bell in 1954 and since then the development of the technology is an ongoing project (NASA, 2011). A general and basic description of how a PV cell, i.e. solar cell functions are described in figure 2. A semi-conductor material such as silicon has been specially treated to form an electrical field, where one side is positive and the other side is negative. Anti-reflective coating are added. An electrical current is being created when electrical conductors are attached to the positive and the negative sides, which catches the lose electrons that, due to the suns radiation, has been knocked loose from the atoms (NASA, 2011).

At present many PV cells are single junction, meaning that only photons with energy that is equal to or greater than the band gap can free electrons from atoms. The other wavelengths that hit the material only generate heat. The heat production decreases the efficiency of the solar cell and hence is undesirable. A solution for these problems is to use two or more different cells with different junctions, i.e. a multi-junction cell, which thereby can achieve a higher conversion efficiency (NASA, 2011). One example of such a cell is thin film cells as described in section 3.3.

The main two types of solar cell technologies on the market are wafer based crystalline silicon modules (c-Si) and thin films modules. c-Si modules currently account for 85-90 % and the thin films for 10-15 % of the global market (IEA, 2010a). Concentrating PVs are being tested in pilot studies and organic solar cells are predicted to enter the global market soon, via niche markets (IEA, 2010a).

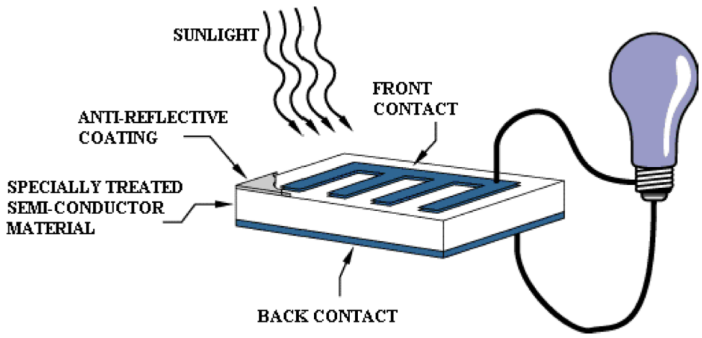


Figure 2: Basic description of how a PV cell functions (NASA, 2011)

3.3.2 Stand-alone Photovoltaic systems

There are three main categories of PV systems: grid-connected PV systems, hybrid PV systems and stand-alone PV systems. Grid-connected PV systems for the main part pumps the energy from the PV modules into the grid while hybrid PV systems are combinations of PV arrays together with other energy production sources such as diesel generators. Stand-alone systems are neither connected to the grid nor to other means of power generation. The sizes and applications vary greatly, from calculators to satellites (Reddy, 2010).

When designing a stand-alone PV system the main factors to consider are the life cycle costs, the tolerance of load and variations in insolation, the flexibility, how easy O&M will be, the quality of power supply, the reliability and social factors (Green et al., 2007). Figure 3 exemplifies the main components in a stand-alone PV system. The array of PV modules produces DC and the amount varies depending on the design. The charge controller is placed between the PV array and the battery bank in order to protect the battery bank from damage due to overcharging and over-discharging. The battery bank is required to be able to use electricity when the sun is not shining. An inverter is used to convert DC to AC, as most electrical appliances used on the market work on AC. Finally the balance of system (BOS) implies all components that is required for a functioning solar system except from the solar modules (Reddy, 2010).

Array of PV modules: When several solar cells are attached together the construction is called a module. The modules can be constructed in several ways in order to meet different demands within electricity production at different voltages. The cells can be connected in both parallel and series connections but will always produce DC (Reddy, 2010). The main feature that determines the lifetime of a module is what type of encapsulation it has, which protects the module from moisture and other ingression. Other aspects that affect the temperature of the cells and thereby the efficiency are which materials they are made of, situation, shading, tilt angle and which types of self-cleaning properties the modules have (Green et al., 2007).

Charge controller: Blocking diodes and battery voltage regulators, i.e. charge controllers are used in power conditioning and regulation units. The diodes block the batteries to discharge through the solar cells as well as protects the batteries from short circuits in the solar cells. The charge controllers protect the batteries by limiting the discharge levels and overcharging (Green et al., 2007).

Battery bank: There are several different types of batteries currently available on the market and within the research areas. Even for batteries of the same technology there is a wide range of efficiency and lifetime values. For stand-alone systems the most common is lead-acid batteries (Green et al., 2007). The main desirable requirements for batteries are that they should have low losses, low temperature increase, very low self-discharge, long lifetime, long duty cycle (have long periods of low charge), high charge storage efficiency, low cost and easy maintenance (Green et al., 2007). There are several main characteristics of batteries. The capacity is measured in ampere-hours (Ah) or kWh at a constant discharge rate (Green et al., 2007). (If a battery should be able to deliver energy on one day that is not sunny it needs to have more capacity installed than what the load requires during one day. This is called autonomy (Gyani, 2011a).) The efficiency of stand-alone PV systems varies between 80-95 %, and depending on how well they are maintained the efficiency can quickly decrease (Green et al., 2007). How deep the battery is discharged is named Depth of Discharge (DoD), and batteries can have a DoD of up to 80 % (Green et al., 2007; Kyocera, 2010). The batteries could also be either sealed or unsealed. The advantages of sealed batteries are that they need less maintenance (such as periodic watering), that they are spill-proof and don't emit corrosive fumes. The disadvantages are that they are in general more expensive, need more accurate charging control and may have a shorter lifetime, especially for higher temperatures (Green et al., 2007; Stubbs, 2008).

Inverter: Inverters are used to convert DC power to AC. Switching devices are used for the conversion as the voltage increases, normally for smaller systems from 12, 24 or 48 V_{dc} to 110 or 240 V_{ac}. Main requirements are to supply constant voltage and frequency even if the load varies (Green et al., 2007). The inverters can have an efficiency of 80-85 % with loads that are 25-100 % of the inverter rating. However for smaller systems the efficiency decreases drastically. Further on there are two other aspects to consider concerning inverters, the wave shape and standby power draw. It is desirable to create an AC wave that is as close to a sinus wave as possible. Many smaller inverters though create a wave more resembling a square, which can lead to motor starting problems and appliances that burn out. Some inverters also require a significant standby power in relation to the system, which over time can run down the batteries. Hence it could be desirable to install some kind of inverter control. Finally, the inverter should be durable against short circuits (Green et al., 2007).

Balance of system (BOS): As mentioned above BOS implies all components in the PV system except from the modules. Apart from charge controllers, batteries and inverters other required components are wires, over-current protection devices, switches, connectors, grounding devices, lighting protection, metering and alarms, battery housing, housing of electronics and module mounting. The output electricity is either Alternating Current (AC) or Direct Current (DC). One recommendation is also to have copper wires. On top of this transportation, installation, land etc. are also part of BOS. The largest cost of a stand-alone PV system are due to damages to BOS components (Green et al., 2007).

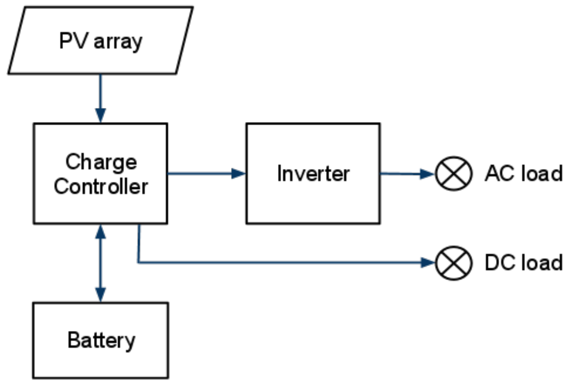


Figure 3: The main components in a Stand-alone PV system (Reddy, 2010)

4 Introduction to CREDA

An introduction to Chhattisgarh State Renewable Development Agency (CREDA) is given in order to get a first understanding of what kind of organisation this study has been based on. The section covers briefly their role and strategy in Chhattisgarh, India, their structure and main competences in the organization and finally their achievements as until year 2009 within the Remote Village Electrification (RVE) program.

4.1 Role and strategy

CREDA was established by the Government of Chhattisgarh in 2001 under the Department of Energy. The main objective is to promote non-conventional and alternative energy sources in Chhattisgarh. CREDA have focused on rural areas and stand alone devices (CREDA, 2011). They are also the node agency of the Ministry of New and Renewable Energy, and are responsible for the execution of the RVE program in Chhattisgarh (see section 5.3). They implement programs within biogas, solar thermal, SPV, village electrification and biomass gasifier development and when it comes to SPV development, CREDA follows the RVE programme (CREDA, 2011). Thus they obtain financial assistance from the state of Chhattisgarh and the Ministry of New and Renewable Energy (MNRE) (see Section 6.6). MNRE oversees the function of CREDA and how they implement SPV systems, and determines several matters concerning the PV systems such as the electricity price, the general technical specifications and the implementation mechanism (MNRE, 2011). Further on at a few occasions they cooperate with other governmental schemes such as sanitation schemes when they for example install SPV water pump systems in places that has the biggest need for health improvements.

The strategy of the organisation is to focus on providing low cost servicing with high quality and high accessibility (Shukla, 2010). In 2006 a cluster based service delivery process with the intention of routine maintenance was implemented (see Section 6.5.1). Along with the strategy they are constructing an infrastructure and network around SPV. The infrastructure and network that until now have been developed are trained staff at the different departments and sites, installation companies, outsourced service providers that takes care of O&M, spare parts, power plants and report systems (Shukla, 2010). Adding to this several documents and contracts have been developed which involved parties have to sign and follow.

4.2 Structure and competences

CREDA is divided into several departments that work with their different programs. When it comes to the RVE program and to electrify villages with solar PV systems CREDA has a centralized power structure that can be seen in Figure 4. Under the Head Office (HO) there are six Regional Offices (RO), which in turn manage 18 District Offices (DO (”Distt.” in Figure 4)) and the number of DO under each RO depends on the size of the district. There is a hierarchical structure and in general the HO makes the primary decisions and the RO and DO executes them. CREDA have outsourced the O&M. Outsourced service providers (OSP) should manage the technicians and the operators.

Today they are approximately 300 people working on a payroll at CREDA and 400 people working for outsourced service providers (Shukla, 2011a). The competences that exist at the HO are two Additional Directors. One heading three EE within the areas energy conservation, SPV and SPV maintenance. The other one heads two EE within the areas biogas & biomass and hydro, wind & geothermal.

The amount of staff in the RO and DO varies depending on locations and project sizes. Each RO is headed by an EE and to his assistance he has one to two Assistant Engineers (AE) one to a few Junior Engineers (JE) and four to five mechanics and electricians. In general, The DOs have two AE, two JE, at least two mechanics and two helpers. The EE and the AE holds a Bachelor degree and the JE holds at least a diploma, which corresponds to four years and three years respectively of higher education at technical schools (Gyani, 2011b).

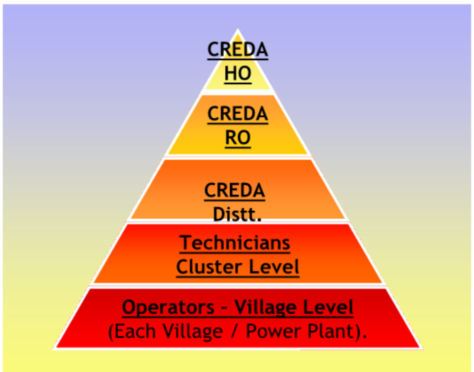


Figure 4: The power structure of CREDA and outsourced technicians and operators (Shukla, 2010).

4.3 Achievements

CREDA's main achievements concerning the RVE program are the installations of SPVPPs and SHSs for lighting purposes in remote villages (see Section 6.3 for technical specifications). CREDA's total achievements within the RVE program (excluding electrified primary health centres, police stations and community places) as until December 2009 are presented in Table 1. The table presents total number of electrified villages and tribal hostels along with total number of installed SPV street lights and total capacity of installed SPVPP. Tribal hostels imply boarding schools for tribal children where the schools provide free education and accommodation. The total number of installed SHSs and the total capacity of them has not been obtained.

Table 1: Achievements of CREDA within RVE program as until December 2009 (excluding electrified primary health centres, police stations and community places) (Shukla, 2010).

Achievements	**No/Capacity**
Total no of electrified villages	1361
Total no of electrified tribal hostels	910
Total no of installed SPVPP	1650
Total no of installed SHS	N/A
Total no of installed SPV street lights	18000
Total capacity of installed SPVPP	8 MW
Total capacity of installed SHS	N/A

5 Views on Success

In order to determine whether a project is successful, the objectives and aims first have to be defined as well as finding means of assessing success. The main actors relevant to rural electrification in India were identified to be the World Bank, the United Nations and the Indian Government. Additional viewpoints on success are also presented. Looking at rural electrification through the lens of these actors therefore provides some important aspects of and ways of assessing success.

5.1 World Bank Policy

World Bank policy reports have had varying focus over the years (see Table 2). In 1975 the World Bank policy paper *Rural Electrification* focused on justifying investments on the benefits from electrification received by the consumer. In subsequent policy papers this was not mentioned, until it was again raised in 2008. The majority of projects take the benefits as self-evident, but the evidence base for the links between rural electrification and poverty remains thin (WB IEG, 2008 : 55). The lack of focus on benefits has lead WB to support mostly cost-effective projects, leaving remote communities as the last ones connected. Connection charges prohibit the poor from connecting to the grid, thus favouring the better-off households. WTP is said to “internalize many of the benefits” (World Bank 2008 : 56), but the effects of lack of awareness about electricity are not discussed. However, WTP is often ”exceeding the long-run marginal cost of supply” (World Bank 2008 : *xiii*). The report concludes that the evidence base for many of the claimed benefits of rural electrification remain weak, and that impacts need to be tested more rigorously. Benefits could be increased further by providing smart subsidies to assist connections for poorer households, promote productive uses and further consumer education. (World Bank 2008 : 57).

Table 2: The WB policy on renewable energy and electrification has evolved over the years (adapted from (World Bank, 2008) and (Barnes and Foley, 2004))

World Bank policies
1975 : Investments justified by the benefits received from electrification
1993 : Emphasis on the private sector and environmental concerns
1996 : Links between energy and poverty
2001 : Poverty and Environment.
2004 : Success factors to “effectiveness” of projects
2008 : Welfare impact of rural electrification

Barnes and Foley (2004) summarize some success factors for programs worldwide, of which the ones relevant for this study are:
1. **Cost-recovery of at least O&M**.
2. The institutional structure of the implementing agency ”does not appear to be critical” provided they have ”**a high degree of operating autonomy**” and a low level of political interference from above to ”pursue rural electrification as its primary objective”. Also, ”dynamic leadership with a capacity to motivate staff and bring a sense of dedication to the task of rural electrification” creating a feeling of ”laying the foundation for the development and advancement of their country” is mentioned as a success factor.
3. **Avoid premature rural electrification**. Only when some basic conditions are already present, such as ”security of land tenure, [...] access to health and education, reliable water supplies and adequate dwellings”, can rural electrification ”make a significant contribution to sustainable development”. ”Rural electrification only makes sense in areas where there is already a demand for electricity-using services such as lighting, television”.
4. Also, ”case studies show that rural electrification programs can benefit greatly from the **involvement of local communities** - or suffer because of its absence”.

5.2 United Nations Millennium Development Goals

The Millennium Development Goals (MDGs) consist of eight goals adopted in 2000. They do not include a goal specifically related to energy. The setting up of a ninth goal, specifically related to energy, was brought up in March 2010 by the International Energy Forum (OECD/IEA 2010). However, all of the MDGs can be linked to energy access, although to varying degrees. Below some benefits towards the respective MDGs are summarized.

1. Eradicate extreme poverty and hunger
Modern energy services facilitate a more efficient way to conduct household tasks, thereby leaving time for e.g. productive activities. Power for water pumping and irrigation can increase yield (OECD/IEA 2010).

2. Achieve Universal Primary Education
Improved cooking technologies reduce the need for fuel collection, which is normally done by children. That time can instead be spent in school. Electric lights also make evening tutoring possible, and electricity can provide for computers. (OECD/IEA, 2010). Electrification has been "found to reduce worker absenteeism in health clinics and schools by improving living conditions and morale". (World Bank 2008 : 56)

3. Promote Gender Equality and Empower Women
Pumping stations can decrease the amount of time spent on water collection. The burden is presently most heavily shouldered by girls and women (United Nations, 2010a), why this would free time for other activities, such as education or employment. A reduced burden in fuel collection is obtained if the firewood is replaced by another fuel. Street lights increase the safety especially of women, allowing for night school and community activity attendance (OECD/IEA, 2010). Increased access to information through TV and radio increases knowledge and has been found to empower women (Panjwani, 2005).

4. Reduce Child Mortality; 5. Improve Maternal Health; 6. Combat HIV/AIDS, Malaria and other Diseases
Improved cooking methods decrease indoor air pollution decreasing the risk of respiratory and lung diseases. Ability to boil water reduces the risk of waterborne diseases. Electricity supports the functioning of health care centers. (OECD/IEA, 2010). Also, mobile phones increase the access to emergency services.

Time savings increase the time available for visiting health clinics etc (Porcaro, 2005). Information and communication tools such as TV, internet, mobiles etc. can help increase awareness and education about diseases and parasites (CITRIS in (Kirubi et al., 2009)). By connecting pumps to the PV-stations, access to cleaner water can be provided, which decreases the exposure to parasites and bacteria, improving health conditions.

7. Ensure Environmental Sustainability
Solar PV systems could also reduce CO_2 emissions by replacing other fuels. In a UN fact sheet it is mentioned that a project provided solar energy systems for 8400 households in Mwanza, Tanzania, collectively reducing CO_2 emissions by 0.93 tons per year by the end of 2009 (United Nations, 2010b). However, as people in Tanzania emit about 0.1 tonnes per capita (United Nations, 2011), this corresponds to 9 people or roughly 2 households or 0.02%. Thus, electrifying villages without prior infrastructure does not replace fossil fuels enough to substantially reduce CO_2-emissions.

8. Develop a Global Partnership for Development
Electricity powers necessary IT and communications services.

5.3 The Government of India

There are several Indian policies for rural electrification and objectives with rural electrification that are aimed to be fulfilled. The Ministry of New and Renewable Energy (MNRE), which is responsible for the Remote Village Electrification emphasizes on emission reductions and reduction of fossil fuel reliance. For the rural context, mainly reliance on kerosene import and subsidy costs are mentioned (MNRE, 2011). Kerosene is subsidised at 18 Rs per litre (The Times of India, 2011) and 5 litres is allocated for each Beyond Poverty Line (BPL) household (Wadhwa, W et al., 2003).

The Indian National Electricity Act from 2003 states that "The Appropriate Government shall endeavour to supply electricity to all areas including villages and hamlets (Government of India, 2003). The National electricity Policy of 2005 states that access to electricity should be "Available for all households in next five years" (i.e. 2010) and that the power demand should be "fully met by 2012" (Government of India, 2005).

Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) has since 2005 been the name of the Indian Scheme for Rural Electricity Infrastructure & household Electrification (RGGVY, 2005). However, RGGVY covers only larger villages, or those not too remote. In the 11th five-year plan, the goal for those households not likely to be covered by RGGVY before 2012 are specifically handled, and the Remote Village Electrification under the Ministry for New and Renewable Energy takes over. The goal was also extended to the end of the 11th five year plan, i.e. 2012 (Ministry of Power, 2007).

The Jawaharlal Nehru National Solar Mission (JNNSM) (JNNSM, 2008) aims to increase the use of solar power in India and will in the initial stage act under the RVE program under MNRE. The first phase (up to 2013) "will focus [...] on promoting off-grid systems to serve populations without access to commercial energy [...]. In the second phase, after taking into account the experience of the initial years, capacity will be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country".

The objective of the Mission is "to create a policy and regulatory environment which provides a predictable incentive structure that enables rapid and large-scale capital investment in solar energy applications and encourages technical innovation and lowering of costs" and "to take a global leadership role in solar manufacturing (across the value chain) of leading edge solar technologies (JNNSM, 2008).

The goal before 2013 is to provide solar lighting systems under the ongoing remote village electrification programme of MNRE to cover about 10,000 villages and hamlets. The use of solar lights for lighting purposes would be promoted in settlements without access to grid electricity and since most of these settlements are remote tribal settlements, 90% subsidy is provided (JNNSM, 2008).

5.4 Additional viewpoints

With a focus on the users, as for instance Amartya Sen (Sen, 1999) argues, there is more to development than merely economical and productive aspects. Sen (1999:296) proposes that development in enhancing human capabilities should take note of:

1. their direct relevance to the well-being and freedom of people
2. their indirect role through influencing social change and
3. their indirect role through influencing economic production

The latter can be estimated by assessing e.g. productive use, micro-finances, habit changes and time savings. For the other two, empowerment of women has been shown to have a beneficial effect on the whole family in terms of many of the MDGs, such as child mortality, education, health etc. (see e.g. (Cecelski, 2005)). Also, involving women in "discussions about implementing energy technologies in rural societies" has shown to be important for success (García and Bartolomé, 2010).

Social capital is a relevant aspect for cooperation in societies (see e.g. (Rothstein, 2004)). Social capital has no generally accepted definition, but there are theories that have been more influential in the field, such as Putnam's research on Italy (Putnam, 1993) and USA (Putnam, 1995). Putnam (1995) defines it as "features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit". As "trust and engagement are two facets of the same underlying factor - social capital" (Putnam, 1993), the amount of social gatherings is also one aspect of social capital. Homogeneity and social cohesion also influences the type of system to install, where de-centralised options are better if cooperation in the village is low (García and Bartolomé, 2010).

6 The CREDA Process for RVE

In order to find aspects that affects the success of decentralised solar power systems in remote villages it is important to investigate how the organisation works. This section starts by describing some views from the Director and other key personnel regarding electrification, as their opinions to a large extent lays the foundation for how the organisation works. Thereafter it is in process order described how the HO, RO, DO and other concerned actors are involved in the preparations, installation and O&M when installing SPV systems, along with technical and economical aspects. A summary of the preparation, installation and O&M process is presented in Appendix A.

6.1 CREDA views on electrification

The aim with CREDA's RVE program through SPV is to electrify villages for lighting purpose along with water pumping for drinking water and commercial purpose. Social, educational and economical empowerment of consumers and finally application of environmentally friendly SPV technology for electrification (CREDA, 2011).

The overall goal with electrifying remote villages according to the Director is to provide electricity to every Indian. Since Chhattisgarh has three national parks which would be disturbed if the grid would be extended through them, decentralized systems are the only solution in order to provide electricity to all the people in the state (Shukla, 2011a). The Director's definition of a successful project is when the social engineering[4] has paid off and the villagers themselves know that it is for them that CREDA is implementing the systems. On top of this the systems should of course be proven to function technically (Shukla, 2011a).

The overall goal with electrifying remote villages according to the EEHO for SPV is to install systems in those villages that are not possible to reach with the grid. They should get two things, light and education. Light in order to prolong the day with two to three hours so children can study more, women can prepare food after sunset, small village industries can work during evening time and to protect themselves from wildlife. Education comes from TV and music systems (Gyani, 2011b). The EEHO for SPV defines a successful project as only when villages adopt the systems that CREDA provides them with. The customers should know how to use the system and have acceptability to use the system. Here social engineering is the most important factor because it is the corporation with the villagers, i.e. the end-users that are crucial for project success.

The Director and the EEHO for SPV do not specifically go out and measure the success of the projects due to limited resources. They do try to listen to comments from staff working there and companies visiting the villages and then specifically how the systems are adopted by the end-users (Gyani, 2011b).

CREDA have planned to try to nurture productive use more by installing SPV systems that supports the local activities and businesses, by for example installing water irrigation systems for farming (Gyani, 2011c). The EEHO for SPV would also like to focus more on creating confidence in the villagers and train them. His opinion is that the government mainly focuses on providing lights but do not have action plans for the future and how to work with the villagers.

[4] CREDA's definition of social engineering: "Social Engineering consist of two aspects- Society & Engineering. Hence prior to conceptualization of any project like RVE CREDA first keeps in mind the social status of the end users & then search out the manners through which engineering part of the project can become part & parcel of the concerned society (end user). In case of RVE project CREDA engage with villagers in such a manner so that both CREDA and the villagers gain trust from each other. CREDA then also understands the needs of villagers at the same time system awareness are spread and the villagers learn how to use & optimize the operation of SPV systems" (Gyani, 2011d).

6.2 Preparation process

The required preparations before installing SPV systems in remote villages is a time-consuming process, which consists of social/civil work executed by the RO and DO and design work of the plant done by DO, RO and the HO. In general they try to visit the villagers three to four times prior to construction with the intention to fully understand their needs and that at the same time the villagers will understand CREDA's intentions. However one problem with solar energy is that the real, remote and poor consumers will never give feedback to the system which leads to CREDA developing the technology from their own experiences (Gyani, 2011a).

Initial visits

The villages that CREDA intend to electrify have been selected with regard to their remoteness. The MNRE have entrusted the Rural Electrification Corporation[5] to identify un-electrified villages or hamlets in each state where grid connectivity is either not feasible or not cost effective. The MNRE receives the lists for verification and sends it to the HO at CREDA. The HO then in turn sends the list of villages to the RO, who double-checks at the State Electricity Board if they are planning to extend the grid to the suggested villages. It is the RO (two to three people per village) who executes the civil work and they try to respect the local cultures and their sentiments. They travel to the villages to initially ask for permission from the village chiefs to proceed with the work in the village. They conduct door-to-door surveys with every household[6] to get a first picture of what the demand is, what the household capacity to pay is and if they want to be connected with solar power or not. In general, according to their experiences all households in a village agree to be connected and have to sign a contract, which states that the electricity will not be free and that the household has to pay a connection fee and a monthly payment (see Section 6.6 for details concerning the finances). Except from the surveys the RO also makes estimations of the future required work, such as sizing and spacing of the plant, availability of the Power Distribution Net (PDN) (connection for household, street lights, possible small offices and schools) along with a basic drawing of the village with roads, location of hand-pumps and other relevant parts of the village. RO finally gathers the senior people of the village and creates a VEC consisting of president, vice-president, secretary and volunteers if not similar committees already exist due to previous forest activities by other companies. They are the ones that approve the building of SPVPP and who donate the required piece of land where the SPVPP will be build on. The donation of land by the VEC is seen by CREDA as a symbolic action because the land already belongs to the government.

Designing tenders

The HO receives the surveys along with the report consisting of the estimations mentioned above. The HO designs the systems for each village and sends proposals to the MNRE (see section 6.3 for example calculation of a plant size). Once approved by the MNRE, tenders can be created. There are two types of tenders. One for firms that do the installations of the control house and the PV modules and one for firms that do the PDN for the villages. The tenders, which consist of a technical and a financial bid, are placed on CREDAs homepage with information on when the final submission date is. The tender can be downloaded or obtained at the HO on payment of 1000 Rs. Before the submission date a pre-bid meeting is held where anybody can participate. A tender committee from CREDA, consisting of two engineers (EE and Assistant Engineer) and two accountants from the HO will listen to ideas about changes to the designs of the systems and a negotiation of the details about the final tender is held. CREDA and companies appreciate this process from both sides because creativity and innovations are utilised (Gyani, 2011a)(Mukhopadhyay, 2011). Once the final tender has been created the involved firms submit their proposal before the final date and

[5]Nodal agency for the government of India with the main objective to finance and promote rural electrification projects in India (REC, 2011)

[6]CREDA's definition of a household is wife, husband and un-married children (Gyani, 2011a)

pays 25000 Rs on submission (CREDA, 2010b).

Selecting installation companies
One or several companies get selected for each site. The firms that are assigned the projects must be technically qualified and have offered to install the system at the lowest price or accepted the rate that CREDA set, and they have to have passed a certification program. The designs have to be approved by HO before start of construction and in general one hard copy of the design is kept at the HO. It is also a requirement for the selected firms, when signing the tender, that they need an office in Chhattisgarh. When firms signs the tender CREDA asks the firms "in turn" how many systems they can manage to install (Mukhopadhyay, 2011). If not all villages have been covered CREDA will turn to the next firm in line to ask how many they can install for their offered price. CREDA hands over the projects to the approved companies and the construction process can start.

All firms that work for CREDA have to be certified every one to two years. The components for the SPV systems need to be inspected prior installation so that they keep the standards. This unfortunately creates an additional workload for the HO but they do it due to two things. The first reason is that if they install the parts and they do not work it will increase the time of installation and thereby costs. The second reason is because if installed parts do not work it will have a negative influence on their and solar powers reputation (Gyani, 2011b).

6.3 Technical considerations

This section outlines the technical considerations concerning the MNRE specified SPVPP and SHS which CREDA implements and works with. To start with some general information of the system components are mentioned followed with separate description of the systems, differences between the systems and finally areas that CREDA staff wants to improve concerning the systems. More technical details are presented in Appendix B.

6.3.1 General information

The MNRE have decided and fixed technical specifications, to limit the amount of designs and to make the maintenance easier, which the nodal agencies in India, including CREDA have to follow (Gyani, 2011b). Still the nodal agencies, i.e. CREDA have the possibility to make changes to the designs of the systems but the recommended changes have to be approved by the MNRE before implementation. According to the Director other nodal agencies have adopted many of the changes CREDA have recommended and implemented (Shukla, 2011a).

The material for the system that is selected by CREDA must be economically feasible to collect, commercially available and relatively long-lasting. All installation companies have to participate in certificate programs and therefore all components are tested prior to installation at approved and specified test-centers. Once the components are installed they have to be clearly marked. When CREDA makes changes in the design of the system they do it either due to cost reduction or an improvement of technology and it has to be easy to maintain. As still they find themselves working with limited resources, compromises are being made in the designs (Gyani, 2011a).

6.3.2 SPVPP

An SPVPP consists of a centralised PP and a PDN that distributes the electricity to the households. It should be on for six hours per day. The designs that MNRE have specified and that now are installed in Chhattisgarh are systems with capacities of 1-6 kWp that have different amounts of modules, each module producing 75 Wp. Systems with installed 1-3 kWp or 4-6 kWp capacity have a battery-bank of 48 V and 96 V respectively. When they design a plant they calculate how much capacity is required to meet the present demand in the village and then they in general have the intention to install 10-20 % extra power on top of this. This is to meet the expected increase in demand that normally occurs in the following five years. For a few exceptions more extra power larger then 10-20 kW on top of the original calculated capacity has been installed due to larger expected population growth, installation of local business or other businesses (Gyani, 2011a).

An SPVPP implemented in the RVE program can be viewed in Figure 5. The modules are made of mono/multi crystalline silicon. The Array Junction Box (AJB) has a reverse blocking diode to protect the modules, the Multi Junction Box (MJB) has ferrules to identify interconnections and the Direct Current Distribution Box (DCDB) withstands high flow of current. The Power Condition Unit (PCU) consists of inverter, charge controller, visual display and needed protections, the Battery Protection Panel (BPP) is a switching device with the aim if wanted to isolate the battery bank and the Battery bank consists of tabular lead acid type batteries. Finally the Alternative Current Distribution Board (ACDB) distributes the AC current with one feeder per phase.

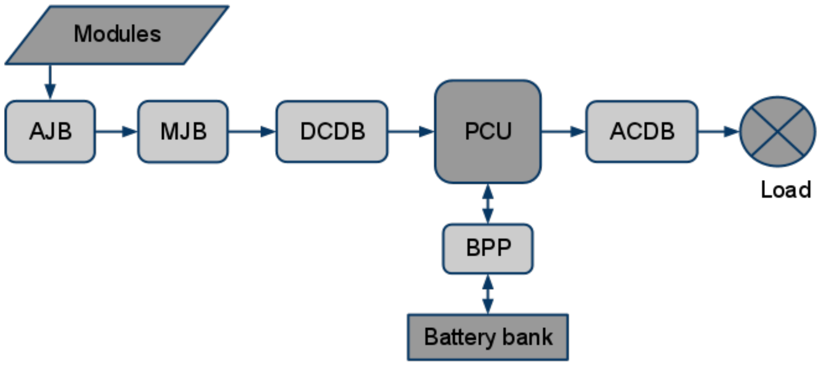


Figure 5: Components in a SPVPP (CREDA, 2010d; Gyani, 2011a)

6.3.3 SHS

An implemented SHS with two lights can be viewed in Figure 6. They should operate 3-4 hours per day. The module is made of crystalline silicon solar cell, the charge controller should protect against overcharging and deep discharging and the battery is of lead acid type (CREDA, 2010a; CREDA, 2010c).

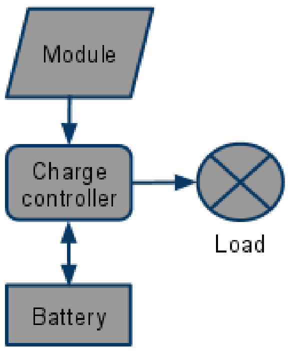


Figure 6: Components in a SHS (CREDA, 2010a; CREDA, 2010c)

6.3.4 Difference between SPVPP, SHS and other systems

There are four main differences between SVPVPP and SHS. The first one is that SPVPP are installed in villages with more than 25 households. Villages with less than 25 households are supplied with SHS for each household. An exception is in the southern parts of Chhattisgarh which is more affected by Naxalites[7]. The Naxalites have in a larger extension only allowed CREDA to install SHS compare to SPVPP. CREDA also provides other standalone devices such as street lights in each village and in some cases lanterns and water pumps. The other main differences are that SHSs have half the installed capacity compared to the calculated capacity for SPVPP households (3 hours compared to 6 hours). The SHS are owned by the household and get less O&M compared to an SPVPP due to the dispersion of systems that one technician is in charge of. The economical differences are elaborated in Section 6.6.

The design of the systems are in general similar to other stand-alone PV systems in the world. They have modules, charge controllers, inverters and batteries. The components can in some cases though be less robust and efficient compared to other components produced from leading PV countries. See below in Section 6.3.5 concerning improving the quality of components.

6.3.5 Areas of improvements

There are several future improvements CREDA either are going to implement or want to do but cannot due to limited resources. Below follows the main two areas of improvements.

Remote monitoring system will in the near future be mandatory to use. It is a system where transmitters are installed in components, e.g. the inverters in the systems, which makes it possible for the user to collect information about the system from other locations, one example is the energy usage. There were no need for this two to three years ago but since the last two years it has been mandatory for the outsourced service providers to install a Supervisory Control and Data Acquisition (SCADA) system[8] in the inverters (Gyani, 2011c). Even if the systems have been installed the reason to why they have not been used is because these costs have not been added to the total salary for the OSP (Mukhopadhyay, 2011). CREDA have given proposals to the MNRE and details are under discussion. Therefore at the moment CREDA do not know anything more and cannot give more technical details about the system. However, some technical problems such as connectivity do exist and need to be solved. In some places there might not be the required reception and then additional constructions and costs will add to the total system costs, such as building antennas. In the end it will be the outsourced service providers that collect the data and send reports to CREDA (Gyani, 2011c).

Improve the quality of the components in the system will occur with time. Innovations are required to enhance the lifetime of the batteries. If for example nickel cadmium batteries that have a lifetime of around 15 years would be introduced the total system costs would decrease because batteries would not have to be replaced as often. The distribution network should also be of better quality than today. The efficiency of the electric wires that exist on the market today is very low, and since a PV system consists of many different kinds of cables there is potential to increase the overall efficiency. Finally the inverters are of low quality and need to be more robust and more efficient. At present almost 10 % of all the installed inverters are damaged every month, which makes them the most costly component in the system. Adding to this is the problem of limited staff and remote availability of spare parts (Shukla, 2011a).

6.4 Installation

The installation process is from the points of views of both CREDA and the companies seen as a difficult task where the preparations right before installation is the most time consuming part. The main contributing factor is the remoteness of the sites, especially during the four to five months of rainy season each year. The sites that have and will be electrified are all

[7]Militant Maoist guerilla groups that operate in different parts of India

[8]Supervisory Control and Data Acquisition (SCADA) system is a control system that monitor and control industrial systems (SCADA Systems, 2011)

remote, which leads to that in some cases all the material have to be transported by hand some distances (Gyani, 2011a). Below follows the installation procedure for SPVPP and SHS.

6.4.1 Constructing SPVPP

Beyond the mentioned contributing factor which increases the installation time, the required height of the buildings for SPVPPs influences also due to that the buildings is larger than average, which is an attempt to prevent theft. Thus the normal construction poles made from bamboo need to be extended. A 10 kW SPVPP with a separate control-room might only take around one week to construct at site, while the total time from start to finish might be around 90 days due to the required preparations (Mukhopadhyay, 2011). These factors also influence the construction of the PDN.

Before the construction work begins some further preparations are made. First the list of households is verified and necessary changes are made. Secondly the villagers are involved in the implementation process. Before construction, CREDA therefore wait to start the construction until the villagers have blessed the selected place and they in turn have cleared the ground (Gyani, 2011a). Some villagers also participate as labourers and get paid by the installation companies. From the local labourers some skilled people are identified and selected (by cooperation by mainly the VEC and the installation company) to become the village operator or a cluster technician. For more information about their training see Section 6.5.2. The selected place itself is always in the centre of the village near water. If there is no water nearby a water tank is built by the house wall of the control-house. This so all villagers can have an eye on the system and the water is required for the maintenance (Gyani, 2011a).

All components in the system have to be clearly marked (Shukla, 2010). The EEHO for SPV also stresses the importance of tidiness with all the parts (wires, cables etc), to make the O&M easier and so that the villagers will get a feeling of tidiness (Gyani, 2011a).

The RO supervises the work during the construction of the plants and acts as mediator between HO, companies and villagers. They visit each site about ten times during the installation process and check the quality of the material, the PDN and the companies installation procedures. After the installation of the system is done they investigate the system and involved actors sign a contract (Garg, 2011). They also have a brief meeting with the villagers where they explain how the system works, what the limitations are for the plant, how long time it can be used, advantages and disadvantages and what they should and should not do. The system is finally handed over officially to the VEC and the installation process is completed (Garg, 2011). CREDA stresses the importance of completing the projects in time (Gyani, 2011c).

6.4.2 Constructing SHS

The procedure for installation of SHS is similar to the one for SPVPP except for two main differences. The first difference is that only one company installs the whole system compared to two (for SPVPP one company installs the SPVPP and the other installs the PDN in the village). The other main difference is that less villagers are involved in the construction process. None or only one to a couple of villagers get selected to become helpers to the company staff, e.g. one electrician. At completion of installation the system is also handed over directly to the households instead of the VEC (Gyani, 2011c).

6.5 Operation and Maintenance

Below follows information about the Cluster Service Model and the training of technicians and operators.

6.5.1 The Cluster Service Model

After a couple of years since CREDA was established they found it hard to operate and maintain the increased number of electrified villages. Thus since 2006 they have outsourced the O&M and in general the company that installs a system get contracted (Gyani, 2011a). The OSPs are contracted for a minimum of one year and the contracts are reviewed every year or till they desire to contract for. The Cluster Service Model (CSM) indicates their cluster based service delivery process with the intention for routine maintenance. One cluster consists of several villages and the cluster sizes are decided by RO on the basis of the total distance between the villages. In general one cluster consists of 10 − 15 villages. Each cluster has one technician, one helper to the technician, several operators and VECs, which corresponds to the amount of villages in the cluster. Adding to this one cluster also has a service centre (Gyani, 2011a; Garg, 2011). The OSP are thus responsible for the appointed clusters. See Figure 7 for a general overview of the CSM.

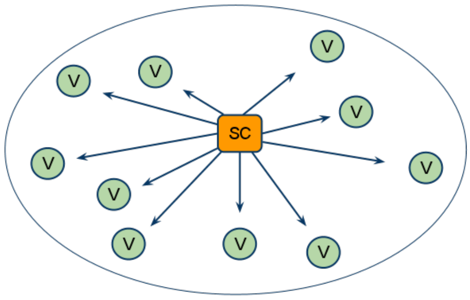


Figure 7: General overview of the CSM with a service center (SC) and villages (V)

Responsibilities
The outsourced service provider (OSP) has full responsibility for O&M and thus the supervision of the appointed clusters. They should do monthly visits to the villages, monthly reviews of the technicians and provide spare parts if needed within each components warranty period (Shukla, 2010). Some OSP repairs on site and others replace components and investigate them at their offices in nearby town (Mukhopadhyay, 2011). After the warranty period have ended it is CREDA who must bear the costs of broken parts, but still the OSP should respond to emergency calls made by the technicians (Garg, 2011). The OSP should also collect the repair and maintenance reports from the technician, summarize it into the Remote Monitoring Report and send it to the RO. At the service centers only some wires and CFLs are kept. Other spare parts such as PCUs and batteries are kept at the RO or at the OSP offices, due to the risk of theft.

The cluster technician is responsible to visit each village once a month if no problems have arisen, to conduct routine maintenance (Gyani, 2011a). The predefined work is to check the system and while doing it fill in the repair and maintenance report. The areas of concern are to measure voltages and currents of system components along with checking their physical status and the electrical connections. If necessary they should refill the fluid level, clean the deposit and check the tightness of the connections. Finally they should do meter readings. The document should be signed by both the technician and the plant operator (Garg, 2011). The technicians are also responsible to supervise the operators and respond to emergency calls (Uppal, 2011).

One *operator* is responsible for the plant in their village. They should do routine maintenance regularly such as cleaning of modules, check and fill if needed the batteries distillate water level and do PDN checks. If they notice problems they should call the technician and report the faults.

Except from that the *VEC* gives consent to that systems will be installed in their village and that they donate land to a SPVPP, which was described in Section 6.2, they are also the ones that should select operators, sign the at completion of installation work and in general keep track of the villagers so they are not mistreating the system and overuse it. To be a member in the VEC is an unpaid volunteer work.

Challenges and enablers
CREDA have identified several challenges and enablers when it comes to servicing rural markets. Even if they now have a large number of customers the challenges according to them lies in low awareness, dispersed population, poor road access (especially during $4-5$ months per year due to the raining season) and unorganised servicing channels. All mentioned factors leads to higher costs. The maintenance might also become a routine and the PV might be seen as a product to plug in and play with (Shukla, 2010). The enablers on the other hand are the fact that a large number of villages already have been electrified and still several un-electrified villages exist (where not only SPVPP and SHS are installed but also more standalone devices such as water pumps, HLS, lanterns and street lights increases), hence an increase in rural customers will occur (Shukla, 2010).

6.5.2 Training of technicians and operators

The technicians and the operators get selected during the installation of the SPV systems on the basis of individual capabilities, basic nature, inclination and acceptability in the local community. They do not have to have had prior experiences. When a technician or an operator is replaced similar attributes in other people are searched for from the concerned villages. CREDA pays for all the expenses during the training sessions. CREDA tries to gather as many people as possible at each session and in general $20-30$ people attend. CREDAs intention is to do refreshment training every six-month with technicians, operators and VEC members.

The training session for the technicians varies depending on how well the attended people learn, but it is in general around one week with six hours training per day. They learn the basics about electricity, electronic components, batteries and solar power and further on how to maintain the system. The basics about electricity and electronic components are taught by university educated technicians or engineers within CREDA or contracted consultants. If possible manufacturers to the batteries and/or the PCUs teach about their own products and senior technicians or engineers participate to shares their experiences. In total around four skilled people should participate during the training sessions. The operators are mainly trained at site where the SPVPP is located by CREDA staff before the gathered training sessions. The gathered training sessions might not always correspond to when technicians or operators are replaced and new people needs training. In those cases if possible CREDA staff tries to visit the concerned people and instruct them themselves or previous technician or operators might pass on their knowledge.

6.6 Economical aspects

The installation costs for the rural electrification program and the salaries to the CREDA staff are 100 % financed by the MNRE and the Chhattisgarh state government. The funds to CREDA come mainly from taxes on electricity bills paid by customers in Chhattisgarh connected to the grid (Shukla, 2011a). However the subsidies for the rural electrification program are yearly slightly reduced (Gyani, 2011b).

The MNRE are also those who decides the connection fee and the tariff. At present the connection fees are 100 Rupees (Rs) for BPL households, 200 Rs for non BPL households and 500 Rs for other households. The tariffs are 30 Rs per customer, i.e. household for two connected lights where CREDA pays 25 Rs out of these. Although the government can make quick changes if desired, CREDAs intention for now is to maintain 30 Rs, i.e. 5 Rs per household. According to the Director and the head EE for SPV it is good that the customer must pay something because it gives them a sense of ownership (Gyani, 2011a; Shukla, 2011b).

The cost for SPVPP, SHS and solar street light systems are presented in section 8.6. The installing companies are paid 90 % of the total sum at completion of installation. The remaining 10 % is paid after the warranty period of five years has expired if all of the components function according to agreements (CREDA, 2010b). The warranty period varies for the different components in the system. In older systems the SPV modules is warranted for their output peak watt capacity, which should not be less than 90 % after 10 years and 80 % after 25 years and the BOS components which includes batteries and PCU is warranted for two years. Since the last three years the SPV modules are warranted as before, while the BOS components, excluding the PDN, warranty period must now be for a minimum of five years. The components in the PDN have different warranty periods which ranges from one to two years (Gyani, 2011e; CREDA, 2010d).

7 Overview of Field Study

A field study was carried out in two areas; Bilaspur and Jagdalpur in Chhattisgarh. Eleven villages were visited, of which seven had SPVPPs and four had SHSs. A general overview of the visited villages can be seen in Table 3.

Energy monitoring reports (showing village-wise number of installed and working Home Light Connections (HLCs), street lights (SLCs) and installed capacity, as well as electricity output for the SPVPPs and any broken components) for Bilaspur and Jagdalpur areas for the month of February 2011 were obtained and used for the analysis of energy output. The two more recent ones of the remaining five were among the 10 best out of all of the 68 villages in the monitoring reports, and thus not very representative for the whole sample, whereas the three others were fairly average.

In total 158 women were interviewed with a survey, covering: general household information, energy, time use, productive use, social capital, economy and own perceptions. Operators, technicians, village chiefs, school and health care personnel were interviewed qualitatively. A general overview of the survey statistics ordered by village can be seen in Table 4. Averages are shown where applicable, unless otherwise stated.

Table 3: Data about visited villages in the districts of Bilaspur (B) and Jagdalpur (J). Data gathered from monitoring reports for February 2011. Interviews conducted in March 2011. The table shows type of system, capacity installed, year of installation, number of households, working Home Light Connections or SHSs and Street Light Connections, number of surveyed households and the total electricity output. The energy meters in Nagalsar and Kawapal were broken and output is not metered for SHSs

Village	System	kWp	Year	hhs	HLCs/SHSs	SLCs	Survey	kWh
Sarsoha (B)	SPVPP	3	2010	38	38/38	8/8	17	171
Babutola (B)	SPVPP	5	2010	70	70/70	8/15	26	318
Shantipur (B)	SHS	–	2009	29	29/29	2/2	8	–
Dhudwadongri (B)	SHS	–	2009	21	21/21	2/3	19	–
Manjuraha (B)	SPVPP	4	2005	82	82/82	7/8	12	218
Tiriya (J)	SPVPP	4	2004	88	110/122	15/17	16	124
Mardaya (J)	SHS	–	2010	28	28/28	2/2	11	–
Nagalsar (J)	SPVPP	4	2009	64	128/128	15/16	13	–
Kawapal (J)	SPVPP	6	2006	84	152/169	12/18	19	–
Kirmari (J)	SHS+grid	–	2009	24	22/24	0/0	12	–
Gudiya (J)	SPVPP	3	2004	36	47/48	6/7	5	101.9

Table 4: Survey statistics ordered by village. From left: name of village, hours the system is on per day, proportion that did not state any benefit from electrification, proportion of broken CFLs (includes those replaced by incandescent bulbs), monthly kerosene savings compared to before electrification (litres), cooking time difference compared to before electrification, monthly attended meetings in village, proportion that would choose more light over more appliances, proportion that trusts everybody in the village, proportion that produces anything in the household (mainly bamboo articles), Willingness to Pay monthly for more electricity, and yearly *median* household income

Village	On h/d	Cuts /mth	NoBen %	CFL br %	ΔKer l	ΔCook min	Meet /mth	Light /appl	Hon %	Prod %	WTP Rs	Med.Inc Rs/hh-yr
Sarsoha	6	3.3	5.9	11.8	2.6	19	1.6	57	65	31	6	5000
Babutola	6	2.2	0	11.5	1.5	20	1.2	39	96	0	16	3300
Shantipur	3	0.8	0	0	2.3	15	1.4	43	50	25	36	10800
Dhudwad.	3	1.0	0	27.8	2.8	48	1.1	17	94	61	19	5500
Manjuraha	1.5	20.0	81.8	80	0.7	9	0.8	92	54	46	22	6000
Tiriya	6	3.7	13.3	20	2.3	24	0.7	47	93	33	7	10100
Mardaya	3	2.6	9.1	45.5	2.9	60	1.2	73	91	0	14	2500
Nagalsar	7	2.0	7.7	46.2	2.5	39	0.6	69	100	69	4	4800
Kawapal	4	4.7	36.8	84.2	2.3	13	0.7	100	100	37	14	6600
Kirmari	3.5	3.5	18.2	81.8	2.1	66	0.6	100	100	92	13	2000
Gudiya	0.5	2.5	20	80	1.8	30	0.6	100	100	50	16	12000
Total avg.		3.7	15.7	39.9	2.2	29	1.0	63.6	87	69	14	8900

8 Results and Analysis of Field Study

The results and related analysis of the field study are presented in the same process order as has been presented in sections 4 and 6. Initially the CREDA organization and their preparation process are discussed. After that technical considerations are elaborated by using statistical data from remote monitoring reports and results from surveys along with a discussions about CREDA's installation phase. The installation and the O&M phase is described with the help of observations from the field study, interviews with key people from CREDA and actors in villages along with statistical data from surveys. Results are analysed concerning areas of improvements and other findings such as electrification of schools and coordination of involved actors. Economical aspects are then covered. Finally the CREDA approach is described in relation to success factors from the World bank, MDGs, Indian Governmental policy and additional viewpoints. The main findings are summarized in Table 5 with references to where in this section they are elaborated.

Table 5: The main findings from field study presented section-wise

Section	Findings
CREDA organization	• CREDA have succeeded in establishing an emerging group of competent people (engineers key competence) and domestic SPV market is stimulated. (Section 8.1).
Preparation process	• Social engineering is a key factor for project success but due to high time pressure from government along with limited resources, this might not be performed as much as needed. (Section 8.2) • CREDA's tender process is appreciated by involved actors. (Section 8.2)
Technical considerations.	• Plants do not degrade dramatically over time and in general overload is not affecting the system to a large extent. Thus, the maintenance of batteries works well (Section 8.3.1). • Too little capacity for SPVPPs has been installed, especially for larger villages (Section 8.3.1). • The minimum installed capacity per household should be around 0.15-0.20 kWp to provide for two CFLs/household (Section 8.3.2). • Service and maintenance works better for SPVPP than for SHS (Section 8.3.3). • Women living with SHS have to a larger extent changed their habits, but this is likely to be for geographical reasons. (Section 8.3.3). • The WTP for more electricity was larger for SHS, reflecting that WTP decreases for increased supply (Section 8.3.3). • The PCU (inverter) is the weakest link in the system and the quality of installation makes a very large difference for the performance of the plant (Section 8.3.5).
Installation	• Women were not to a large extent involved in meetings concerning installation (Section 8.4).
Operation & Maintenance	• CREDA are still highly involved in the field, as their outsource model is not utilized fully. (Section 8.5.1). • Different opinions existed in what the responsibilities were for the OSP, technician, operator and VEC. (Section 8.5.1). • The operator has a tough position in between the wants and needs of the villagers, and the long-term maintenance of the plant and CREDA. Power struggles had arisen when the piece of land that the SPVPP was built on had priorly been owned by the operator (Section 8.5.2).

Continued on next page

Table 5 – continued from previous page

Section	Findings
	• The tariff collection and payment to technician and operators were made in different ways with different success rates. (Section 8.5.3). • Overload occurred for all the installed systems. Usage of incandescent bulbs was the main reason. (Section 8.5.4) • Limited information is passed upwards in the chain of CREDA and sometimes false reporting occurred. (Section 8.5.5).
Economical aspects	• The systems are not economically self-sufficient, even for O&M. (Section 8.6). • It would be profitable to invest in better inverters, as they are the weakest link but presently only cost 5% of the total installation. (Section 8.6) • SPVPP are 37 − 85% more expensive to install than SHS for the same amount of hours of light, although more research is needed to assess the decline of SHS power output (Section 8.6). • Provision or subvention of CFLs would be profitable as maintenance costs would decrease more (Section 8.6).
Success factors	• The World Bank factors are largely not satisfied. However, they provide a rather narrow view (Section 8.7.1). • MDGs have been fulfilled to some extent but the potential is larger, especially from investing specifically in e.g. schools (Section 8.7.2) • Coordination of programmes active in the villages would benefit both the local villagers and the programmes (Section 8.7.4).

8.1 CREDA organization

Despite the government's ambitious goals for installing SPV systems in India, the Director and others have made a halt, reflected and identified O&M as one of the most important elements when it comes to working with SPV and hence developed and implemented a model for O&M, where they try to keep the customer in mind (Shukla, 2011b). This along with several dedicated, hard working and open-minded employees might be the most important features of CREDA and their effort should be highlighted. In addition to this, to create an infrastructure and network around SPV in Chhattisgarh, India is understandably a challenging task. CREDA have despite this succeeded in several ways. They have and are investing in educating staff in Chhattisgarh (since CREDA foundation approximately 5000 people have been trained and every year youth are sent to larger cities such as Kolkata for training within different fields (Shukla, 2011a)) and hence have established an emerging group of competent people within the state, where engineers are the key competence (though only male engineers but the culture within India, i.e. the difference in status between men and female has a large affect on this outcome). Due to their requirement for installation companies to have or set up offices in Chhattisgarh and mandatory participation in certification programs, the domestic market for SPV is stimulated. It also seems that CREDA have developed good and clear documents that are appreciated and followed by involved actors.

However the system that exist in keeping track of all the installed systems, their total capacity etc. might need to be improved along with, as the director for CREDA has pointed out, a system to keep track of broken and replaced components in the systems are required.

The main problem according to the Director and the EEHO in association with infrastructural needs in Chhattisgarh is that manufactures of solar power systems don't have marketing strategies or solar shops. According to others it is up to the government to reduce the subsidies on solar systems for a private marketing to take place (Mukhopadhyay, 2011).

8.2 Preparation process

CREDA staff have identified the important need for conducting social engineering prior and during installation in order for project success. In connection also that people working with solar power needs to be dedicated due to the time consuming process of social engineering. If then high pressure is put on nodal agencies such as CREDA from the Indian government, to install many systems during a short period of time and with limited resources, this identified important need might be less prioritized. Thus as observed during the study and as mentioned by several CREDA staff this has negative ripple effects in many areas. CREDA will never know what the real remote consumers feedback are, they might not fully understand the need of the villagers and hence might install a wrongly or bad designed system. The villagers are not fully informed with how to maintain the system or they are informed but due to illiteracy needs to get the information many times before fully understanding it along with that responsibilities distributed to key people in the villages such as operator and VEC members might not be fully understood. They might also feel that their culture is not respected and that they have been run over. Problems that have occurred when land for SPVPP has been chosen are discussed in section 8.5.2.

8.3 Technical considerations

CREDA staff are aware of flaws in their system and possible improvements, though due to limited resources, time and staff resources they can not change as much as they would like to (Gyani, 2011c). Concerning technical considerations capacity of the SPVPP when it comes to output per household and efficiency are discussed with statistical data from remote monitoring reports followed by a comparison between SPVPP and SHS with help from information gathered about the systems and statistical data from surveys. Finally observations concerning technical considerations from field study are presented.

8.3.1 Capacity of SPVPP - Output per household

In Figure 8a the electricity outputs from the plants are plotted against the time of installation. As can be seen, there is no consistent decline related to the time since installation, which indicates that plants do not in general degrade dramatically with the organisational methods performed by CREDA. This holds true also when plotting only systems with similar installed capacities per household as can be seen in Figure 8b), as well as for other installed capacities (not shown).

Two factors determine largely the output per household. The installed capacity per household correlates moderately[9], and the efficiency[10] of the plant correlates very strongly with output per household[11]. When analysed by multiple regression[12] the installed capacity is not surprisingly shown to contribute by far most to the energy consumption of these two[13].

Ideally, a household with two fully functioning CFLs for six hours per day would have an energy consumption of 0.13 kWh/hh/day[14]. However, only a small fraction of the villages obtain an average of 0.13 kWh or more per household as can bee viewed in Figure 8a), even though street lights are not included in the calculations and the meter readings exclude losses in the PDN. This shows that too little capacity has been installed to begin with, which means that the way CREDA calculates the required capacity greatly overestimates the efficiency.

[9] Spearman's $\rho = 0.332$, $p = 0.005$

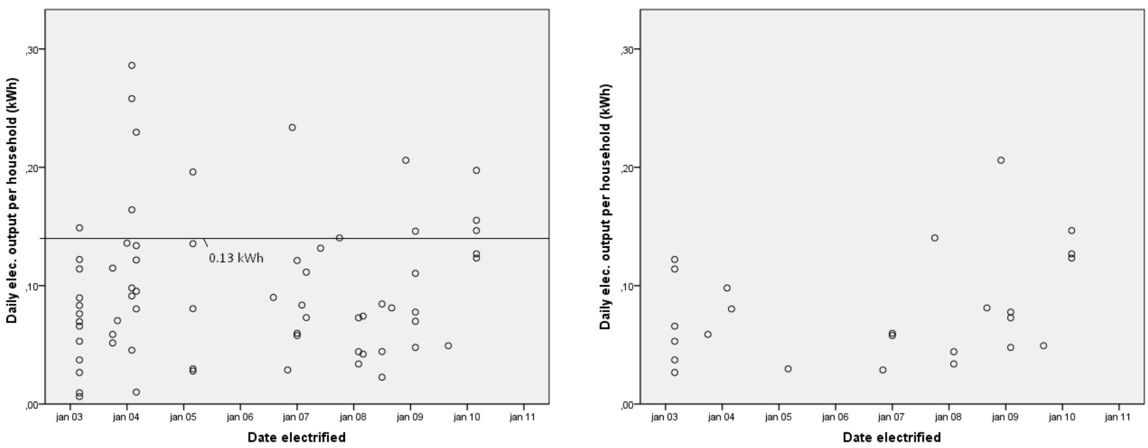
[10] Calculated as kWh output generated per hour assuming a 12 hour daily insolation, divided by kWp installed

[11] Spearman's $\rho = 0.851$, $p = 0.000$

[12] $Constant = -.079$, $F = 237$, $R^2 = .878$

[13] $b = 1.069$, $p = .000$ and $b = 0.072$, $p = .000$ respectively

[14] 11 W/CFL·2 CFLs· 6 h= 0.132 kWh



(a) Electricity output per household against time since electrification for all villages with available data in the surveyed areas. 0.13 kWh is the required supply for two 11W CFLs for six hours, which is the intended requirement.

(b) Only plants with installed capacity 0.06-0.07 kWp per household. Not even for plants with virtually constant capacity per household can a trend over time since installation be seen.

Figure 8: Electricity output against time since electrification. The vast majority of plants do not supply the required 0.13 kWh per household to the meter, and losses in the grid or street light consumption are not included, which shows that too little capacity has been installed or that significant losses occur due to poor wiring or inverters. No trend over time since installation can be seen, indicating that the maintenance in general works to keep the system going.

8.3.2 Capacity of SPVPP - Efficiency

Figure 9a shows the household energy consumption per day in kWh against efficiency of consumed power generation. As can be seen, the average efficiency of the plants is $\eta = 0.11$, with a maximum of $\eta = 0.27$ (with the five best having an average of $\eta = 0.24$), i.e. for the five best plants a factor of 0.24 of the maximum stated installed capacity was generated and supplied to the meter. The figure indicates that there is a strong correlation[15] between efficiency of supply to the meter in the control room and actual consumption, especially below an efficiency of $\eta = 0.1$ where the correlation is very strong[16]. The large disparities indicate that some systems are functioning much better than others. There are at least six possible explanations for low plant output:

1. Overload, either because of installed appliances or bulbs which would cause a peak overload, or because the power is on until the lights dim out in these villages. Both cases would decrease the battery capacity.
2. Poor maintenance of batteries.
3. Broken, stolen or shaded panels.
4. Losses in the wiring, inverters or elsewhere leading up to the meter.
5. Plants deliberately turned off or not used every day.
6. Faulty meters or meter readings.

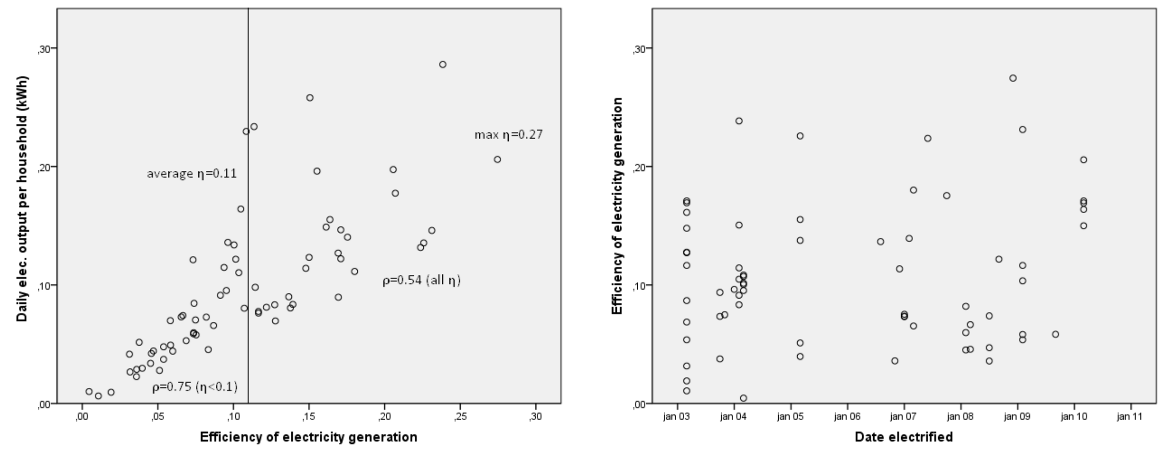
Figure 9b shows the household electricity consumption per day in kWh plotted against the installed capacity per household. As can be seen, the efficiency does *not* decline with the time since installation, which holds true even for plants with efficiencies below $\eta = 0.1$ (not shown). Thus, it must be concluded that the low efficiencies are not due to overload or poor battery maintenance. Furthermore, assuming that plants are generally not installed in

[15] Pearson's $r = 0.540$, $p = 0.000$
[16] Pearson's $r = 0.795$, $p = 0.000$

the shade, shading would come from dust and thereby increase over time. Again, as there is no trend this is not a general problem. Also, broken and stolen panels are monitored in the reports, and they show no large general problems regarding this. Deliberate early shut downs of the plants are not probable as there is a strong correlation especially for the villages with low efficiency, but also for the rest. The consistency of data also refutes that faulty meters or meter readings would be a general problem. The reason that remains is losses in wiring and inverters. Since there is a large difference in efficiencies, but no trend over time it must be concluded that the quality of installation and components creates a large difference. Additionally, poor repairs and maintenance of wiring affect efficiencies. Thus, quality of installation should be more in focus, as well as more education on maintenance of wires.

PDN losses are of course of large importance to the delivery to the consumer but as the meter is positioned in the control room this is not measured, and hence no reason for the low measured efficiency. For the consumer, incandescent bulbs also reduce the amount of hours of light even if there would be sufficient output.

Nevertheless, CREDA has overestimated the efficiency of the systems. On average, to obtain 0.13 kWh/hh/day as stated above (and assuming no autonomy, i.e. that no extra power for a cloudy day is generated) with an efficiency of $\eta = 0.11$ and with 12 hours of daily sunlight, 0.1 kWp is required per household[17]. Including losses, occasional appliance uses, street lights, occurrence of cloudy days etc, the installed capacity should probably be 50-100% higher, i.e. 0.15-0.20 kWp/hh (CREDA calculates with 36% losses excluding street lights, see Appendix B).



(a) Electricity output against efficiency of generation (b) Efficiency against time since installation

Figure 9: Efficiency of generation against electricity output and time since installation. The efficiency is calculated as kWh output generated per hour and supplied to the meter, assuming a 12 hour daily insolation, divided by kWp installed. The efficiency is not found to decline over time since installation (b), so the quality of installation and components makes most of the large difference seen in (a).

The installation pattern by CREDA can be seen in Figure 10, where capacity of plants are plotted against number of households. Also plotted are ideal installation patterns for different efficiencies. Only a handful of the plants meet the required output with the average efficiency of $\eta = 0.11$. A majority of the plants fall below the recommended installed capacity even when assuming an efficiency of $\eta = 0.2$. Only with an efficiency of $\eta = 0.3$ (recall that the highest efficiency in the sample was $\eta = 0.27$) would all plants generate the required output. The graph shows also that the disparity between actual and ideal output increases the larger the village is. A village with about 125 households has obtained a 6 kWp plant, whereas it

[17] $\frac{0.13[kWh/hh/day]}{0.11 \cdot 12[h/day]} \approx 0.1kWp/hh$

should be between $10 - 20$ kWp depending on assumed efficiency, i.e. two to three times the presently installed capacity. Two solutions are at hand: increase the efficiency or increase the capacity.

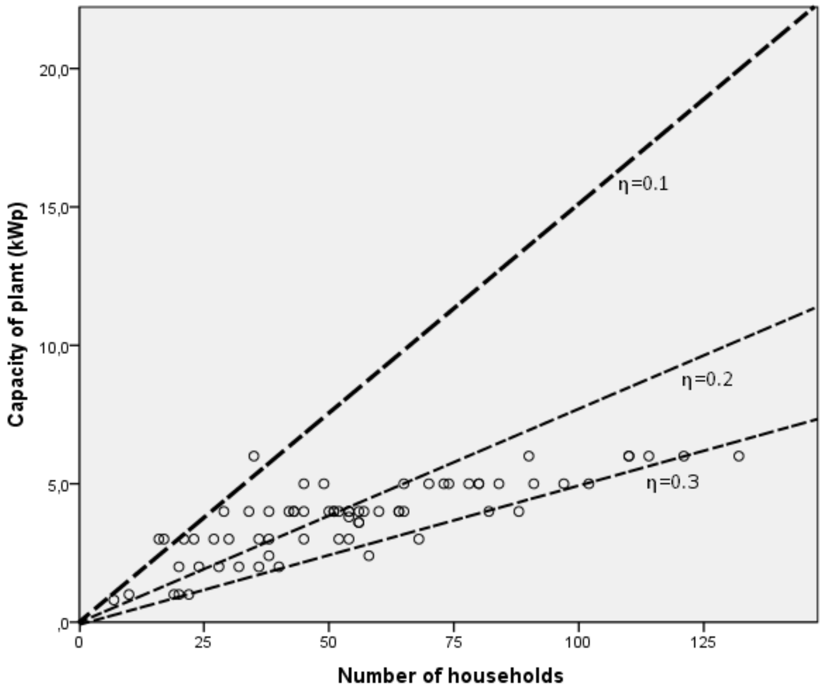


Figure 10: Capacity of plant over number of households in the village, for all villages with data available in the two surveyed areas. An efficiency from stated installed capacity to delivered power (to the meter, assuming a daily 12-hour insolation) of $\eta = 0.11$ was found to be the average value, where the range was from virtually zero to $\eta = 0.27$. The difference between ideal and actual installed capacity can be seen to increase the larger the village is.

8.3.3 Comparison between SPVPP and SHS

When analysing results from the surveys, there are certain preconditions that are not all directly related to the technology used. Four main differences were identified and judged to contribute to the differences in answers found between villages with the two types of system. The findings have been sorted under these fundamental differences.

In the comparison, only plants installed in the past 27 months were taken into account, leaving three villages with SPVPPs (56 surveyed households) and four villages with SHSs (48 surveyed households). The reason for this limit is that no older SHSs were surveyed (due to political instability and safety issues), and the time factor was assumed to make a large difference for the results (and did so for the sample). For instance, the number of unexpected power cuts shows a significant[18] difference between types of system if all of the villages are included, but not for those installed in the past 3 years[19]. The same can be seen for the study habits of the children, where the results lose relevance the longer the time since electrification, since the children would have advanced from primary to secondary school. A summary of the comparison between SPVPP and SHS can be viewed in Table 7.

Capacity differences

CREDA installs SHSs to supply for three hours of light per day, whereas the SPVPPs are stated to supply six hours (although this difference has been shown to decrease the larger the village is).

[18]Mann-Whitney U-Test, p=0.005

[19]Mann-Whitney, p=0.249

The WTP for more electricity of the households was significantly different[20] between the types of system. For SHS households the average WTP was 19 Rs/hh/month and for SPVPP households 10 Rs/hh/month. Although the median values were closer (12.5 Rs/hh/month for SHS and 10 Rs/hh/month for SPVPP), the higher WTP may reflect the fact that the SHS households get 3 hours of installed capacity instead of 6 hours, which is in line with there being a decreasing marginal benefit for increased electricity consumption.

There was also a significant difference[21] in whether the households expressed seasonal power cuts during rainy season, where 42% stated so for SHS households and 14% for SPVPP households. This indicates that there is better output autonomy for SPVPPs (although this was not specifically asked in the survey), and leads to a larger reliance on kerosene for the SHSs households during rainy season.

Ownership

SHSs are owned by the households and thus can be controlled individually, whereas SPVPPs are centrally operated.

Although the field work lacks data from older SHSs, the argument can be made that SHS systems require more responsibility from the owners, thereby circumventing the problem of tragedy of the commons which might be a problem in some villages where the level of cooperation and social cohesion is not high. The effects of overload on the battery capacity and output are felt quicker for SHS households with TVs and other appliances than for SPVPP systems, and arguably the more direct the effects the more obvious the reason for the user. One household in an SHS village had a TV, and although their system was only one year old the output was only for one to two hours at the time of surveying, compared to three hours before. When households notice that their overloaded systems cannot sustain the power as long as the other households, the reason will hopefully be apparent with additional guidance by CREDA staff.

Operation & Maintenance

SPVPP villages have an operator on site, whereas SHS villages do not.

The distribution of how many CFLs that were broken (average of 0.5/hh for SHS and 0.2/hh for SPVPP) was significantly different[22]. 40% of the SHS households had at least one broken CFL in contrast to 20% for SPVPP households. The difference is statistically significant[23]. However, when checking the same thing for the whole sample regardless of the time since installation no significant difference[24] exists. This result indicates that service and maintenance works better in SPVPP villages during at least the first 27 months.

There were large and significant[25] differences between the system types in how long the CFLs had been broken (on average 252 days/hh for SHSs and 54 days/hh for SPVPPs) in the cases they were broken at the time of surveying. The difference in number of power cuts[26] and their duration[27] was not significant.

Distance between houses

CREDA installs SHSs in villages smaller than 25 households. These villages often have larger distances between houses, which is the likely reason for the results below.

Kerosene use was before electrification on average 3.5 litres for SHS households and 3.1 litres for SPVPP households with the difference slightly above the significance level[28]. The

[20] Mann-Whitney, p=0.013
[21] Fischer's Exact Test, p=0.002
[22] Mann-Whitney, p=0.017
[23] Fischer's Exact Test, p=0.031
[24] Fischer's Exact Test, p=1.00
[25] Mann-Whitney, p=0.004
[26] Mann-Whitney, p=0.249
[27] Mann-Whitney, p=0.996
[28] Mann-Whitney, $p = 0.068$

average of the individual household differences compared to before electrification was 2.6 litres less for SHS households and 2.1 litres less for SPVPP households, also slightly above significance[29]. The values changed only by a small fraction when excluding the households with fused CFL(s). The average and median figures for both SHS and SPVPP households were 1 liter/hh/month after electrification. The differences in kerosene use changes, although slightly above the significance level, also indicate that there is even more benefit for SHS households in getting electric lights, as the difference on average evens out after electrification.

Table 6 shows the results from the survey concerning time aspects for cooking, eating, studying and sleeping. Owners of SHS live in less densely populated and smaller villages, which could account for some differences in habits stated before installation. The difference however evens out significantly after installation, showing a larger habit change for the women of SHS households. The changes in cooking habits for the individual households are strongly significant[30]. One of the households had a habit of preparing the food in the morning, and was not included in the calculations for cooking habits. Study habits are strongly individual for the household, regardless of the type of system[31].

Table 6: Average time use stated by the households in the surveys. Before electrification and now for the cooking and study habits, and for the sleeping habits times the respondents stated to go to bed and get up. Mann-Whitney U-test (significance p) has been used.

Average time use				
		Before	**Now**	**hh diff**
Cooking start	SHS	17:15	18:06	0:48
	SPVPP	17:38	18:03	0:23
	p	.057	.444	.003
Study hours	SHS	0:29	1:04	0:39
	SPVPP	0:41	1:27	0:49
	p	.153	.112	.941
		Bed	**Wake**	**hh diff**
Sleep	SHS	21:04	04:45	7:54
	SPVPP	21:25	04:26	7:10
	p	.003	.098	.001

The sleeping pattern of the women interviewed also shows a significant[32] difference between the time spent in bed of on average 44 minutes between the types of system.

One can speculate that the street lights allow people to move within the village after dark without having to fear animals, which can mean that they can work longer, but also that they can socialize longer (although the number of stated social gatherings was not significantly different[33]). The fact that the differences were *before* electrification indicates that the result is not dependent on the type of system, but rather on the distance between houses and size of the village. It is clear that there are benefits for both types of village, but that in terms of changing habits for the women, the benefits are larger for women where SHSs have been installed. The proportions of stated benefit were almost the same across the types of system, with 94% stating a benefit for SHS households and 96% for SPVPP households (keeping in mind that the sample contains only young power plants). The changed habits in both types of village indicate that electrification allows a larger freedom of choice in when to cook as well as providing extra time for household chores and productive activities.

[29]Mann-Whitney, $p = 0.079$
[30]Mann-Whitney, $p = 0.003$
[31]Mann-Whitney, $p = 0.941$
[32]Mann-Whitney p=0.001
[33]Mann-Whitney, $p = 0.978$

Table 7: Comparison of features between SPVPP and SHS. Initially general differences are described, and thereafter some important conclusions from the analyses above are summarized.

SPVPP	SHS
• Requires longer installation procedures	• Easier and cheaper to install
• More involvement during construction for villagers and one person as the operator during O&M	• None or little involvement during construction from villagers. No operator in village is required during O&M
• AC appliances are used. Losses in transformation from DC to AC.	• DC appliances are used. Harder for user to find DC appliances.
• Possibility to control overload centrally.	• Owned and operated by the household.
• Easy and centralised maintenance but requires more expertise available in the village.	• Technician has to go to each household for maintenance.
• Energy metering provides data on functionality.	• Energy metering costly.
• Increases of plant capacity done centrally.	• Capacity increases need to be made in each household.
• If the SPVPP is disconnected the PDN can still be used for grid connection. N/A for villages in protected areas.	• No PDN required i.e. no losses from the PDN.
• More theft from SPVPP systems in "normal" conditions	• More theft from SHS systems in areas affected by Maoist guerillas.
• Maintenance works better - 20% of the hhs had broken CFL(s) for an average of 54 days.	• 40% of the hhs had broken CFLs for an average of 252 days.
• The weakest link in the technical system are the inverters, but also poor wiring is likely to reduce efficiency.	• Less parts in the chain that can break or reduce efficiency.
• Better autonomy as long as the system is working	• More expressed power cuts during rainy season, due to smaller relative storing capacity
• Requires the village to cooperate regarding the running of the power plant, and the operator to be respected.	• No "tragedy of the commons" as everybody has to take responsibility of their own system.

8.3.4 Percieved Benefits

Table 8 presents the variables that showed significant differences in distribution between those who stated a benefit and those who did not. The presented data are average results for the sample. The average for the village of stated hours per day the light was on was 4.5 hours per day for those who stated a benefit and 3.1 hours per day for those who did not[34].

A multiple regression of the answers[35] shows that the time since electrification was not significant[36], and neither was system type[37] or kerosene use[38], of which the latter is arguably related to the amount of power cuts and downtime. Rather there was a significance for the amount of power cuts[39], the average of the stated on-times for each village[40] and the amount of school the head of household had attended[41]. The latter is perhaps the most interesting, since more education meant less stated benefit by the woman in the household, which may be linked to a larger awareness of how the system could work ideally.

Table 8: The variables that showed significant differences in distribution between those who stated a benefit and those who did not (Mann-Whitney significance). The columns from the left: months since electrification, how many hours per day the light was on, how many unexpected power cuts that were stated to occur per month, how many years the head of household (HoH) have attended and how many girls and boys in the household attended school at the time of surveying, number of functioning CFLs, number of broken CFLs and for how many days they had been broken, the difference in kerosene use compared to before electrification, and when they ate and woke up

	Time	**On**	**Cuts**	**School**			**CFL**	**CFL broken**		**Kerosene**		**Habits**	
Benefit	mth	h/d	/mth	HoH	Girl	Boy	work	pcs	days	Now	Δ l	Eat	Wake
YES	30	4.5	2.7	1.2	0.8	1.0	1.6	0.5	237	1.2	2.3	20:02	04:33
NO	56	3.1	12.4	2.9	0.3	0.5	1.0	1.0	621	2.7	1.1	19:36	04:56
p	.000	.000	.007	.010	.030	.012	.001	.000	.008	.000	.001	.022	.036

8.3.5 Observations during field study

There were several observations of importance made during the field study. The first and main one is that the weakest link of the SPVPP systems are the PCUs as confirmed by CREDA staff and other involved actors and one reason for failure is overload. In order to improve the situation there needs to be a combination of actions, more robust inverters and more social engineering so the villagers understand the importance of not overusing the system.

Although tidy wiring is a policy of CREDA, many cases of untidy and in cases even dangerous wiring was observed. Losses in the wiring in the control room and in the PDN due to poor installation may be one important reason to why the efficiency is not as high as it could be. The large differences in efficiency between the villages shows that there is a lot to gain from improvements in many installation and maintenance procedures, by studying and learning from the good examples.

CREDA have installed timers since the last two years on the newer plants. The relay switch was in cases counter-circuited so the operator or anyone with access to the control room could switch the power on and off. Either the switches had broken, been deliberately circumvented or both. One problem with this is that in many cases the power appeared to be left on to dim down by itself, which further weakens the batteries. The same problem was

[34] Mann-Whitney $p = 0.000$
[35] $N = 111$, $Constant = 0.740$, $F = 9.3$, $R^2 = 0.588$
[36] $b = -0.001$, $p = 0.636$
[37] $b = 0.137$, $p = 0.114$
[38] $b = -0.026$, $p = 0.279$
[39] $b = -0.013$, $p = 0.009$
[40] $b = 0.057$, $p = 0.015$
[41] $b = -0.027$, $p = 0.003$

found in some SHS households, where the relay had broken and thus the only way to turn the system on and off was to connect and disconnect the wires, which would create sudden power surges, damaging the batteries. Furthermore, junction boxes were often observed to be wide open and filled with spider webs. The dust, water and vermin proof boxes are not to any help if they are not shut.

8.4 Installation

The involvement of the villagers when installing an SPVPP seems high on the surface, with a "puja" ceremony first blessing the site, and then villagers being involved in the construction of the buildings. This gives them an extra income and hopefully a higher sense of responsibility for the system. However, in general only a limited amount of people can participate and it was observed throughout the surveys that the women had not participated in information meetings and decisions about the electrification. As the meetings are held at night, many are drunk and the information is clearly not as well received as during other times.

8.5 Operation and Maintenance

The finding that CFLs were more likely to be broken and for a longer period of time in SHS households is an indication that service and maintenance works better in SPVPP villages. The fact that normally the weakest link in a PV system is the batteries and that the main problems in Chhattisgarh appeared to be with inverters, is an indication that the O&M structure is working in the right direction. This is further confirmed by the finding that capacity of SPVPP's do not generally seem to run down dramatically over time, but that it appears to be highly dependent on the village (see section 8.3.1). Still there are several important findings that need to be highlighted. The responsibilities of the OSP, technician, operator and VEC varied, the operators have a tough position, the methods to collect money varied and were not without flaws, load patterns changed over time and false reporting occurred.

8.5.1 The Cluster Service model and training

Despite that CREDA outsource O&M they are still in general highly involved in the process. It varied who's responsibility it was to collect broken parts after the warranty period of the components ends, and some technicians called CREDA staff directly when problems occurred instead of calling the OSM. CREDA have asked the contractors to instruct their technicians to work under guidance of CREDA staff because the final reports of O&M are either way taken up by CREDA (Gyani, 2011f). Still by doing this they are adding extra workload on their staff that are already understaffed and are making the process less effective.

According to some, a *supervisor* existed who's responsibilities were to supervise the technician and to be the first person to respond to emergency calls that the technicians can not handle. After that they should contact the RO or the DO to solve the problems. The supervisors should be hired by the OSP and in some places had to have a technical education that corresponds to 13 years in school. Others, including the Director and EEHO for SPV, did not mention such a working position within the CSM.

There were different opinions in how often the cluster *technician* should visit the villages if no problems had been reported. Some said once a week and others once a month. Comments were also made that the technicians felt that they did not have any training in how to manage the operators because that was their responsibility. They also said different things in who they called if they could not solve the problem. Some called the supervisor and others called CREDA staff directly. Adding to this some CREDA staff saw it as the technicians responsibility to inform the villagers that they should buy CFLs instead of light bulbs and where they can be purchased, or that they should be present at market days and sell them themselves.

Any *helper* to the technician was not found and instead it was one or a couple of technicians that were responsible for each cluster. The *operator's* responsibilities are discussed below (Section 8.5.2).

Different opinions existed in what the responsibilities of *VEC* are. In some villages not even the VEC members knew and did not see the point of having a VEC. In those cases decisions concerning the SPV systems were made during regular village meetings. Others mentioned responsibilities such as giving reports to CREDA in case problems would arise, to make decisions regarding the operators and to turn the system on and off if the operator was not doing his job. The issue of payment seemed to have an influence on the motivation levels of the VEC members. One VEC president was very angry about the lighting system because many houses did not have power, did not want to do any more work for the VEC, and said that "as he does not get paid he is not serious about his job". None of the interviewed VEC members had received any training or been on training sessions arranged by CREDA.

One solution concerning the involvement of the OSP could be to have longer contracts, perhaps for ten years instead of one, as both the Director and the EEHO for SPV mentioned. The difference in opinions in responsibilities could either be a sign of flexibility in the O&M, that each RO and DO can choose how they want to work. Or it can be a sign that clearer guidelines and instructions from the HO are required in order to improve the O&M.

8.5.2 Operator

The role of the operator was found to usually be fulfilled by a man in his early twenties, who often seemed to lack the authority and the position required in terms of respect from the villagers. The operator was found to be in a position between the wants and needs of the villagers, and the long-term maintenance of the plant and CREDA. It seemed difficult for them to take care of bulbs when they spotted them, or to stop TV watching. In some cases TV watching was even on the initiative of the operator.

Three areas of concern were identified. Choosing operator by VEC and land ownership, blaming the operator and problem with authority and the responsibilities and handling overload.

Choosing Operator by VEC and Land Ownership
CREDA faces a tough situation in finding the optimal position for the plant in the villages and at the same time satisfying the villagers. Complications have arisen when the operator previously owned the piece of land that the SPVPP was built on. In one village the person that gave away the land did it on the condition that he became the operator. The VEC members then are in a position where it becomes harder for them to change the operator if they are not satisfied with him. Some VEC members in some villages felt that they lacked control over the operators. The operators did as they wanted with the SPVPP and the VEC members did not know how to change them, who to complain to or even if they were allowed to change them. In one village CREDA chose one piece of land and the owner said no, so the villagers picked another piece of land and blessed that. CREDA still wanted the first piece of land and the operator eventually gave away his land on the condition that he became the operator, hence CREDA created the power struggle that evolved afterwards. In another village the operator claimed he had been promised 1200 Rs/month for giving away his land. The EE of Jagdalpur claimed such arrangements never occur, that the land belongs to the government and that the VEC has to sign for giving the land away for free. One can then speculate that some kind of miscommunication has occurred between VEC members, landowners and CREDA staff.

Blaming the Operator and problem of authority
In the more recently installed SPVPP the operators have not met much complications with the villagers. However, some operators found themselves in a situation where they were blamed for almost everything that happened with the SPVPP systems and occasional violence as a

consequence, especially with drunk villagers. Several operators were reluctant to their posts as were their predecessors. The villagers accused the operators for the occurring blackouts and argued that they should turn the systems on again. The arguments in some villages frequently developed to fights and one operator had been threatened to his life several times. In one village padlocks had been put on the control room several times but the villagers kept breaking into the control room so they themselves could turn on and off the system.

In one village the operator had informed CREDA officials, who assembled the villagers and told them that the short-cuts were not the blame of the operator, that they should not overload the system with appliances or regular bulbs and that they could elect another operator if they were unsatisfied, which they did. The current operator had been so for three months at the time of surveying, but had no training and had not met any CREDA staff since being elected. Due to fights, he did not want to be operator anymore.

One operator experienced problems with villagers who wanted the lights fixed, especially when they were drunk. He felt powerless because when he asked for CFLs from CREDA, they provided him with five to six when he asked for 50, and he had no money himself to buy lights.

In these villages the incidents might be exceptions, but nevertheless CREDA's actions have not been enough to solve the problems.

Responsibilities and handling overload

The opinions varied about which responsibilities the operator had and the sense or responsibility for not over-loading the system. Some mentioned the routine *maintenance* of cleaning the modules, filling distilled water and put grease on the connections. Others said that it was only to turn the system on and off and one said that he did not know who was responsible for maintaining the system and that he only sends a boy to turn of and on the system. A few operators did not turn of the systems during night-time at all because the electricity output faded out anyway. Instead they went in the morning to turn it of. No SPVPP was turned on during morning time.

Some operators said that they are allowed to *disconnect faulty appliances* such as bulbs and TV's in households, while others said that they are not allowed to do that. The operators that had disconnected bulbs stated that they were met with aggression from villagers. One operator claimed that he had collected 15 bulbs but later corrected it to 25 pieces altogether. Even if the villagers got angry he said he managed and sometimes collected them with the help from the VEC president. Instead he had sold CFLs to the villagers, of which he had sold 12 pieces at 120 Rs a piece. The rest of the villagers said they could not afford it. The CREDA mechanics had told him that the villagers could pay in instalments, but instead when telling them they got angry and wanted to be disconnected.

Another operator said that his responsibility was to start the TV they had used occasionally, and they even had had one in the power plant. The TV was rented from another village every second to third months. He said he had no power to stop people from using regular bulbs as they would only get angry. In another village they had a community TV every fourth to six month. Several houses in one para (part of a village) claimed that one day per month they were without power because some in the village disconnected the cables to that para to run a TV. In one village, the operator seemed to have found a compromise by himself starting the TV, but only after 10 PM when the lights were off. In yet another village, the VEC president had a TV to the frustration of the operator, and there had even occurred death threats to the operator about the control of the plant.

Some operators thought it was okay for the villagers to take some extra electricity from hot-wires as long as they used CFLs. One operator had himself hot-wired an extra light to his house and another operator charged his phone by hot-wiring to one junction box in the control room.

8.5.3 Money collection

There seemed to be different opinions on who were supposed to collect the monthly fee of 5 Rs, which had lead to several households never paying at all. Some saw it as the operators responsibility and if some problems would exist with not being able to collect enough money the OSP should pay the difference (Gyani, 2011c). Some still saw it as the operators responsibility to collect the monthly fee but if he did not manage to collect enough the missing sum would be taken off his salary (Trivedi, 2011). Sometimes they then had an annual program to collect all the missing money from the villagers. Others saw it as the VECs presidents responsibility to collect the monthly fees. The collected money should then in turn be handed to the technician or CREDA staff passing by, who delivers it to the RO offices.

The salaries to the operators and the technicians were in all the observed cases less then CREDAs recommendations. In some cases the operators did not even get any salary because they did not manage to collect the monthly fee from the villagers. There were also different views on who should pay the operators. Some said it was supposed to be the technician, who got the money from either CREDA staff or OSP. Others said that it was CREDA staff directly.

It could be an advantage of not having a fixed model of how the money should flow because it can then be adapted to the local conditions. Still the collection of money did not seem to work fully in many villages. The EEHO for SPV thoughts concerning this matter is that payments will improve as soon as awareness increases (Gyani, 2011c).

8.5.4 Output differences

Load appears to increase a certain time after installation, as was also mentioned by the EEHO of SPV (Gyani, 2011a). Partly because of increased awareness about appliances that can be used and partly because bulbs are installed when CFLs break. It appears that the measures that CREDA take to handle this (more instructions from CREDA personnel and installing more capacity in a few villages) are not enough. However, the fundamental problem is that too little capacity is installed from the beginning.

When after some time CFLs start fusing, it seems hard to obtain them from CREDA in sufficient quantities, especially in villages where a large number of CFLs have fused. This leads to the users purchasing regular bulbs, which require perhaps 60 W compared to the 11 W CFLs. If all households follow this pattern, a five to six times overload is obtained, and the three day autonomy is subsequently used up in half a day. Overload from TVs appears to be a smaller problem in comparison, since only a small number of TVs were present in the villages, and often they were borrowed in on occasion, seldom run and during off-peak hours or after 10 pm.

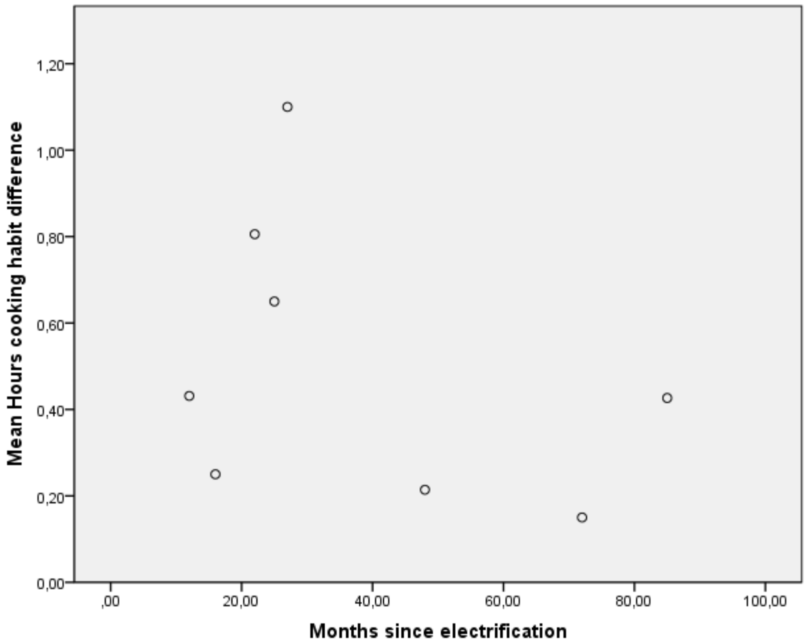
How many CFLs that were working was moderately negatively correlated over time[42] for the sample of the eleven villages, i.e. the older the system the more broken and un-replaced CFLs. The number of unexpected power cuts also increased over time[43], as did their average stated duration[44].

The hours the system was stated[45] to be on per day correlates strongly with the difference in kerosene use since before electrification[46]. The cooking habits (Figure 11) increases with a weak correlation[47] until about 2.5 years after installation, but then it drops dramatically to virtually no difference to before electrification (the plant in Tiriya from 2004 has a supplementary biodiesel generator, why the cooking habit difference for that village is likely to be higher than it would be otherwise). This may be related to the reliability of the systems.

[42] Spearman's $\rho = -0.49$, $p = 0.000$
[43] Spearman's $\rho = 0.30$, $p = 0.001$
[44] Spearman's $\rho = 0.37$, $p = 0.000$
[45] n = 14
[46] Spearman's $\rho = 0.58$, $p = 0.03$
[47] Spearman's $\rho = 0.283$, $p = 0.005$

When the women could no longer rely on the system coming on in the evening, they could no longer take the risk of cooking after sunset.

Figure 11: Mean cooking habit difference compared to before electrification over time since installation



As the time per day that the system is on decreases, several correlations can also be observed. How many CFLs that are broken correlates with a strong relationship[48], a correlation even stronger than for the time since installation[49]. How many bulbs that were installed is obviously strongly related to the number of broken CFLs, but also correlates very strongly with WTP for more electricity[50].

8.5.5 False reporting

The monitoring reports heavily understate the number of household with broken connections in at least one village to be 17 individual CFLs (i.e. 8 households), when the surveyed households did have in total 27 broken CFLs (and only 19 out of 84 households - 23% were surveyed). Whether this is a general trend cannot be said, but since the monitoring reports filled in by the operators are the only source of information the higher levels within CREDA have, there may be considerable under-reporting since the operators may be scared to loose their payment. Another reason could be due to the payment scheme. The OSPs are paid per working connection and hence they might not report all the faults in order to get higher income.

The EEHO stated that they had never had to replace a single battery (Gyani, 2011a), which was found not to be accurate. In one village there was a pile of old batteries stored in addition to the replacement batteries. Whether these batteries had been replaced by CREDA, the OSP or by the villagers themselves does not change the fact that batteries had indeed been replaced. In most of the villages which had plants older than 5 years there were problems with the battery capacity, in one there was only power for half an hour a day, and none of them had power for the stated six hours from the SPVPP alone. In the one village where

[48]Spearman's $\rho = -0.58$, $p = 0.000$
[49]Spearman's $\rho = 0.52$, $p = 0.000$
[50]Spearman's $\rho = 0.70$, $p = 0.025$

there was an older plant *and* six hours of supply, the solar power was supplemented by a biodiesel generator which provided power for the two peak hours in the evening.

Whether the knowledge of the diminishing battery capacity reaches the HO remains unanswered. The authors judgements and observations point towards that limited and sometimes false information is passed upwards in the chain from the operator - technician - DO - RO - HO.

8.6 Economical aspects

The RVE program is not economically self-sufficient for the installation costs, which are completely financed by the MNRE and the government of Chhattisgarh. For the O&M, the tariff is set for 30 Rs/hh, of which the household pays 5 Rs. Most villages in the monitoring reports obtained between 0.05-0.15 kWh/hh/day (See Figure 8a), which amounts to 1.5-4.5 kWh/hh/month. The 5 Rs/hh/month that is supposed to be paid, corresponds to 1.1-3.3 Rs/kWh. The total O&M cost of 30 Rs/month corresponds to 6.7-20 Rs/kWh. As reference, the average conventional grid price in India is 3.5 Rs/kWh (Page, 2009). As the households have on average stated to save on average 2 liters of kerosene monthly since before electrification, and the price they pay is 15 Rs/l, the households should have the capacity to pay on average 30 Rs/month.

Table 9 shows the costs for different systems and components. Assuming an efficiency (highly) of $\eta = 0.15$ and 50 % extra installed capacity, a 3 kWp SPVPP is suitable for 27 households (see Section 8.3.2 for calculations and reasoning). The installation cost corresponds to 37000 Rs/hh, or roughly three times the cost for an SHS. However, an SHS is stated to be on for three hours/day. For an SPVPP outputting three hours of light, half of the capacity is required, corresponding to an installation cost of 18500 Rs/hh. Still, the installation cost is 37 % higher. Counting with the average efficiency for the sample of $\eta = 0.11$, a 3 kWp SPVPP becomes suitable for 20 households, whereby the installation cost becomes 25000 Rs/hh for three hours of light per household, making an SPVPP 85 % more expensive than an SHS per household. In this reasoning it is assumed that the power output from an SHS generates three hours of light per day and that it declines negligibly. More research is required to assess whether the decline in power output from SHSs outweighs the difference.

Table 9: Costs for different systems and components. SHS with standard capacity of 37 Wp and 40 Ah, 12 V battery. SPVPP figures are for a 3 kWp plant. SPVPPs of this size installed in 2004 consisted of 40 panels and 24 batteries and the total installation cost was between 993.904 Rs to 1.130.992 Rs. The cost for the plant stood for 80 % of the total installation costs and the cost for the PDN stood for the remaining 20 %. The MNES and the state of Chhattisgarh financed 50 % each of the costs (CREDA, 2011). In 2004 – 2005 modules for a 3 kWp system cost around 180 Rs/W. Sources (CREDA, 2011; Gyani, 2011g)

Component	**Costs [Rs]**
SHS	13 500
SPVPP (3 kWp)	1 million
PV modules	0.54 million
Battery bank	0.2 million
PCU	52000
Stand-alone Streetlight	25000

CREDA's cluster based O&M system (see section 6.5.1) has the intention to cover all O&M costs. Table 10 gives a general overview of the economical aspects of the CSM. They give a lump payment each month to the outsourced firms, which is based on 25 Rs per working connection. The outsourced firm in turn decided which salary to give to their technicians, operators and occasionally helper and there are no rules from CREDA in what these salaries should be. The guidelines that CREDA instead provides are that the technician's salaries should be around 4000 Rs per month and that they might be provided with some benefits such as a motorcycle and an additional 2000 Rs for fuel costs. The operator's salaries should be around 500 Rs per month. Some technicians have helpers and their salaries could be around 2000 Rs per month. Each month other expenses occur such as broken components (Shukla, 2010) and the biggest O&M costs in the system are damaged inverters (see section 6.3.5) (Shukla, 2011a).

The households have stated to save on average two litres of kerosene compared to before electrification. Since the central and regional governments subsidize kerosene by 18 Rs/liter (The Times of India, 2011) in addition to the saved O&M costs presented in Table 10, the total saved cost is 44 Rs/hh/month[51].

In the financial model for O&M as stated in Table 10, the expenses are heavily understated. When taking into account what CREDA staff have mentioned about broken components, the extra expenses become much larger. Each year 10 % of all inverters are broken and need replacement (Shukla, 2011a), and the batteries have a lifetime of maximum 10 years (Gyani, 2011c). Neglecting interest rate and price changes, assuming that no theft occurs and that two extra inverters and one battery bank per installed SPVPP are needed during 15 years, the cost for only replacing inverters and batteries is 4.56 million Rs/cluster[52]. This figure is 25 times the stated "extra expenses"[53]. For a 50 household village a high estimate would be that 20 CFLs break yearly. Again neglecting interest rate and price changes, the cost of replacement for CFLs becomes 0.54 million Rs/cluster[54], or 12 % of the replacement costs for batteries and inverters.

It is reasonable to think that the saved expense from having to replace less inverters outweighs the extra expense of including provisioning of CFLs into the O&M costs. Additionally, installing sufficient capacity from the beginning would reduce the risk for overload and would probably pay off in under a decade when including replacement costs. As the inverters are a weak link and they cost about 5 % of the total installation cost, a doubling of this investment would improve the quality of the system considerably while raising the expenses by only 5 %. This is likely to pay off within a few years.

Table 10: Typical revenues and expenses for one cluster with 15 villages (Shukla, 2010). Revenues come from payments from household and expenses from salaries to people working with the plant, as well as extra expenses. No=number, rev=revenues, cl=cluster and exp=expenses

Revenues [Rs]		**Expenses [Rs]**			
No. of villages in one cl	15		**No**	**Salary**	**Total**
No. of hhs/village	50	Technician	1	4000	4000
Total no. of hhs/cl	750	Helper	1	2000	2000
Collection per hh	30	Transportation	1	2000	2000
(- hh)	(5)	Operator	15	500	7500
(- From CREDA)	(25)	Extra expenses	-	1000	1000
Total rev/cl/month	22500	**Total exp/cl/ month**			16500

TOTAL REVENUES AND EXPENSES [Rs]	
Totals/cl/month	**+6000**
Totals/hh/month	**+8**

8.7 The CREDA approach in relation to success factors

In this section, the different views on how to assess success regarding rural electrification (Section 5) are first analysed to assess the quality and relevance of argumentation behind the viewpoints, and then the findings from the field study are analysed in light of the respective

[51] $(22500 - 16500)/750 + 2\ \text{liters} \cdot 18\ \text{Rs} = 44\ \text{Rs}$

[52] $15\ \text{villages/cluster} \cdot (2\ \text{PCUs} \cdot 52000\ \text{Rs} + 1\ \text{BatteryBank} \cdot 200000\ \text{Rs}) = 4.56\ \text{millionRs/cluster}$

[53] $1000\ \text{Rs} \cdot 12\ \text{months} \cdot 15\ \text{years} = 180000$

[54] $20\ \text{CFL} \cdot 120\ \text{Rs/CFL} \cdot 15\ \text{years} \cdot 15\ \text{villages} = 540000\ \text{Rs}$

viewpoints. This is hoped to provide an objective, varied and more holistic view than the viewpoints and frameworks would on their own on how benefits from a rural electrification program can and should be assessed. It is also hoped to show what might be missing in the agenda of the more commonly cited sources.

8.7.1 The World Bank

World Bank (2008) provides a healthy criticism of the lack of discussion about benefits of rural electrification. If the benefits are not quantified it cannot be ascertained that electrification is the best investment to obtain them. However, relying on WTP to internalize and measure the benefits appears to be an oversimplification. Judging the future benefits of factors that don't obviously provide economic advantages, especially to someone who is not aware of the potential opportunities and awareness arising with education, seems inconceivable. As it is often men making decision like these, and the women are often the main responsible for the children, the decisions may not include as large considerations about benefits to the children. There is also a gender bias in investments. Investing in a daughter who will be married and move to another household as early as possible and thereby won't provide any income or benefits to the parents is not as likely as for a son on economical grounds.

A purely economic focus does not quantify benefits in terms of soft values in the short run and in terms of soft values and welfare and independence increases in the longer run. The women clearly obtain a benefit as long as the power is provided and works reliably, both by their own statement obtained through the conducted surveys, but also judging on the changes in habits in cooking and the willingness to pay. They do not have to plan the daylight hours according to when they have to cook, and they do not have to rush the cleaning of the utensils and the households after eating before sunset. This provides both a reduction in stress, but also an increased hygiene and prolonging of the time that they can work in the field or with productive activities. It increases the choice they have and their adaptability to unforeseen events, which otherwise might disturb their routine before sunset. However, this only applies as long as the light in the evenings is reliable to them. Once it passes a threshold of unpredictability, the habits must return to adapting to the time of sunset regardless of if there is light on that particular day.

The awareness of the benefits of technology and the short- but especially long-term benefits of having lights in the evening or the presence of TVs in the village needs to grow, seemingly for a while. When the benefits are eventually understood, and the harms of e.g. overload is realized, there is a good opportunity to install new batteries and enforce a more rigid structure of control over not overloading the plant. In this kind of common pool there is, in contrast to most threatened common resources, a second chance.

In accordance with the World Bank study (2008), there are no connection charges for BPL households, but productive uses have not been specifically promoted, and there are few examples of productive use apart from that the time spent working in the field can be longer as cooking starts later. Education programmes for mainly operators and technicians are increasing awareness, and courses are held often to refresh their knowledge, also in accordance with the recommendation from WB IEG (2008).

The article by Barnes and Foley (2004) is widely cited, but there are some aspects that would require more elaboration than what is provided. Regarding cost-recovery, it is claimed as "probably the single most important factor determining the long-term effectiveness of rural electrification programs". However, how this effectiveness is measured is not mentioned. If it is measured in economical terms, this is merely a circular argument. Further it is claimed that: "concessionary capital should never be provided to organizations which are not covering their operating and maintenance costs; it will simply worsen their financial situation" and that the "highly subsidized Indian program [...] has drained the resources of many of the state power companies". What these claims are based on is not referenced or mentioned.

It is also claimed that only when some basic conditions are already present, such as "security of land tenure, [...] access to health and education, reliable water supplies and adequate dwellings", can rural electrification "make a significant contribution to sustainable development". How this contribution is measured is not mentioned. It is further claimed that "Rural electrification only makes sense in areas where there is already a demand for electricity-using services such as lighting, television", but one could question where there would not be a demand for lights.

In comparing CREDA's approach to Barnes and Foley (2004), cost recovery is not achieved as the households are subsidized to over 80% of the O&M costs, even though the stated WTP would cover most of the costs. The institutional structure is however rather autonomous and CREDA have had the freedom to develop their own solutions to many problems. The director describes it as more of a company than a government institution, and corruption is stated to be low. "Dynamic leadership" seems to be present judging on observations, and many of the CREDA staff interviewed were motivated and expressed pride for the work they were doing in bringing electricity to the people living in the jungles. The issue of premature rural electrification is complex and village specific. In some villages land ownership was a problem in the sense that the forest sanctuary wanted the people to leave. Also, the issue of irrigation was brought forward, and was in some villages what they wished for the most. In other villages problems such as these were not brought forward. The level of involvement of local communities is relative, but compared to a project where it is installed and left to it's destiny the involvement is high, as the communities are involved in all stages, and responsible for the running of the plants. However, the involvement of the women has been low.

8.7.2 Millenium Development Goals

The CREDA approach was found to indeed work towards some of the MDGs, although not as many or as much as has been mentioned and exemplified in the literature. The findings from the field survey are below analysed in light of the respective MDGs.

1. **Eradicate extreme poverty and hunger;** 3. **Promote Gender Equality and Empower Women**

Since there was light after sunset, work could commence until a later time, as household activities and cooking could be done later. This provides for a better yield or income, provided that the women can rely on the system. As it was found that this reliance was not present where the output was low, and the output was low for the vast majority of the installed systems, in general the women can be assumed not to have had large benefits.

Women were found not to have been heavily involved in the decision process, other than as passive consumers. However, there is a benefit in that women have a larger freedom in when to cook.

Street lights appeared to have a number of positive effects, as the possibility to move outside without threat from animals, ability to meet under a street light, ability to put on the street lights and have emergency meetings, ability to visit neighbours and socialize later in the evening etc. Although not limited to women, the benefit is likely to be larger for women and children.

2. **Achieve Universal Primary Education**

There is no admission fee for attending school, and books, uniform and lunch are provided by the government. Teachers in several villages stated that after electrification of the households some students had improved their performance. The lights in the households provide for the possibility for students to study at home later in the evenings, and having especially boys but also girls in school was significant for the benefit expressed. Also the adults could of course read at night, but there was an opposite effect for the number of years the HoH had studied and expressed benefit. There were too few women interviewed that had attended school for any substantial such benefit for them.

The presence of TVs in the villages had in a short time provided educational benefits identified by some teachers. The TVs make the students able to learn about other societies and the modern world. A concrete example was that the "children can learn about trains and birds so they don't have to learn about that in school any more", so the time can be spent on learning other things. This is perhaps a larger benefit than can be conceived with modern eyes.

As parents go to work during the days, they cannot watch over the children. The elder children look after the home and the younger children, and are thereby prevented from going to school. In many villages there were government initiated daycare centres for below school-age children. However, many children also did shepherding, ploughing fields, collecting water and other household duties. In other cases the children from minority communities did not understand the language spoken in school fully. Also, the attendance of the teachers in some villages was stated and observed to be irregular. They often lived in another village or town some distance away.

In several villages, the schools had had all the equipment installed by the tribal department, such as fans, sockets etc, but they were not connected to the SPVPPs or any other power source. Only in one village had the school received a connection to the SPVPP, one month before the surveys were conducted, and there they had started with evening schools and tuition, but when they could no longer provide dinner the children stopped coming. Several teachers mentioned installing fans as the highest priority, but also computers if they were to be provided by the government.

4. **Reduce Child Mortality;** 5. **Improve Maternal Health;** 6. **Combat HIV/AIDS, Malaria and other Diseases**

Health improvements could be linked to the ability to see better and thereby clean better which improves hygiene. Also, the decreased use of kerosene indoors may have a certain positive health effect, although probably small. The presence of TVs and radios could increase the information flow and awareness. One problem to be noted is that no TV, radio or movies are produced in the local languages, why information mainly reaches people who already possess some education. However, of course they can spread it further.

The only health clinic present near any of the surveyed villages had a malfunctioning solar power plant, and a problem for repairing it seemed to be that no ladders were available to reach the roof according to the doctor at the clinic, who did not see it as his responsibility to solve that problem.

7. **Ensure Environmental Sustainability**

As the solar power replaces kerosene (according to the surveys on average 2 l/hh/month), there is a certain reduction in CO_2 emissions at this end. The full effect over a life-cycle perspective including production and transportations is however uncertain, and more likely to be negative. Reliance on wood for cooking is still the same, although in general it was observed that dead wood was gathered and used, so pillage was not an issue.

8. **Develop a Global Partnership for Development**

This goal is not affected by this program, as mobile phones were rare in the villages and computers non-existent.

8.7.3 Indian policy

The fact that the object of the RVE program is not directly related to the direct benefits for the consumers may seem rather strange. However, if the objectives of reducing the dependence of kerosene and especially of developing solar power technology in India would not be present, the program would not be cost-effective towards a goal of providing welfare to the users. As the goal at present is to learn from the experiences with solar power and provide lights to replace kerosene, and not explicitly to improve the welfare, no better option can be found. If the objective was to improve the welfare of the users, perhaps other measures such as providing power for irrigation or school electrification would be more effective measures. Also, in terms of rupees per lumen, for instance solar lanterns could be much more cost-effective.

However, to be able to replace kerosene the installation pattern of installed kWp per household has been too low, and thus towards that end the program can be improved. For the ends of JNNSM, perhaps the stimulation of the national production in solar power technology is the more important aspect. One way CREDA is working towards this is that all involved actors are demanded to have a local office in Chhattisgarh, which helps provide continuity with suppliers even for other projects.

8.7.4 Additional viewpoints

As already mentioned, there were benefits for women in that they could more independently choose when to cook as long as the systems were reliable. Differences in social gatherings between the villages were rather small. More research is needed where more and less successfully maintained examples are compared to assess whether the number of monthly social gatherings and level of trust in the village can be an indicator for long-term success of centralised solar power plants, and serve to decide what type of system (centralised or de-centralised) should be installed. Trust and presence of minorities are handled below.

Trust

The director of CREDA claimed that there was no corruption in the organization and that they spent only 3 % of the total expenditures on Direction and Administration. Since the foundation in 2001, 20 people had been fired on the basis of complaints from villagers and service providers (Shukla, 2011a). Although corruption might be low within CREDA, they still operate in a society marked by corruption and mistrust.

Several reasons for mistrust were described. One woman told about how she was going to the market to sell bamboo handicrafts, which is illegal in the forest sanctuaries. The bamboo was confiscated by the police who also took her bicycle and demanded 2000 Rs in return for it (Survey #66). A woman in charge of collecting money from a group of ten women in another village said that when a jealous woman outside of the group (who could have joined initially) started spreading rumours about her and what would happen to the money, the women quickly lost trust and the collection stopped. In one village, all villagers were being forced to move from the sanctuary for reasons of natural protection. In another village, a whole section of the village did not want to be electrified for fear of lightning. This all serves to illustrate that suspiciousness is high towards outsiders.

In two villages the main grid had been drawn to the villages. In both cases, the villages had recently obtained SHSs. This shows of poor communication with the other agencies involved. Coordinating efforts may increase trust among villagers towards agencies from the outside, and also have scale benefits as the people visiting and maintaining the systems can also take responsibility for other areas. Cooperation between agencies, such as CREDA, the Forest Department, Chhattisgarh State Electricity Board and the Tribal Department would therefore have benefits, as a more continuous and holistic effort can be achieved. If the same people were responsible for or at least involved in all or most efforts, a relationship with villagers could be achieved and trust increase.

Minorities

In line with García and Bartolomé (2010), people who belong to a minority community in the respective villages show some interesting differences. Three out of the five households that were not electrified were minorities (all of whom lived in the same village). The total number of people belonging to minorities was 17 out of the 153 women who stated their community belonging.

People in minority used on average 2.0 litres of kerosene per month, compared to 1.4

litres for people belonging to the majority community[55]. Before electrification the people from the majority communities used slightly more than the others, 3.6 litres compared to the minorities' 3.2 litres per month. The difference for the individual households is statistically significant[56] and on average 1.3 l for minority households and 2.3 l for majority households.

29% of people belonging to minority communities did not trust all the people in the village, compared to 10% for people belonging to majorities. This difference is statistically significant[57].

The presence of minorities in a village could serve as *one* signal for the level of cohesion. Perhaps minorities, or houses slightly off the rest of the village should be provided with SHSs to prevent "power discrimination", or at least be given a choice. A larger flexibility in the solutions offered to these households might be advisable. Perhaps the whole village should be given a de-centralised option if the level of cohesion and homogeneity is found to be low.

8.7.5 Policy summary

There are several viewpoints to consider when looking through the perspectives of the different institutions. In the World Bank view, an investment is justified if it provides economic benefits that outweigh the investment. However, the measures used to assess this are rather short-term focused, such as WTP and productive use. From the viewpoint of the MDGs, the social and to some extent the environmental dimensions are satisfied, but there is no economic perspective. Finally, the Indian Governmental policy is mainly looking to decrease dependence on fossil fuels and prevent global warming. Here, the environmental and economical perspectives are the most prominent. The implementing agency CREDA however focus on the end consumers but are working within economical and technical boundaries set by MNRE. The different influential views on success altogether cover the main aspects regarding the Triple Bottom Line[58], but none of them was found to provide a holistic view.

More research is needed in the field to develop frameworks that are locally adaptable and focus more on the end consumers rather than merely technical and economic aspects (see e.g. (Susanto and Smits, 2010)), as has been the norm in the influential literature.

In terms of welfare impact it is hard to measure the benefits, especially when measuring with a “modern” view. There are clear benefits to the users, but the question whether they outweigh the investment costs on their own is difficult to answer objectively as there are many uncertainties and soft values to consider. The benefits in health and education from the household lighting alone have not been measured in this study, although (some) students did study at home more. Also, there are educational benefits from watching TV as the students do not have to learn about the modern world in school and thereby can learn other things there. However, many children of school age did not attend school regularly, so electrification alone might not be enough for this end. As some older children have to attend to their younger siblings they are not able to go to school. Several initiatives did exist to work around this, such as subsidized childcare centres and tribal hostels, although the latter brought substantial costs to the households that chose to send their children there and it would not be affordable to all. In the evenings the parents are back from the field and could take care of the young, but for instance the one school found which *was* electrified could not attract the students to evening tutoring at times when they had no food to offer. Perhaps prioritizing these issues would bring more welfare impact in the long run. However, with the JNNSM objectives in mind, the picture changes. To this end, the efforts in the villages are justified, as they provide experiences necessary to further the ambitious Solar Mission.

[55] Mann-Whitney, p=0.0035
[56] Mann-Whitney p=0.011
[57] Fischer's Exact Test, p=0.041 (2-tailed)
[58] TBL=Economical, environmental and social aspects considered together

9 Discussion on Method

This section presents a discussion on chosen method when it comes to selected villages, the survey and the interpretation. The value of field visits to see the reality before and during designing a system of any kind is of great value, and cannot be comprehended through reading reports or articles. The authors travelled to India with an open mind, and the focus changed several times before the final result because of new understandings of realities in the villages, both during and after the field study. During the course of the study, numerous choices had to be made between different solutions and finding a balance between quality and quantity of results along with time constraints. Hence it is valuable to reflect on the chosen method.

Villages

Since none of the villages were chosen randomly, the results from the survey cannot be taken as quantitative evidence whether the CREDA approach is successful or not. However, the study can hopefully shed some light on what parameters determine why things go wrong with decentralised electrification, as the households in the respective villages were chosen as randomly as was practically possible (some bias in the households proximity to the road did for instance exist).

A further analysis of the comparison between the types of systems could be checked to see if the respective villages contribute to the differences found between the types of system installed. This can be done roughly, through substituting villages (from SHS to SPVPP) and see if that contributes largely to the difference. Other, more sophisticated methods would be to generate a Classification and Regression Tree, or by a Principal Component Analysis to see if the differences can be attributed to the specific villages rather than the specific systems. However, as a specific village (in terms of size or population density) also obtains a specific system (SHS for smaller and less densely populated villages) from CREDA, the factors are rather co-dependent on a certain level, and the further analysis would contribute little.

Survey

The survey was not translated into Hindi or Chhattisgarhi as time was a constraint, and it would have still required a translation to English and the local language during interviewing. Ideally, a translation made by an authority would have been made to refer to during the interviews in cases of uncertainty. However, the translators each conducted on average 40 interviews, whereby the amount of misunderstandings would have been corrected for the vast majority of answers.

In hindsight, a few more questions about social cohesion would have been added to have a broader measure of the trust in accordance with the Putnam definition (Putnam, 1995). Also, it would have been beneficial to ask about household expenditures to match the income with and thereby get a more accurate estimate of the income. However, as the analytical results from the data and testing of effects of electrification and the hypotheses above were of main concern, income and other descriptive variables were not in focus.

Interpretation

The questions and the answers obtained did go through several layers of interpretation before the answer was conveyed. Sometimes this generated certain surprise and frustration on the part of the authors. Occasional unclarity as well as a modern bias in the questions were the main weaknesses on behalf of the authors. The interpreters sometimes did not understand or misunderstood the questions, which was sometimes picked up on by the authors, at times by chance after several interviews had been conducted, at times perhaps not at all. The question was interpreted into Chhattisgarhi, and sometimes again into the local language if the translator spoke it. That interpretation was interpreted by the interviewee into the local world view and language. Sometimes the questions demanded considerable explanation from the interpreters, at times with remarks leading to certain answers. The interviewee often had to withstand many bystanders and their opinions and bias, before giving an answer if at all.

Often they were also handling their children, cooking or doing some other household task. More often than not, it seemed that the bystanders, who were often from the same household helped give the interviewee a better understanding of the question, thus improving the answer. On the other hand, at times drunk men and women, and occasionally violent men of the village had to be handled, and local politics and relationships as well as false expectations or beliefs on the authors could make the interviewees too aware of their answers to provide any substance. Nevertheless, the answers took the opposite route back, if the authors were present, otherwise directly to the survey sheet through the hand of the interpreter/surveyor.

An example of an often misunderstood question would be the question "How often do you attend social gatherings", which in retrospect could be interpreted in several different ways by all of the actors in the chain, providing an array of possible different results depending on the people involved. The authors have to the best of their ability taken this into account when analysing the results from the surveys, and excluded the results that were misinterpreted before the misinterpretation was corrected.

10 Conclusions and Recommendations

The purpose of this Master Thesis project has been to identify crucial factors regarding organisation and design of village-scale Solar Photovoltaic Power Plant (SPVPP) systems and Solar Home systems (SHS). A case study on solar power systems installed by the Chhattisgarh State Renewable Energy Development Agency (CREDA) in India served as basis for the thesis.

The thesis has attempted to answer the following questions:

1. What defines "success" of electrification according to the United Nations, the World Bank and Indian Governmental Electrification Policy?
2. What factors have affected the success of CREDA's electrification by solar power of remote villages?

How the main actors define success is explained in Section 5 and elaborated in relation to the CREDA approach in Section 8.7. The final conclusions about what factors affect the success of CREDA's electrification by solar power of remote villages are drawn below.

10.1 Factors influencing success

As has been shown there are several quite contrasting influential viewpoints on how to measure a successful project, such as stimulation of production, welfare increases and benefits to the solar power market in India. The focus in this thesis has been on benefits and impact for the users. Irrespective of what viewpoints one chooses, technical longevity and organisational functionality are matters that affect those goals. These aspects are highlighted below, followed by a discussion about policy and goals of electrification along with main recommendations to CREDA.

10.1.1 Technical Longevity

Monitoring reports for SPVPPs show insufficient output to provide for two CFLs per households. Thus, too little capacity has been installed, and increasingly so the larger the village is. With and efficiency of $\eta = 0.1$, approximately 0,11 kWp per household should be the minimum installed capacity to provide the required 0.13 kWh per day for two CFLs. For villages of 100 households only half to one third of this has been installed, and on average 30 % too little has been installed.

From the monitoring reports it was also seen that there was no pattern of electricity output connected to the time since installation. Thus, it must be concluded that the low efficiencies are not in general due to overload or poor battery or panel maintenance and that in that sense the O&M functions. PDN losses are not included in the meter readings, which is of course of large importance to the delivery to the consumer but not measured, and hence no reason for the low measured efficiency up to the meter. The consistency of efficiency data refutes deliberate early shut downs of the plants and faulty meters and readings as general reasons. The reasons that remain are losses in wiring and inverters and problems with the panels. The inverters were found to break down often, and are in that sense the weakest link in the system. The large differences in efficiency between the villages (spanning from an average of 11 % to the maximum of 27 %) show that there is a lot to gain from improvements in many installation and maintenance procedures. Thus, quality of installation should be more in focus, as well as more education on maintenance of wires.

Losses from poor fixes and re-installations when wires are disconnected affects the overall efficiency. In the village where one part of the village was disconnected for watching TV, the re-installation is crucial, and losses unavoidable if the wires are not reconnected tightly. Such losses could in this case be prevented by providing a connection for a TV in the village, or occasionally offer TV viewings. TV watching has benefits apart from entertainment, as it also can be educative and "the children don't have to learn about trains in school".

As under-reporting was found, a remote monitoring system is recommended as it would show overload, since the kW output would be measured and monitored. This would increase the transparency and reduce the possibilities for false reporting as well as help focus the efforts on the villages where there are problems.

Timers were often found to have been circumvented. A more rigid system for turning the systems on and off, perhaps built in to the PCU or somewhere harder to reach for deliberate circumventing, in combination with better educating the operators in how the batteries are affected by leaving the system on could be one solution to this problem.

10.1.2 Organisational Functionality

A well implemented outsourced O&M model influences the success of electrifying remote villages in a positive way. The fact that normally the weakest link in a PV system is the batteries and that the main problems in Chhattisgarh appeared to be with inverters shows that the O&M structure is working. This is further confirmed by the finding that SPVPPs do not run down over time, but that it appears to be highly dependent on the village. The finding that CFLs were more likely to be broken and for a longer period of time in SHS households is an indication that service and maintenance works better in SPVPP villages during at least the first 27 months.

However, the O&M is not fully outsourced and CREDA are still highly involved in the process. If the outsourced model would be optimised, i.e. if the OSP took full responsibility for O&M, more time could be devoted to other matters which could increase the success rate of the electrification program. Apart from this this CREDA has succeeded in establishing an emerging group of competent people (key competence is engineers), they have a functioning tender and contract system and the domestic SPV market is stimulated to a certain degree.

The operator's situation is important to consider. When the system does not deliver as much capacity as stated (which is the case for almost all villages) and increasingly so the less is delivered, the operator finds himself in a position where his competences and responsibilities are not enough. The complaints and threats from the villagers become a burden that makes the position undesirable, with a high turnover of operators as a result, leading to low training and subsequently worse functioning of the system.

Social engineering is a crucial factor for success, as identified by CREDA staff. Any organisation implementing systems in remote areas needs to fully understand the needs of the people and the people need to understand how they should treat the systems and why. Basic trust in the system has to be achieved. Due to seasonal blackouts during the monsoon, and blackouts due to deliberate disconnections, short-cuts, inverter failures and decreasing light output for different reasons, the women seem unable to rely on the supply. In villages where the problems have been substantial, no changes in habits have occurred, or at least habits have gone back to the way they were before electrification.

Clear responsibilities for all the involved actors in the O&M model, i.e. OSP, technician, operator and VEC needs to be conveyed and understood. The responsibilities of the VEC and operators seem locally adapted, which sometimes lead to certain responsibilities not being handled by anyone, such as maintenance and tariff collection. This was also the case for the OSP and technician and then concerning service of broken components and payment to operators and technicians. Further It is recommended to decide who's responsibility it is to provide villagers with new CFLs. Due to illiteracy in villages it could be advisable to put up descriptive pictures of the responsibilities, at least for the VEC members and operators. Training of technicians and operators is crucial and could be one solution to convey the importance of their responsibilities.

Also, the procedure by which the operator is chosen needs to be considered. As was found during the field study, the operator sometimes was chosen on basis of being the person giving away his land for the SPVPP. The procedure is understandable to ease the work of CREDA, but may be counterproductive unless the VEC know how and have the authority to elect a new operator, which was found not to be the case.

Upward under-reporting of problems within CREDA within both organisational and technical matters seemed to be common and influences the success of electrifying villages. This could be one reason why several issues have not been recognised and dealt with.

There was a strong tendency towards installing regular bulbs when the CFLs broke, due to lower price and low provision of CFLs from CREDA. Including provision of CFLs into the responsibilities of CREDA would benefit the long-term performance of the plants, as overload would be avoided. Even if it did not seem to drastically affect the overall output over the years, the daily obtainable hours of light are reduced. The CFLs should at least be sold at a price similar to regular bulbs. As the market price for CFLs will decrease, the price for this service will decrease and overall save the performance of the plants and thus ease the work of the operator. The saved expense from having to replace less inverters is likely to outweigh the extra expense of including provisioning of CFLs into the O&M costs.

Installing sufficient capacity from the beginning would reduce the risk for overload and would probably pay off in under a decade when including replacement costs. Also, as the inverters are a weak link and they cost about 5 % of the total installation cost, a doubling of this investment would improve the quality of the system considerably while raising the expenses by only 5 %. This is likely to pay off within a few years.

Suspicion of people from the outside has been found to be a negative and important factor. Also, programs and agents involved with projects in the villages were working independently of each other. Both the users and the organisations would benefit from coordination of these efforts. If the same people were responsible for or at least involved in all or most efforts, a relationship with villagers could be achieved and trust increase. This way efforts would be effectivised towards benefits for the users.

The presence of minorities in a village is proposed as *one* signal for the level of cohesion. A larger flexibility in the solutions offered to these households is advisable. The whole village should be considered for a de-centralised option if the level of cohesion and homogeneity is found to be low.

10.1.3 Policy

Electrification by means of supplying light has made a rather small contribution to improvements in terms of measurable aspects. On the other hand it is difficult to quantify benefits like not having to feel with the hands when looking for things while cooking, or the reduction in fear of animal attacks, etc. Focusing the efforts on education and health-care would perhaps increase the long term benefits per invested rupee. If schools were to be electrified, it must also be combined with other policies, such as providing food in the evenings and daycare facilities for younger children. However, with the JNNSM objectives in mind, the efforts in the villages are justified economically too, as they provide experiences necessary to further the Solar Mission.

In the World Bank view, an investment is justified if it provides economic benefits that outweigh the investment, but the benefits are measured on the short term. From the viewpoint of the MDGs, the social and to some extent the environmental dimensions are satisfied, but there is no economic perspective. The Indian Governmental policy is mainly looking to decrease dependence on fossil fuels and prevent global warming, so the environmental and economical perspectives are the most prominent. There is no influential policy or framework which covers the triple bottom line fully. More research is needed in the field to develop frameworks that are locally adaptable and focus more on the end consumers rather than merely technical and economical aspects, as has been the norm in the influential literature.

10.2 Recommendations

Concluded recommendations for CREDA and other agencies working with remote electrification:

- Install sufficient power as it would reduce conflicts in the villages as well as maintenance costs
- Consider also homogeneity and cohesion in villages when choosing what type of system to install
- Higher demands on installation firms and more focus on maintenance of wiring
- Install more robust inverters with timers
- Focus on implementing a Remote Monitoring System as it would increase transparency and focus attention on the villages that need it
- Older, more respected people as operators
- Better possibilities for VEC to change operator
- Clearer responsibilities for OSP, technicians, operators and VEC members
- Include provision of CFLs into CREDAs sphere of responsibilities
- Cooperate with other governmental schemes and agencies involved in the remote locations

References

AGNI (2010). *Solar PCU, single phase.* Agni Power & electronics Pvt. Ltd., Kolkatta, India. Technology specification document.

Barnes, D. and Foley, G. (2004). Rural electrification in the developing world: A summary of lessons from succesful programs. UNDP/ESMAP, Washington D.C.

Bhandari, A. K. and Jana, C. (2010). A comparative evaluation of household preferences for solar photovoltaic standalone and mini-grid system: An empirical study in a coastal village of indian sunderban. *Renewable Energy*, 35:2835–2838.

Bhattacharya, S. and Jana, C. (2009). Renewable energy in india: Historical developments and prospects. *Energy*, 34(8):981–991. Energy and its sustainable development for India, Energy and its sustainable development for India.

Cecelski, E. (2005). Energy, development and gender: Global correlations and causality. `http://www.energia.org/`. Energia International Network on Gender and Sustainable Energy.

Census India (2011). Provisional population totals and data products - census 2011:chhattisgarh. `http://www.censusindia.gov.in/2011-prov-results/prov_data_products_chhattisgarh.html`. Census of India.

Chaurey, A. and Kandpal, T. (2010). A techno-economic comparison of rural electrification based on solar home systems and pv microgrids. *Energy Policy*, 38(6):3118–3129. The Role of Trust in Managing Uncertainties in the Transition to a Sustainable Energy Economy, Special Section with Regular Papers.

CREDA (2010a). *Supply installation and commissioning of solar photovoltaic home lighting systems, street lighting systems & LED based solar lantern.* CREDA, Raipur, Chhattisgarh. Tender Document, Dated 2010-11-30.

CREDA (2010b). *Tender Document EOI No 2552-B/CREDA/RSB/EOI/Sys Integrators/2010.* CREDA, Raipur, Chhattisgarh. Tender Document.

CREDA (2010c). *Tender Document No 5977/CREDA/CP/2010-11.* CREDA, Raipur, Chhattisgarh. Tender Document, Dated 2010-11-26.

CREDA (2010d). *Tender No 4610/CREDA/T4/JNNSM/SPV/Tender/2010.* CREDA, Raipur, Chhattisgarh. Tender Document, Dated 2010-10-11.

CREDA (2011). Chhattisgarh state renewable energy development agency homepage. `http://www.credacg.org/index.php`. Accessed on 2011-01-23.

García, V. G. and Bartolomé, M. M. (2010). Rural electrification systems based on renewable energy: The social dimensions of an innovative technology. *Technology in Society*, 32(4):303–311.

Garg, N. (2011). Personal communication with Nikhil Garg, Assistant Engineer, Regional office Raipur. Raipur, India. 2011-04-07.

Glewwe, P. (2005). *Household Sample Surveys in Developing and Transition Countries*, chapter III. United Nations Statistics Division.

GNESD (2007). Reaching the millenium development goals and beyond: access to modern forms of energy is prerequisites. Global Network on Energy for Sustainable Development, ISBN 978-87-550-3600-0.

Government of Chhattisgarh (2011a). Official website of chhattisgarh - chhattisgarh profile. http://cg.gov.in/profilenew/profile1.htm. Raipur, India. Accessed on 2011-05-17.

Government of Chhattisgarh (2011b). Official website of chhattisgarh - resources. http://cg.gov.in/development/cdevelopment.htm. Raipur, India. Accessed on 2011-05-17.

Government of India (2003). Electricity act 2003, national electricity policy and plan, part ii:3.6. Government of India.

Government of India (2005). National electricity policy. Government of India.

Green, M., Watt, M., Corkish, R., and Wenham, S. R. (2007). *Applied Photovoltaics*. Earthscan, 8-12 Camden High Street, London. ISBN: 9781849770491.

Gyani, R. (2011a). Personal communication with Rajeev Gyani, Executive Engineer at the Head Office of CREDA. Raipur, India. 2011-02-21.

Gyani, R. (2011b). Personal communication with Rajeev Gyani, Executive Engineer at the Head Office of CREDA. Raipur, India. 2011-03-03.

Gyani, R. (2011c). Personal communication with Rajeev Gyani, Executive Engineer at the Head Office of CREDA. Raipur, India. 2011-04-06.

Gyani, R. (2011d). Personal correspondence from Rajeev Gyani, Executive Engineer at the Head Office of CREDA to T. Marlind. (2011-06-20).

Gyani, R. (2011e). Personal correspondence from Rajeev Gyani, Executive Engineer at the Head Office of CREDA to T. Marlind. (2011-05-22).

Gyani, R. (2011f). Personal correspondence from Rajeev Gyani, Executive Engineer at the Head Office of CREDA to T. Marlind. (2011-05-26).

Gyani, R. (2011g). Personal correspondence from Rajeev Gyani, Executive Engineer at the Head Office of CREDA to T. Marlind. (2011-06-22).

Gyani, R. (2011h). Personal correspondence from Rajeev Gyani, Executive Engineer at the Head Office of CREDA to T. Marlind. (2011-05-27).

Harvey, A. and Taylor, M. (2000). *Designing Household Survey Questionnaires for Developing Countries - Lessons from 15 years of the Living Standards Measurement Study, Vol 2*, chapter 22. The World Bank.

IEA (2009). World energy outlook 2009. International Energy Agency. ISBN 978-92-64-06130-9.

IEA (2010a). Technology roadmap, solar photovoltaic energy. International Energy Agency.

IEA (2010b). World energy outlook 2010. International Energy Agency. ISBN 978-92-64-08624-1.

Jacobson, A. (2007). Connective power: Solar electrification and social change in kenya. *World Development*, 35(1):144–162.

Jager, W. (2006). Stimulating the diffusion of photovoltaic systems: A behavioural perspective. *Energy Policy*, 34(14):1935–1943.

Janssens, W. (2010). Women's empowerment and the creation of social capital in indian villages. *World Development*, 38(7):974–988.

JNNSM (2008). Towards building solar india. Government of India. Jawaharlal Nehru National Solar Mission, JNNSM.

Kanagawa, M. and Nakata, T. (2008). Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. *Energy Policy*, 36(6):2016–2029.

Kirubi, C., Jacobson, A., Kammen, D. M., and Mills, A. (2009). Community-based electric micro-grids can contribute to rural development: Evidence from kenya. *World Development*, 37(7):1208–1221.

Kyocera (2010). Solar energy products - batteries. `http://www.kyocerasolar.com/solar/batteries.html`. Accessed on 2011-01-28.

Lambert, D. W. H., Holland, R., and Crawley, K. (2000). Appropriate battery technology for a new, rechargeable, micro-solar lantern. *Journal of Power Sources*, 88(1):108–114.

Lemaire, X. (2009). Fee-for-service companies for rural electrification with photovoltaic systems: The case of zambia. *Energy for Sustainable Development*, 13(1):18–23.

Malaviya, J. N. (2010). Indian pv market report. *Solarplaza*. January 2010.

Ministry of Power (2007). Report of the working group on power for eleventh plan (2007-12) volume-ii - main report. Government of India.

MNRE (2011). Strategic plan for new and renewable energy sector for the period 2011-17. Ministry of New and Renewable Energy.

Mukhopadhyay, K. (2011). Personal communication with Dr. Kanak Mukhopadhyay, Agni Power & Electronics Pvt. Ltd. Raipur, India. 2011-03-04.

Muntasser, M. A., Bara, M. F., Quadri, H. A., EL-Tarabelsi, R., and La-azebi, I. F. (2000). Photovoltaic marketing in developing countries. *Applied Energy*, 65(1-4):67–72.

NASA (2011). How do photovoltaics work. `http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/`. Accessed on 2011-02-01.

Nouni, M., Mullick, S., and Kandpal, T. (2009). Providing electricity access to remote areas in india: Niche areas for decentralized electricity supply. *Renewable Energy*, 34(2):430–434. Renewable Energy for Sustainable Development in the Asia Pacific Region.

OECD/IEA (2010). Energy poverty - how to make modern energy access universal? International Energy Agency.

Page, J. (2009). India looks to the sun for ambitious surge in green power. `http://www.timesonline.co.uk/tol/news/world/asia/article6736726.ece`. The Times. Dated 2009-08-03, Accessed 2011-06-26.

Panjwani, A. (2005). Energy as a key variable in promoting gender equality and empowering women: A gender and energy perspective on mdg 3. Report to DfID KaR R-8346 Gender as a key variable in energy.

Plonsky, M. (2009). Psychological statistics. `http://www.uwsp.edu/psych/stat/7/correlat.htm`. University of Wisconsin, Accessed on 2011-06-08.

Porcaro, J., editor (2005). *Achieving the millennium development goals: The role of energy services, case studies from Brazil, Mali and the Philippines*. New York: United Nations Develpment Programme.

Putnam, R. D. (1993). The prosperous community: Social capital and public life. *The American Prospect*, 4.

Putnam, R. D. (1995). Bowling alone: America's declining social capital. *Journal of Democracy*, 6:65–78.

REC (2011). Rural electriciation corporation limited - a government of india enterprise. http://recindia.nic.in/profile.html. India. Accessed on 2011-06-27.

Reddy, P. J. (2010). *Science and Technology of Photovoltaics*. BS Publications, Kundli Haryana, India. ISBN: 9789350437438.

REN21 (2009). Renewable global status report 2009 update. Renewable Energy Policy Network for the 21st Century. Paris: REN21 Secretariat.

RGGVY (2005). Rggvy in the 11th plan. http://rggvy.gov.in/. Rajiv Gandhi Vidyutakaran Yojana. Accessed on 2011-06-06.

Rothstein, B. (2004). *Sociala fällor och tillitens problem*. SNS Förlag, Kristianstad. ISBN 91-7150-852-X.

SCADA Systems (2011). Scada systems. http://www.scadasystems.net/. Accessed on 2011-06-27.

Sen, A. (1999). *Development as Freedom*. Oxford University Press, Oxford. ISBN-13: 978-0-19-289330-7.

Shukla, S. (2010). Creda's experience in implementing & maintaining solar power plants in remote rural areas. CREDA, Chhattisgarh State Renewable Energy Development Agency. Conference: Solar Transitions Workshop, Kolkata, India. February 12th 2010.

Shukla, S. (2011a). Personal communication with Shailendra Shukla, Director CREDA. Raipur, India. 2011-04-07.

Shukla, S. (2011b). Personal communication with Shailendra Shukla, Director CREDA. Raipur, India. 2011-02-21.

Solar Transitions (2010). Department for Sociology and Human Geography - Solar Transitions. University of Oslo. http://www.sv.uio.no/iss/english/research/projects/solar-transitions/. Oslo, Norway. Accessed on 2011-05-17.

Stubbs, R. (2008). Solar power batteries. http://www.solar-power-answers.co.uk/battery.php. Accessed on 2011-01-28.

Susanto, J. and Smits, M. (2010). Towards a Locally Adapted Rural Electrification Assessment Framework: A Case Study of the Lao PDR. GMSTEC 2010: International Conference for a Sustainable Greater Mekong Subregion, 26-27 August 2010, Bangkok, Thailand.

The Times of India (2011). Cash for kerosene instead of subsidy. *The Times of India*. Dated 2011-05-29, Accessed 2011-06-22.

Trivedi, R. (2011). Personal communication with Rajesh Trivedi, Executive Engineer, Regional office Jagdalpur. Jagdalpur, India. 2011-04-31.

United Nations (2010a). Millenium development goals: Gender equality and women's empowerment: Progress chart 2010. United Nations.

United Nations (2010b). Millenium development goals: goal 7 – ensure environmental sustainability fact sheet. UN Department of Public Information: DPI/2650 G.

United Nations (2011). Environment statistics country snapshot: United rep. of tanzania. http://unstats.un.org/unsd/environment/envpdf/Country_Snapshots_Sep/%202009/United/%20Rep./%20of/%20Tanzania.pdf. Accessed on 2011-06-26.

Uppal, V. (2011). Personal communication with Vijay Uppal, Consult, Innovative Technology. Rawan, India. 2011-02-07.

Urmee, T. and Harries, D. (2009). A survey of solar pv program implementers in asia and the pacific regions. *Energy for Sustainable Development*, 13(1):24–32.

Wadhwa, W et al. (2003). Access of the poor to clean household fuels in india. UNDP/ESMAP.

World Bank (2008). The welfare impact of rural electrification: A reassessment of the costs and benefits - an ieg impact evaluation. The World Bank Independent Evaluation Group, Washington D.C.

A Flowchart of CREDA process

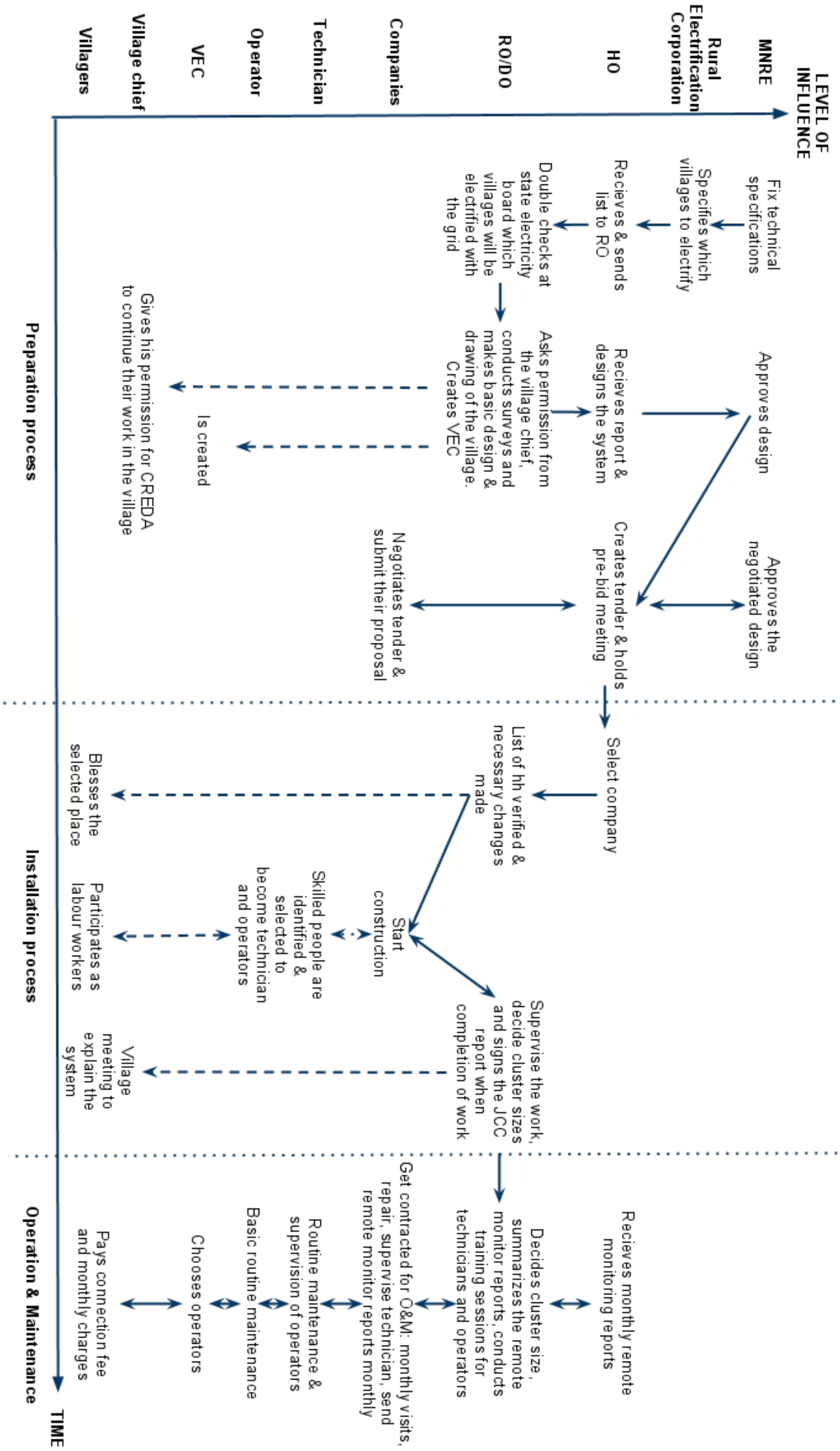


Figure 12: The process which CREDA applies when installing SPV systems

B Technical specifications for SPVPP, SHS and Standalone solar street lighting system

Solar Photovoltaic Power Plant (SPVPP)
Below follows one example of how CREDA computes the required amount of modules and batteries for an SPVPP system. In the following calculations it is assumed that no losses occur in the battery bank, PCU or due to dust factor etc. For a village with 50 households and 10 street lights, where the household lamps and the street lights are lit for 6 hours (6-10 pm and again 4-6 am). Each house has 2 CFL lamps with 11 W capacity (but calculated with 15 W due to possible losses) and each streetlight has two 11 Wp CFLs. The required AC capacity is then:

$$2 \text{ CFL} \cdot 50 \text{ hh} \cdot 15 \text{ W} \cdot 6 \text{ h} + 10 \text{ streetlights} \cdot 2 \text{ CFL} \cdot 11 \text{ W} \cdot 6 \text{ h} = 10320 \text{ Wh/day} \approx 11 \text{ kWh/day}$$

The AC output should be 240 V. Hence 11000 Wh/240 V = 48,83 Ah at 240 V should be provided. Assuming that there are no losses in the inverter, the relation between the DC and AC voltage is $V_1A_1=V_2A_2$. CREDA has specified two types of battery banks for systems with 1-6 kWp installed; 24 batteries with 48 V DC and 48 batteries with 96 V DC. The battery capacity on the DC side for both systems is thus:

$$48 \text{ V DC system}: A_1 = \frac{240 \text{ V} \cdot 45,83 \text{ Ah}}{48 \text{ V}} = 229,166 \text{ Ah}$$
$$96 \text{ V DC system}: A_1 = \frac{240 \text{ V} \cdot 45,83 \text{ Ah}}{96 \text{ V}} = 114,58 \text{ Ah}$$

With three days autonomy and a DoD of 80 % the capacity in the battery banks should be:

$$48 \text{ V DC system}: \frac{229,166 \text{ Ah} \cdot 3}{0.80} = 859,37 \text{ Ah} \approx 900 \text{ Ah}$$
$$96 \text{ V DC system}: \frac{114,580 \text{ Ah} \cdot 3}{0.80} = 343,74 \text{ Ah} \approx 400 \text{ Ah}$$

Assuming that modules generate energy mainly during five hours per day and that each module has four arrays with a capacity of 125 Wp each, which generate 12 V at approximately 6 A, the required number of arrays is:

$$48 \text{ V DC system}: \frac{4 \cdot 229,166 \text{ Ah}}{5h \cdot 6A} = 30,4 \approx 32 \text{ no}(125 \text{ Wp} \cdot 32 \text{ no} = 4 \text{ kWp})$$
$$96 \text{ V DC system}: \frac{4 \cdot 114,58 \text{ Ah}}{5h \cdot 6A} = 15,3 \approx 16 \text{ no}(125 \text{ Wp} \cdot 16 \text{ no} = 2 \text{ kWp})$$

Higher voltage in systems reduces the current flow and thereby decreases the losses in copper wires on the DC side, which leads to that thinner wires are required. To conclude, the optimum capacity to be selected for the example village is thus a system with 4 kWp modules and a battery bank of 96 V.

The components in a SPVPP are (CREDA, 2010d; Gyani, 2011a):

▷ *Control room:* The dimensions of the control room varies depending on the size of the system. CREDA has found that the cost of building a control-room large enough to have the modules on the roof costs almost the same as a system where the modules are placed on the ground with fencing along with additional maintenance costs (cleaning of vegetation, risk for animals destroying the modules and increased risk for theft). However, as the construction of the control room is the most time consuming part CREDA is giving serious thought to reduce the cost of the control room in some way. The control-rooms should always have a minimum of four lights burning, two powered by DC and two powered by AC if any part of the system breaks (Gyani, 2011a).

▷ *SPV modules:* Type is mono/multi crystalline silicon with capacity of 75 Wp and have to be MNRE approved and tested at approved test-centres. The reason for using higher wattage modules are to reduce the shadow-free space, which in turn reduces the number of cables on the DC side and therefore reduces power losses. Each module should be clearly labelled and marked with serial number, capacity, specifications etc. and needs to be approved by ISO 9000 series. After 10 years the capacity of the modules decreases in general to 90 % (CREDA, 2010d; Gyani, 2011a).

▷ *PCU:* Consists of inverter (which has a MOSFET $\leq$ 6 kW and an IGBT $>$ 6 kWp)[59], charge controller, visual display and needed protections. It should have remote monitoring system installed (see section 6.3.5) (Gyani, 2011c). The PCU has separate spare control cards with the intention to be able to make quick repairing. Soft start with the input voltage range of $190 - 270$ V_{DC} for single phase and when the frequency is 50 Hz. The output voltage is 230 V_{AC} with a voltage regulation on +/- 1 %. The inverter wave form is true sinusoidal. The efficiency should be above 90 % at nominal load (AGNI, 2010).

▷ *Battery bank:* Consists of tubular lead acid type batteries with features of slow charging and deep discharging. They are unsealed and need to be filled regularly with distilled water. The batteries should always overall be more charged than discharged. Each cell is 2 V/Ah and they only use 2 V batteries due to their long lifetime, hence a system that for example requires a battery bank of 96 V has 48 cells. At present the batteries has a DoD that is 80 % and 2 or 1, 5 days of autonomy but CREDA will in the near future decrease this to only one day of autonomy in an attempt to reduce the investment cost. The batteries are designed to have extra power during rainy days but in Chhattisgarh that is only 10 days out of 365. Therefore they have decided to reduce the capacity of the batteries to save money (Gyani, 2011a). The batteries have a lifetime of 8-10 years if properly maintained. Every cell should be properly marked and be placed on wooden racks which in turn are placed on non-reactive, acid proof mat (CREDA, 2010d).

▷ *Module Mounting Structure (MMS):* should be of steel with a hot dipped galvanized type (minimum 80 microns) and should be able to withstand winds to up to 150 km/h. The foundation should be designed on the basis of the weight of the MMS and the fasteners for the modules and MMS should be of stainless steel (SS 304). Each MMS should have four legs grouted on pedestals with a minimum size of 500x500x500 mm (CREDA, 2010d). Installation firms have found it hard to install different heights of the pedestals and steel-bars. Therefore CREDA are considering to only install steel-bars of the same height (Gyani, 2011a).

▷ *Junction boxes:* They should be made of Fiber Reinforced Plastic/Poly Propylene/Acrylonitrilie Butadiene Styrene and should be dust, water and vermin proof (with IP 65) and provided with good locking devices. They should have proper sizes for cable entries and outputs and be clearly marked along with the interconnections (CREDA, 2010d).
- AJB: The first junction that the cables from the modules reaches. After that they are connected to the MJB and DCDB. AJB should have a suitable reverse blocking diode to protects the modules by blocking the current to go back to the modules from the batteries. They should be mounted on a heat sink to increase the lifetime of the diode. Each AJB should preferably not have more than four array inputs.
- MJB: Installed in systems with capacity of more then 2 kW. Proper ferrules need to be installed to identify interconnections.
- DCDB: Should be connected between MJB, BPP and PCU and be made out of powder coated metal casting. The components inside should withstand high flow of current and the option should exist to isolate the battery bank and the SPV arrays.
- ACDB: Should be connected between PCU and the Load and be made of powder coated metal casting. One feeder per phase shall be provided. For a village with 50 households there might be the need for 4 feeders, one for street lights and two to three for domestic loads. One energy meter (single/three phase) to measure the consumption of power in the village.
- BPP: A switching device providing the possibility to isolate the installed battery bank to

[59] MOSFET=Metal-Oxide Semiconductor Field Effect Transistor, IGBT=Insulated-Gate Bipolar Transistor

the rest of the BOS components. Should be connected between battery bank and PCU and be made of powder coated metal casting.

▷ *Cables and wires:* All cables should be of copper and be of 650 V per 1.1 kV grade. Good connections should be made with the usage of proper cable glands.

▷ *Street lights:* As of now they consist of only 11 W CFLs (Gyani, 2011h).

▷ *Other components: Lighting and over voltage protection*: The aim is to reduce the over voltage to an acceptable level before reaching any components in the PV system. Each lighting arrestor has to be earthed. *Earthing protection*: Each module should be grounded properly. *Fencing.* It is a requirement for never systems at CREDA to have fencing if the modules are on the roof. *Lights*: All connected households in the system are provided with two CFLs.

Solar Home System (SHS)

The components in a SHS are (CREDA, 2010a; CREDA, 2010c):

▷ *PV Module:* 1 x 37 Wp under Standard Test Conditions (STC), crystalline silicon solar cells.

▷ *Battery:* 1x12 V, 40 Ah flooded electrolyte type, positive tubular plate, low maintenance lead acid battery. One or two days of autonomy.

▷ *Control electronics:* Total efficiency of the electronics should be 80 % and the idle current consumption should not be more than 10 mA.

▷ *Electronics protection:* The system should have protection against overcharging and deep discharging conditions. Fuses should be provided to protect against short circuit. A blocking diode to prevent reverse flow of current through the PV module should be provided. Also protection against open circuit, accidental short circuit and reverse polarity.

▷ *Lamps:* 2 9 W or 11 W CFLs.

▷ *Other components:* MMS of galvanised steel that should be able to tilt in an angle between 0-45 degrees, battery box, inter-connecting wires/cables and switches. Also operation, instruction and maintenance manuals as specified by MNRE.

▷ *Other features:* Two LED lights, one green indicating charging and one red indicating deep discharging of the battery. Serial number of the system.

Stand-alone solar street lighting system

A stand alone solar street lighting system is designed to automatically switch on at dusk and switch of at dawn and should be lit for 6 h. MNRE have specified two types of standalone solar street lighting systems, 37 Wp and 74 Wp. The standalone solar street system with a minimum of 37 Wp consists of the following components (CREDA, 2010c):

▷ *PV Module:* Crystalline silicon solar cells with a power output under STC of minimum 37 Wp and an operating voltage of 16.4 V. The open circuit voltage under STC should be a minimum of 21,0 V.

▷ *Battery:* One 12V, 40 Ah flooded electrolyte type, positive tubular plate, low maintenance lead acid battery.

▷ *Inverter:* Quasi sine wave/sine wave type with frequencies in the range of 20-35 kHz.

▷ *Control electronics:* Total electronics efficiency should be80 %, they should operate at 12 V and the idle current consumption should not be more than 10 mA.

▷ *Electronics protection:* The system should have protection against overcharging and deep discharging conditions. Fuses should be provided to protect against short circuit. A blocking diode to prevent reverse flow of current through the PV module should be provided. Also protection against open circuit, accidental short circuit and reverse polarity.

▷ *Lamps:* Either 4 - Pin or 2 Pin types CFL with a rating of 11 W. If a 4 -Pin type CFL is used an appropriate pre-heating circuit must be provided or instead four super white LED lamps with an output of 11 W CFL. The lamps should be housed in a water proof container with a reflector on its back wall.

▷ *Other components:* MMS of galvanised steel that should be able to tilt in an angle between 0-45 degrees, a four meter high steel pipe painted with a corrosion resistant paint and a acid proof and corrosion resistance metallic box to house the battery. Also operation, instruction and maintenance manuals as specified by MNRE.

C Survey sheet

Date

Region **District** **Village**

SURVEYOR Name **INTERPRETER Name**

GENERAL HOUSEHOLD INFORMATION

RESPONDENT Name **Gender** Male Female

Age **Language** **Tribe:**

How many years in school did you finish? 0 1 2 3 4 5 6 7 8 9 10

Other people present during the interview and their relationship to respondent?

1 2

HEAD OF HOUSEHOLD Name? **Age of HoH?**

How many years in school did HoH finish? 0 1 2 3 4 5 6 7 8 9 10

Respondents relationship to HoH Self Wife Child Other:

No of married couples in HH **No of adult women** **No of adult men**

No of unmarried children **No of rooms**

How many children in the HH go to school? girls boys

ENERGY

1. How many of the following appliances do you have in the household?

2. How much are they on per day?

Mobile phone pcs TV pcs hrs/day

Radio pcs hrs/day CD-player pcs hrs/day

Fan pcs hrs/day Lights pcs working broken

Power tools pcs hrs/day Sewing machine pcs hrs/day

Other, please specify: pcs hrs/day

3. Where do you charge your mobile phone(s)?

4. If you have any fused light at the moment, how long has it been broken?

4.1 Who do you tell to repair it?

4.2 Why are they still broken?

5. What fuel(s) did you use for lighting prior to electrification?

Kerosene Candles Wood Gas Other:

5.1 How much kerosene did you use per month before electrification? litres/month

5.2 How much kerosene do you use *now* per month? litres/month

6. How often do you experience unexpected power cuts? times/month

6.1 What is the average duration of the unexpected power cuts? hrs

7. What electrical devices are you allowed to connect in your home?

TIME

8. What time do you usually start cooking? ____ PM **8.1 Eating time?** ____ PM

8.2 What time did you start cooking prior to electrification? ____ PM

9. What time do you go to bed? ____ PM **10. What time do you get up?** ____ AM

11. How much time do *you* watch TV per day? ____ hours/day **12. Radio?** ____ hours/day

13. How much time do *you* spend on studying per day? ____ hours/day

14. How much time do the children in household study at home per day? ____ hrs/day

15. How much did the children study at home per day before electrification? ____ hrs/day

PRODUCTIVE USE

16. Do you produce anything in the household to sell to others? ____

17. What power equipment, if any, do you use for the production? ____

SOCIAL CAPITAL

18. How often do you attend social gatherings in the evenings? ____ times/month

18.1 What happens at the gatherings? What is discussed during the gatherings?

18.2 How many people are present at the gatherings? Who is present at the gatherings?

OWN PERCEPTION

19. What are the main benefits of electrification?

20. What are the main problems with electrification?

21. Are *all* people in this village honest and trustworthy? YES NO

22. Can you solve technical issues with the electricity yourself? YES NO

ECONOMY

23. What do the main earnings of the *whole household* come from?

24. What is the *total* household income? ____ Rs/month

25. How many months per year do you have that income? ____ months

25. How much would you be willing to pay for more electricity? ____ Rs/month

26. Would you use it for an appliance or more light? More light Appliance: ____

27. Would you prefer to have more lights or more hours of light? Lights Hours

Notes