Appropriate modern lighting systems for off-grid India

Identification of important enablers and inhibitors for a successful off-grid modern lighting project

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Abstract

This research focusses on systems of lighting for low-income households in off-grid remote rural areas. In the dissemination of these systems a significant contribution could be made to CO_2 emission reduction, as lighting use with kerosene is replaced by a cleaner technology. As previous researches have focused either on small-scale lanterns or on mini-grid systems supplying electricity, this research considered a more extensive spectrum of the different solutions and delivery models. Literature reviews, interviews and case studies give valuable input in understanding the enablers and obstructions in order to bring successfully modern lighting solutions to remote rural areas. Depending on local conditions different systems are considered more appropriate.

An important part of a lighting system is the technology part. These are solar lanterns, solar home lighting systems and points of lighting using electricity supplied by a mini-grid. Electricity generated through the stand alone mini-grid can be addressed by several means, which are solar, biomass, hydro power and wind. The key factors for user satisfaction and willingness to pay are the lighting duration at sufficient illuminance and the robustness of all components.

Lighting systems in this research also contain the delivery models. The following delivery models have been identified for small-scale solutions: fee-for-service, leasing and consumer financing. For mini-grids these are: community managed systems, village cooperatives and private models. There is not a single lighting system that can be considered the most appropriate. However, several important enablers and inhibitors have been identified. Important factors for successful dissemination are the post-sales service, intelligently designed credit solutions for the end-users and financial solutions for the implementer. Successful implementations is obstructed when the lighting solutions is too expensive and no financial solution is provided. The policies that are unrolled should be carefully prepared and the implementing agencies should be instructed.

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Abbreviations

AC	Alternate Current	NEST	Noble Energy Technologies
BoP	Bottom of the Pyramid	NGO	Non-governmental Organization
CDM	Clean Development Mechanism	NPV	Net Present Value
CEA	Central Electricity Authority	NSSO	National Sample Survey Organisation
CERC	Central Electricity Regulatory Commission	OECE	Organisation for Economic Co-operation and Development
CFL	Compact Fluorescent Lamp	PBP	Payback Period
CSP	Concentrated Solar Power	PCB	Printed Circuit Board
CSR	Corporate Social Responsibility	PDD	Project Design Document
DC	Direct Current	PDS	Public Distribution System
DISCOM	Electricity Distribution Company	PM	Particulate Matter
DSM	Demand Side Management	PO	Partner Organisation
EMI	Equated Monthly Instalments	PPA	Purchase Power Agreement
ESCO	Energy Service Company	PPP	Public Private Partnership
GDP	Gross Domestic Product	PV	Photovoltaic
GEF	Grid Emission Factor	R&D	Research and Development
GHG	Greenhouse Gas	RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
GNI	Gross National Income	RPO	Renewable Purchase Obligation
GoI	Government of India	RRB	Regional Rural Bank
HDI	Human Development Index	SCS	Solar Charging Station
HPI	Human Poverty Index	SERC	State Electricity Regulatory commission
IEA	International Energy Agency	SHG	Self Help Group
IFC	International Finance Cooperation	SHLS	Solar Home Lighting System
IFMR	Institute for Financial and Management Research	SHP	Small Hydro Power
IPCC	Intergovernmental Panel on Climate Change	TRC	Technical Resource Centre
ITI	Industrial Training Institute	UN	United Nations
JNNSM	Jawaharlal Nehru National Solar Mission	UNDP	United Nation Development Programme
LaBL	Lighting a Billion Lives	UNEP	United Nation Environmental Programme
LCA	Life-cycle Analysis	UNFCC	United Nation Framework Convention on Climate Change

LED	Light Emitting Diode	UNFPA	United Nations Population Fund
LPG	Liquefied Petroleum Gas	UREDA	Uttarkhand Renewable Energy Development Agency
MFI	Micro-finance Institute	VEC	Village Energy Committee
MNRE	Ministry of New and Renewable Energy	VESDM	Village Energy Committee Village Energy Service Delivery Model
MoP	Ministry of Power	VESP	Village Energy Security Programme
MPCE	Monthly Per Capita Consumer Expenditure	VLE	Village Level Entrepreneur
NABARD	National Bank for Agricultural and Rural Development	WBREDA	West Bengal Renewable Energy Development Agency
NEDA	Non-conventional Energy Development	WLED	White Light Emitting Diode

Used currency exchange rates[1]:

US Dollar (US$) - Euro	€ 1	US$ 1.26
Indian Rupee (Rs.) - Euro	€ 1	Rs. 70.43

1 Source: Reserve Bank of India on the 2nd of July 2012

1 Introduction

1.1 Background

In the last decade the contours of the world economy have been changing. Formerly strong economies from the North are bypassed by emerging economies located in the South (Dicken, 2008). Inherent to this process is the shift of power in the political arena, the roles in the energy security debate and the contribution to global climate change. With respect to the last two aspects, concerns have been expressed about the effect of increased energy consumption expected in rising economies such as India and China. The augmentation of energy use has led and could lead to a further increase in the greenhouse gas (GHG) emissions from these economies and would significantly contribute to the damaging effects of anthropogenic climate change (IPCC, 2007). Steps need to be taken to reduce these emissions as it could lead to irreversible damage to the climate system (van Vuuren et al., 2011). As world leaders are still arguing on which countries have to reduce their future emissions by how much, there are already schemes being initiated within these emerging economies to reduce their future emissions.

For achieving global well-being the UN set the Millennium Development on the international agenda in 2000 (UN, 2000). Despite energy access not being one of its goals, it is a major contributor to the poverty reduction, health and education goals, not understating the contribution for the remaining goals. In India the poor are still a large part of the population deprived of the benefits of the increase in welfare. They are or could be further marginalised if no action is taken. These social groups are estimated to be about 42% of the population of India, where they live in the peri-urban areas, the rural areas, the urban suburbs and the slums (Dicken, 2008). The Indian population lives in the rural areas for 70% (UNFPA, 2007). This share of the population is expected to reduce to 60% by 2030.

History has shown that the development of human civilisation and industrialisation has coincided with the development of artificial light (IEA, 2006). This is not only a necessity for the privileged parts of society, but also for the poor. In India the economic development has already shown an improvement in welfare for a large part of the population. As India is developing at a rapid pace it is to be expected that there will be an increased demand for lighting which will consequently increase energy needs.

Improvements in lighting services can not only have the potential to reduce emissions and energy consumption, it can also aid in strategies to alleviate poverty (Barkat, 2005). In climbing the energy ladder[2] one of the primary steps forward is improved access to better quality lighting. Development of low cost, more efficient and cleaner lighting technologies will positively impact the lives of those at the bottom of the pyramid[3](BoP).

[2] The terminology of the energy ladder is often used in the evaluation of household energy consumption. It describes the transition between different stages of fuel switching (Heltberg, 2004). The lowest phase is when the household relies mainly on biomass, the second phase is when the household is moving to kerosene, coal when there are limitations in the availability of biomass and the increase in income. The final phase is when households are starting to use LPG, natural gas and electricity. It however does not capture the concept of multiple fuel sources that are available to the households. There are some stylized facts as the ordering of fuels corresponds with the efficiency of the associated systems (UNDP, 2000).

[3] The term Bottom of the Pyramid has been introduced to describe the large group with low purchasing power in developing countries. Those have been identified as a potential market for different for profit enterprises that offer products with a small margin and has to focus on scale. The multiple aim is to eradicate poverty through targeting markets at the bottom of the pyramid and making a profit (Prahalad and Hart, 2002).

As part of project Lighting a Billion Lives (LaBL) there have been implementations of stand-alone solar lighting in India (TERI, 2011). Other small-scale solar lighting initiatives have been for example in Malawi (Adkins et al., 2010), Nepal (Zandh and Kimber, 2009). Also decentralized electricity generation through a biomass gasifier have been employed (Palit et al., 2011). These different approaches have not yet been scaled-up fully, which is needed to address the lighting needs of the rural population. As opposed to these studies that have aimed at either small-scale lighting or decentralised energy provision through mini-grids, this research analyses the different implementations of the different technologies. It will contribute to the recommendations on the policy level on how to increase the dissemination of rural systems for lighting.

1.2 Traditional lighting means India

To meet all of India's lighting needs there is a huge dependence on kerosene and traditional fuels (Bhattacharyya, 2006). The traditional lighting means are mostly fuel-based lighting like candles, the PetroMax, the Hurricane lantern, the chimney wick lantern and an open fire. These are shown in Figure 1. The fuels needed for these lighting technologies are respectively candle wax, kerosene and wood residues and biomass.

Figure 1: Traditional lighting means from left to right: candle, Petromax lantern, Hurricane lantern, Chimney Wick lantern and an open fire.

Candles were invented around 3000 BC (IEA, 2006). The purchase of the candle can be considered cheap, however the inefficiency and low quality of light are the disadvantages of candle use. The Petromax is a pressurized kerosene lantern and gives a very bright light with a low soot output. A disadvantage is the high operating costs. Hurricane lanterns are used indoor and outdoors. The lantern can be carried around easily as the flame is enclosed by a glass wind-protector. At its highest setting the soot production can increase and can darken the interior of the glass. Chimney wick lanterns give a very large, dancing smoky flame. The lamp appeared to be used more often outdoors than indoors due to the large flame produced. It has the largest soot production compared to other kerosene lanterns. Open fire is regarded as a very inefficient form of lighting. It is often free of capital expenditure, but the wood and biomass have to be collected.

The National Sample Survey Organisation (NSSO) data shows over multiple years that in urban areas a rapid substitution has taken place of traditional fuels. The substitution has resulted in an energy mix dominated by commercial energy sources, while rural households are still largely dependent on non-commercial energy sources, shown in Figure 2 (Bhide and Monroy, 2011). For cooking the rural residents predominantly use biomass, fuel wood and dung, and for lighting mainly kerosene. Only the households in the top decile in rural regions show a preference for the substitution of solid fuels by non-solid energy forms.

Table 1 shows the monthly levelized lighting costs for a fishing village in India. The average cost for kerosene lanterns is Rs. 425 (Apte et al., 2007b). Estimating an average income of an household of 2000 Rs./month implies that a large portion is spent on lighting fuels (Chaurey et al., 2004).

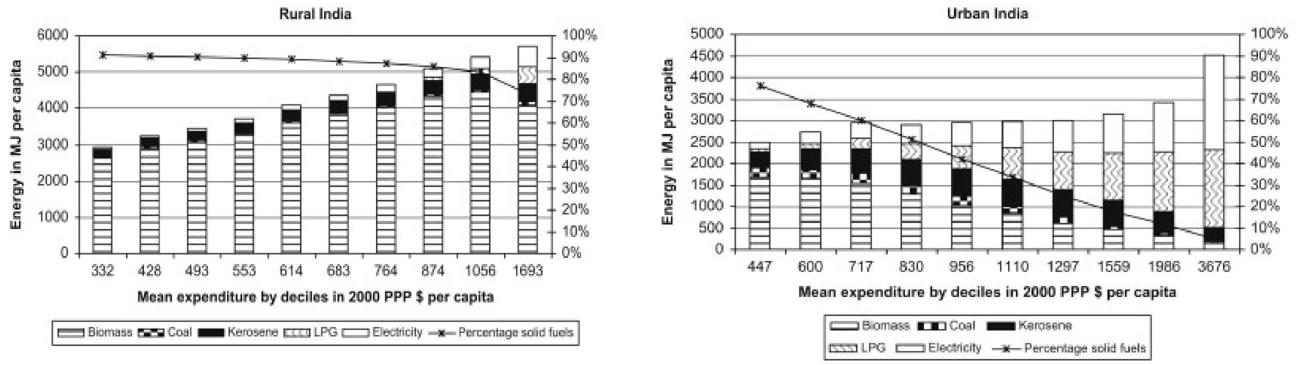

Figure 2: Per capita energy consumption patterns across left) rural deciles right) urban deciles (Pachauri and Jiang, 2008)

Table 1: Traditional lighting costs assuming a consumption of 20 litre kerosene per month (Apte et al., 2007b).

Lantern Type	Lantern Cost(Rs.)	Lantern Life(yr)	Rate of fuel consumption(g/hr)	Monthly levelized cost (Rs./month)
Hurricane	*100*	*1*	*12*	*70*
Chimney	*100*	*0.5*	*80*	*377*
PetroMax	*400*	*1*	*62*	*338*

Other non-renewable off-grid alternatives include biofuels like wood, animal dung, crop waste, battery powered light devices, and diesel generators for the richest households and small businesses. These alternatives are either labour intensive, expensive, dangerous or environmentally harmful.

1.3 Grid electrification

Electricity can play a significant role in the development path of the rural population enabling different energy services. The central government of India has supported electrification by the Electricity Act. This act mandates 100% access to electricity by the year 2012 for all Indian households (GOI, 2005). Each State Electricity Regulatory Commission (SERC) aims to purchase a minimum amount of renewable power. It allows the Central Electricity Regulatory Commission (CERC) to set a preferential tariff for electricity generated from renewable energy technologies and gives open access to the transmission and distribution system to licensed renewable power generators (MoP, 2003) The co-generation and generation of electricity from renewable sources are promoted by the SERCs. In order to encourage grid connection, the following measures are taken: the possibility to sell generated electricity by any person to the main grid and by specifying a minimum percentage of electricity to be generated by renewable sources in the area of a distribution licensee.

In India the definition of an electrified village is: a) Basic infrastructure such as distribution transformer and distribution lines are provided in the inhabited locality b) 10% of the households of the village has a connection, c) Electricity is provided to public places like schools, village head office, health centres and community centres (MoP, 2006). Even in officially connected villages a large number of households remain unconnected. In addition power-outages are frequent in Indian households. Although the electrification rate increases, large number of households are still not connected to the main grid. This overview of traditional lighting and limited connection of Indian households to the main grid indicate the importance of off-grid modern lighting alternatives.

2 Research questions, methodology and overview

In this chapter the main research question is introduced, which is answered by addressing the sub-questions in the various chapters of this thesis. A general description of the methodology will be given, followed by an overview of the research.

2.1 Research questions

This research focusses on low carbon technologies for lighting in off-grid remote rural areas. In the dissemination of these systems a significant contribution could be made to CO_2 emission reduction, as lighting use often addressed by kerosene is replaced by a cleaner technology. The advantages of the implementation of an efficient and low carbon system for lighting is two fold, it can aid in the CO_2 emission reduction and alleviate poverty. The main question is formulated as follows:

What are appropriate modern lighting systems for the rural consumers in off-grid regions in India?

To provide an answer to this research question the following sub-questions have been determined:

- What are the lighting needs before and after implementation of a lighting system in remote rural areas?
- Which modern lighting technologies are available for remote rural areas?
- Which implementation mechanisms for a remote rural system for lighting are available?
- What is the appropriateness of these systems for lighting, taking into account resource availability, technological appropriateness, economic viability, sociocultural acceptability and environmental sustainability?
- What circumstances have led to success and failure of implementation of the rural systems for lighting?
- What enablers and inhibitors to scaling of modern lighting systems should policy mechanisms take into account?

2.2 Methodology

In the assessment of the lighting solutions it is important to understand what the lighting needs are of the rural population. To obtain this knowledge, first of all a literature review is conducted to get an understanding of the energy and lighting use. Based on the determination of the lighting needs, choices are made on how to categorize the final outputs.

Information on lighting needs and the energy use will give insight on local context and the preferences of the target population. Aspects like the study time of children, the start of new businesses and the air quality are considered. The effect on the changing lifestyles of the target population will be examined through literature studies and analysis of several case-studies.

In this assessment of lighting needs it is chosen not to solely base the information on off-grid application. The idea is that to identify the need it is not essential how the need is met. This implies that in evaluating the needs, cases can be considered where an off-grid solution is introduced as well as a village that became electrified through the main grid. The regions of interest in this research are the areas not serviced by the grid. It is either not feasible to extend the grid or it is for several reasons very attractive to use off-grid electricity generation.

After establishing the lighting needs of the consumers in remote rural regions, the next step should be obtaining an overview of different clean lighting technologies that are available in these areas.

The succeeding step is to bring the lighting service to the target population. After discussing the delivery models several distribution challenges are addressed. In order to chose the most appropriate technology understanding of the local circumstances is essential. The information gathered is based on scientific literature, field experiences and interviews conducted in India.

In order to acquire insights on distribution challenges and the policy environment, interviews were conducted with different stakeholders. At the centre of the delivery models in the remote lighting implementation area are its stakeholders. To understand the various dynamics and interactions in the delivery of lighting solutions, 20 interviews were conducted with various stakeholders in India and one in the Netherlands. The interviews are used to get insight in the stakeholders perspective on the way forward. These stakeholders are different people who are affected by the implementation or used the lighting solution. The qualitative interviews were done with implementing actors, operators, customers and non-customers, policy makers at the national level, NGOs, research institutes and manufacturers. The various interviewees are given in Appendix B. The interviews provide information to understand appropriate delivery models, pitfalls and challenges for lighting systems in the Indian market. The stakeholders together with a literature study provide information on the criteria applied on the technology and the delivery model.

Case studies in this paper are defined as situations where a modern lighting is introduced in a community or a group of villages. The case studies provide additional information on the challenges encountered and how they were overcome with the different delivery models. The different case studies are used to analyse the important distribution challenges and how these challenges are overcome.

2.3 Research overview

An overview of this research is given in this section and is visualised in Figure 3. The thesis starts with the evaluation of the lighting needs of rural households (chapter 3). In Figure 3 these are visualised in the rows of intermediate outputs and final outputs. The lighting needs were differentiated in education, productivity, entertainment/communication, convenience and comfort/protection. After this evaluation an inventory is done of available clean lighting solutions. To place this activity within the research one can observe the right side of Figure 3, which corresponds with the rows of the lighting technology and lighting type. The following step is a compilation of Indian experience of implementations of lighting technologies. This activity corresponds with the arrow between the two blocks in Figure 3 (chapter 4). An evaluation of the local conditions is done to select the most appropriate range of technologies (chapter 5). The different demands and criteria of the technology and delivery models are discussed (chapter 6). The case studies provide information on how certain criteria are met (chapter 7). Different actors are experimenting with different lighting solutions, financial models and marketing models on a relatively small scale. The different implementation mechanisms and technologies will be assessed on the economic viability and the impact on the CO_2 emissions. These are aspects that need to be considered in a project implementation. This corresponds with the arrow at the bottom of Figure 3 (chapter 8).

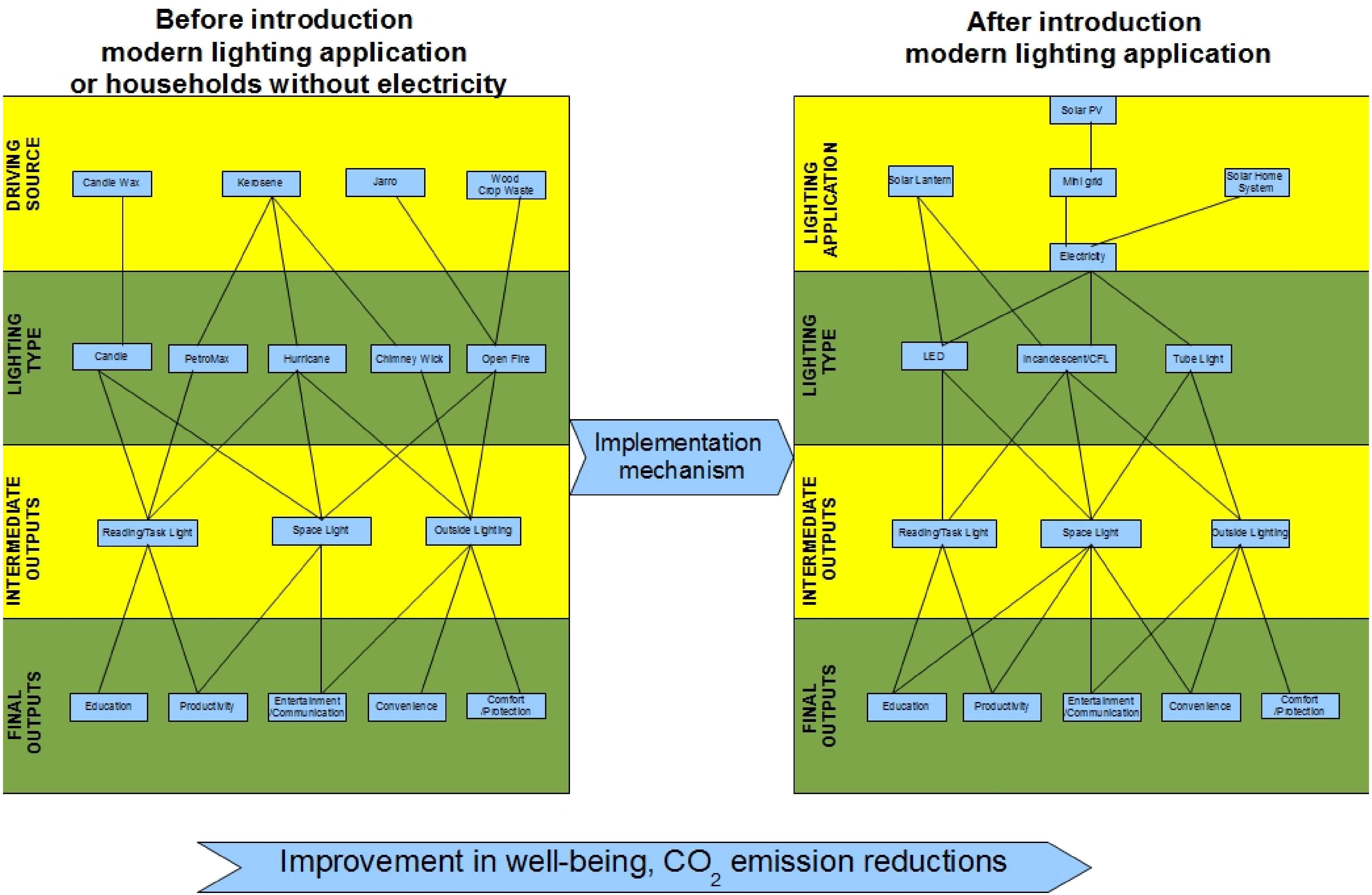

Figure 3: Overview research

3 Lighting Needs

3.1 Application of lighting

When analysing a lighting solution it is convenient to categorize the lighting needs of its users. The modern lighting solution is expected to benefit the life of a household on different levels. The rural consumers prioritized the needs addressed by lighting (Ochieng et al., 1998). These are as follows:

1. entertainment and communication
2. education
3. convenience
4. comfort and protection
5. productivity

These final outputs together with health are all contributors to the well-being of the end-user. As can be seen from this list, environmental concerns were not directly put forward as a motivation for purchasing a better lighting device as is supported by a more recent survey (GIZ, 2011). The different final outputs of lighting and their relation to the lighting sources are illustrated in Figure 3. The final outputs are directly dependent on the light output, while the indirect need of lighting is the improved health condition of people. The type of modern lighting in this section is not considered relevant for the direct final outputs. However, the health benefit does depend on the lighting solution. The use of traditional lighting and the use of modern lighting devices result in different concentrations of particles in the living environment.

Entertainment and communication

The modern lighting could be the enabler of an increased number of social meetings within the village. On the household level people will have the opportunity to see each other and communicate and entertain. In addition longer operation of regional night markets could enhance meetings between the populations of different villages. Modern lighting is also an enabler for communication and entertainment through storytelling.

In a survey conducted in the Philippines the relationship between availability of electric lighting and social gatherings during evening hours was determined. The research showed that in an electrified village 8.4% of the households received people after dark, while in an unelectrified village this was only 1.6% (Worldbank, 2002). However, other factors could also have affected these numbers. In a cleaner environment social activities can be enjoyed better, strengthening the social cohesiveness of the community (Zandh and Kimber, 2009; Hiremath et al., 2009).

Education

The quality of light influences the results of education as a better condition for reading is obtained. Looking at the technical perspective on how lighting supports education, there is a demarcation of what is readable. A study on reading by young adults in Indonesia showed that adults could read in light levels ranging from 0.1 up to 15 lux, depending on font size, contrast, and distance between the reader and paper (Atmodipoero and Pardede, 2004). However, these tests did not take into account long-term eye strain.

Households with electric lighting generally have a higher education than those who do not. The increase of educated women makes it possible for them to break their drudgery of survival activities (UNDP, 2000). This demonstrates the role of education in the empowerment of women. Also as children are studying more at night, better marks can be obtained. In Bangladesh a study showed that solar-powered lighting has resulted in children staying awake. This additional time was used 38% for studying and reading (IFC, 2010). After introduction of modern lighting in a Nepalese hamlet members of households increased the amount of reading with 2 or 3 hours in the evening (Zandh and Kimber, 2009). Other better study opportunities have been suggested by night schooling. Children who don't have modern lighting, visit neighbouring households to study with better lighting (Gustavsson, 2007; ESMAP, 2000).

Improved lighting conditions could effect average years of schooling for a population. Other factors like availability of schools, infrastructure and regional characteristics can also be considered. The majority of the researches and surveys found in the scientific literature, base the results on the perceptions of end-users on the effect of lighting or on the perception of the time that is spend before and after reading (Worldbank, 2002; Peters et al., 2009; Hiremath et al., 2010). A more quantitative survey did measure that the introduction of solar lighting raised average study hours of students per household (Agoramoorthy and Hsu, 2009). The additional 1.5 hours to 2.7 hours per day resulted in better marks. According to another survey among the population of Sagar children obtain on average an additional 2.25 hours per day for study after introduction of lighting (Chakrabarti and Chakrabarti, 2002). However not quantifying specifically the progress in improved mark/study hours/increased literacy rate.

Comfort and Protection

Lighting supports the sense of comfort and protection of the end-users. A lantern can bring a feeling of security when walking at night through the village. It provides protection against wild animals, which reduces the number of deaths or attacks due to game. Light also increases visitors to markets because of the sense of security the light brings (IFC, 2010).

A survey in Benin showed that the primary use of the lighting was for comfort and protection of the women and children, who liked to sleep in lightly lit rooms (Peters et al., 2009). In Namibia after the government had promoted electricity and solar home lighting systems (SHLS), the access to lighting gave the population a improved feeling of safety (Wamukonya and David, 2001; Chaurey et al., 2004; Worldbank, 2002). On the other hand the possession of a modern lighting technology might make the household a target for thieves. Interestingly enough, the owners did not express these fears.

Convenience

Convenience for the end-user is the ease of performing certain livelihood tasks with light. There is a strong correlation between the time women have for economic activities and the time they have for survival activities, collecting fuels for cooking and lighting. Women and children have to travel long distances to acquire the fuels, which makes them unavailable for production tasks (IFC, 2010; UNDP, 2000). Also convenience is the possibility to move at night, and the time freed for household chores in the evening (Hiremath et al., 2009; Wamukonya and David, 2001). In 2011 surveys done during the torch bearers programme[4] indicate that women have more free-time now that they have received a modern lighting solution (TERI, 2012).

Productivity

In Malawi the introduction of modern lighting provided opportunity for economic development

[4] The programme gives students and interns the possibility to work together with the LaBL team and to gain first-hand work experience in the field of rural energy access by undertaking a series of assignments. In December 2011/January 2012 surveys have been done in villages to understand the impact of the introduction of solar lanterns.

according to members of the surveyed households (Adkins et al., 2010). Only a small percentage declared that they had more time to work at night. However, the impact on income of the end-users has not been observed yet. Another survey in Benin, which was held amongst electrified households, unelectrified households, commercial users and social institutions, showed that the hours of operation of the light increased from 7 hours to 9 hours after the introduction of modern lighting (Peters et al., 2009). In addition during the rain season the classes of school were lit and the teachers were able to prepare at night. A similar case occurred in Namibia where the government had promoted electricity through grid extension and solar home systems. The teachers were able to stay up late to prepare for the lessons of the next day (Wamukonya and David, 2001). This case study had a focus on villages where teachers resided. The working day length was extended by 1.5 hours. However, there was no indication that new businesses were initiated due to the access to electricity/light. In India the introduction of modern lighting increased the income as working hours were extended (Hiremath et al., 2009; Chaurey et al., 2004). In a Nepalese hamlet in which Jharro[5] was replaced with modern lighting additional income was obtained by women/households through knitting, bamboo weaving and other handicraft skills. (Zandh and Kimber, 2009).

Other research shows improved sales by market vendors, because better illumination of the products on offer appeal more (Johnstone et al., 2009a; IFC, 2010). The novelty and the brightness of LED light attracts potential customers.

Health

An indirect need of lighting is the reduced indoor air pollution. Cleaner lighting solutions have an impact on health, although health is also influenced by various other factors like lifestyle, environment, and infrastructure (UNDP, 2000). The use of fuel-based lighting has impacts on health in two ways. Firstly, the fuel-based light source has a risk of injury due to the flammable nature of the fuels used. Different studies have shown that the kerosene lamps are a hazard of fire and the ensuing risk to life and property is substantial (IFC,2000; Oduwele et al., 2003; Howells et al., 2005). Overturned and exploding kerosene lanterns and shacks that went into flames have resulted in many death, injured and maimed persons.

Secondly, the inference of the particles emitted by the fuel based sources can cause chronic illness or eye damage of the person in the household (Chakrabarti and Chakrabarti, 2002). Kerosene lanterns emit fine particles and can penetrate in the bronchial system, which can result in a chronic disease and death. In a study in Ghana, a qualitative observation of the impact on health through the introduction of modern lighting showed that the proportion of household members who got blackened nostrils from soot produced by kerosene lanterns was reduced by a third (Obeng et al., 2008). A comparative analysis in the Philippines of households connected to the grid and households that used kerosene lighting, showed that the latter group had a higher incidence of shortness of breath, wheezing and intermittent fever (Worldbank, 2002).

Small particles can penetrate deeper into the lungs, hindering the respiratory system. Particles that are smaller than 0.1 μm can be transported via the lungs into the bloodstream, which could cause circulator problems (Baj et al.,2007). The increase in illumination from switching from hurricane lanterns to high pressure lamps also has the consequence that the concentration of small particles increases.

[5] Jharro produces strong black smoke, soot and a very dim light. To produce it, the local people cut a pine tree's bark and top layer wood, so that the tree had to start producing resin, in order to ''cure'' the inflicted ''wound''. After a week, when the tree has produced so much resin that the ''wound'' can heal, people come and cut out that layer plus the next deeper lay. This part is so soaked with resin that it burns very well, like a torch, generating a dim light with lots of soot (Zandh and Kimber, 2009).

3.2 Quantification of needs

In a study executed by the World Bank in the Philippines, the social and economic benefits of the introduction of electricity in unelectrified regions were quantified (Worldbank, 2002). This quantification was done by putting a price on the need addressed. Lighting was one of the energy services that was measured. It would be desirable that the amount of lumens[6] needed could be mapped for each activity, which would make it possible to identify what type of activities could be deployed when a new lighting technology is introduced.

Improvements in addressing needs are highly contextual and linking improvements between projects can be quite challenging. In order to be able to deduce the impacts of the introduction of modern lighting, consistent measurements enable a quantitative overview. This facilitates future implementations of modern lighting and understanding of the barriers to upscale modern lighting solutions. In Appendix A assumptions in modelling of energy requirements are given for lighting.

Communications and entertainment:
A potential method to quantify the change in entertainment and communication could be to count the number of social gatherings before and after the introduction of modern lighting. The quantification in the amount of lumens could be estimated by comparing the use of the light output with a chimney wick lamp during meetings with the light output of modern lighting.

Education:
A possible attempt to quantify how the need is met by modern lighting could be done by comparing the amount of lumens used for reading with kerosene lanterns with the lumens of modern lighting solutions. The challenge with this type of measure is how to assign the minimum of lumens required for reading.

Comfort and protection:
The change in comfort and protection due to modern lighting could be quantified by crime statistics, deaths due to attacks of animals or the increase in number of visitors of markets at night. Also questionnaires about the sense of security and comfort at night, could provide information. The change of lighting technology comes with a measurable increase of lumens. However, this information will not tell much about the tipping point between feeling secure and insecure.

Convenience:
An attempt to quantify the increase in convenience can be made by multiplying the free time made available with a wage rate (GSVC, 2011). Expressing gains in convenience in lumens could be done by taking into account the light level during cooking before and after the introduction of modern lighting. However, the minimum amount that is needed for cooking is rather contextual.

Productivity:
One way to quantify the change in productivity is to identify the lumens used for the activity before and after the shift to modern lighting. Other options could be to measure the number of participants in the production process, number of hours working at night and the additional income generation activities.

Health:

A quantitative research on the reduction potential of particulate matter measures the exposure of

[6] Lumens is the SI unit of luminous flux, which is a measure of the total number of packets of light produced by a light source.

vendors in Kenya to particulate matter (Apple et al., 2010). The vendors switched from fuel based lighting to electric light sources to determine the particle sizes related to the lamp type. The exposure of the vendor to the particulate matter depended on the positions of the vendor and the lamp. The inhaled particle sizes depend on the lamp burn rate. It was discovered that the particle number concentrations for the sizes bigger than 1 μm produced by a simple wick lamp were 100 times more than from the other fuel based lamps. Only the small hurricane lamp had a similar concentration of $PM_{2.5}$ in the vendor shop as the simple wick lamp for particle diameters smaller than 1 μm.

In order to quantify the gain in health circumstances several indicators could be considered. The indirect measures are counting the days missed at school, work or the frequency of visits to the village medical professional. A direct measurement is the estimation of the intake of particulate matter of members of a household using equation 1 (Apple et al., 2010).

$$Intake_{Total} = B_{ambient} C_{ambient} t_{ambient} + B_{lamp} C_{lamp} t_{lamp} \quad (1)$$

where $B_{ambient}$ is the breathing rate when exposed to ambient background concentrations, $C_{ambient}$ is the ambient $PM_{2.5}$ concentration and $t_{ambient}$ is the time of ambient concentration inhalation. The remaining variables are similar to the previously mentioned variables in the equation, but then caused by a lamp. In this scenario the household has a small hurricane lantern with a burn rate of kerosene of 20 g/hr resulting approximately in a $PM_{2.5}$ concentration of 110 μg/m^3 (Apple et al., 2010). The breathing rate is 1.25 m^3/hr (EPA, 1991). Assuming households will light their room for 4 hr/day with a small hurricane lantern, would result in 550 μg/day additional intake of $PM_{2.5}$. Together with the intake of 24 hours of the ambient concentration, which is estimated to be 300 μg/day, means a total intake of 850 μg/day of $PM_{2.5}$ of which for 65% can be accounted to the hurricane lantern. This analysis shows the particulate matter intake by using the kerosene lantern and the potential reduction of PM intake when using modern lighting solution. The parameter values are underestimated as the concentrations used were measured in an open kiosk. In this evaluation however it is of importance that the lighting application usually is used in a closed room of a household. This means that the reduction of particulate matter is probably higher when shifting to clean lighting.

4 Off-grid lighting systems

As indicated in Chapter 3, the benefits of improved lighting lead to increased livelihood opportunities. For the rural consumers not connected to the main grid, improved lighting can be achieved by various means. An important part of a lighting system is the technology part. These are based on the lamp type and the lighting device. Another part of the lighting system is the delivery model that provides the lighting service.

4.1 Lamp types

Incandescent lamp

The incandescent lamp is one of the first electric lamps used in off-grid lighting. It consists of a glass bulb filled with an inert gas (IEA, 2006). A wire filament between a positive and a negative electrode within the bulb is heated. Electrons within the metal are excited to an higher energy level and heat up the metal. As the electrons return to a lower energy level light is emitted. The efficiency is low because the majority of light output is in the invisible infra-red. The low purchase price and common use in the world are its main advantages. However the disadvantage is the inefficiency and thereby high overall lighting costs.

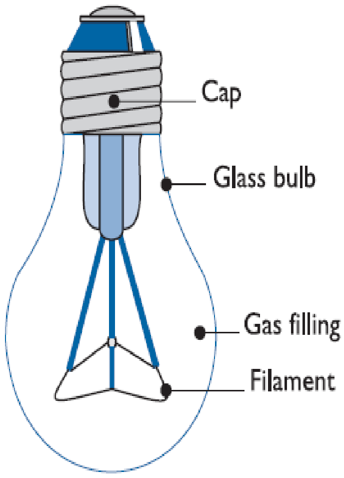

Figure 4: Schematic representation incandescent lamp (IEA, 2006).

Compact Fluorescent Lamp (CFL)

The CFL is 4-6 times more efficient than the incandescent lamp. The CFLs consists of low-pressure gas discharge lamps filled with a noble gas and mercury vapour. Electricity flows through the electrodes and releases electrons brought to a higher energy level into the surrounding gas. Electrons flow across the mercury gas that brings other electrons into a higher energy state. As the electrons return to their original state light is emitted Less heat is generated compared to the incandescent lamp, which results in a higher efficient light. The high energy efficiency ranges from 35 to 80 lumen/W for CFLs.

Figure 5: Compact fluorescent lamp (Statepower, 2012)

Light Emitting Diode (LED)

The majority of the off-grid lighting manufacturers are designing and producing their products with LED technology. The construction of the LED is schematically shown in Figure 6. The LEDs are based on the emissions of photons of light. Figure 7 shows the built-in potential V_o preventing the electrons from diffusing from n^+ to p side. The applied bias reduces V_o and thereby allows electrons to diffuse in the p-side. Recombination around the junction and within the diffusion length of the electrons in the p-side leads to photon emission. The energy derived from the recombination of electrons and

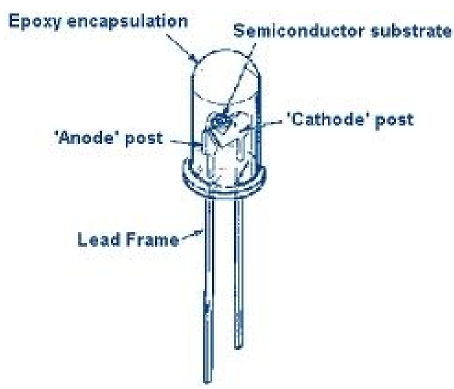

Figure 6: Schematic representation LED (Merg, 2012).

holes at the p-n junction of a semiconductor material is emitted as light. Currently Silicon is widely used as the semi-conductor material for LEDs. The advantages of the LEDs are the energy efficiency and the longer lifetime (Khan and Abas, 2011; Muller and Kamins, 2003). Both reducing the total costs over the lifetime of the LED compared to CFL or incandescent lamps. The LEDs efficiencies ranges from 50 to 140 lumen/W (Gaur and Thakur, 2010).

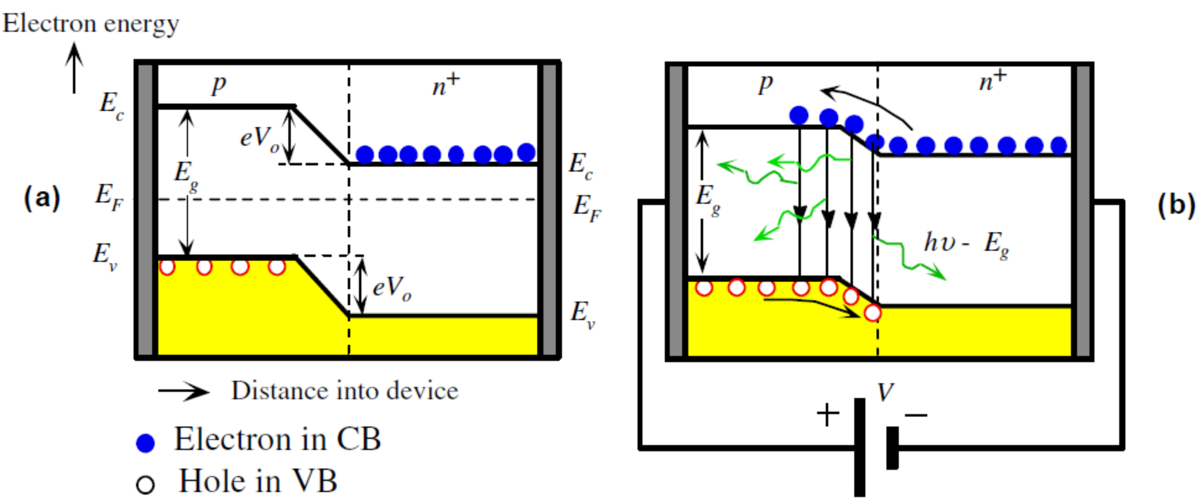

Figure 7: The energy band diagram within LED a) without applied voltage. (b) with applied voltage (Kasap, 2001).

4.2 Lighting products

The incandescent, CFL and LED can be used in different lighting devices. The first possibility is decentralised generation of electricity, which can supply the lighting at the regional or village level. Another option are stand-alone systems on the household level or application level that can provide lighting solutions for the household, shop or school.

Multi-user devices

Decentralised generation of electricity is distributed to multiple users or the whole community. The generated electricity can provide modern lighting using the lamps. The mini-grid is schematically shown in Figure 8. In this paper a 100 Wp to 10 kWp is considered to be a micro-grid. The mini-grid are defined in the power range of 10 kWp upto 1 MWp. The power is generated at an entrepreneurs shop or house and provides the electricity to neighbouring households, social institutions or shops (Worldbank, 2008). In the case larger load factors are needed such that dispersed settlements can be serviced, alternate current[7] (AC) needs to

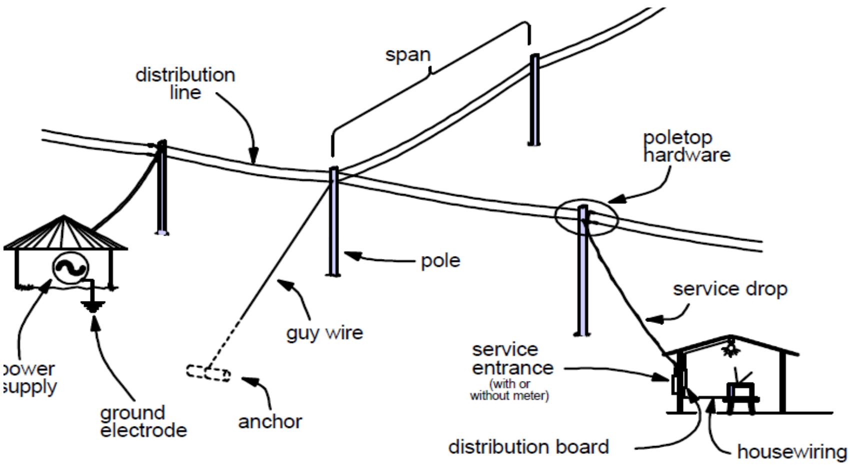

Figure 8: Schematic representation mini-grid (NRECA, 2000)

[7] Alternate current is the movement of electrical charge that alternates its direction. Direct current (DC) flows in one direction. AC main advantage is that the distribution losses are lower as it is related to the square of current.

be provided by the mini-grids. Moving to larger systems means that different resources are attractive to drive the mini-grid, such as hydro and biomass.

Solar Lanterns

The solar lanterns are considered to be small lighting sources having the application of torch, ambient lantern and task light. The ambient light/round lanterns are used to light up a large area such as a room. It can support social gatherings, specific tasks or lighting up a shop. The characteristic is that the lantern has a wide beam up to 360 degrees. It is usually easy to carry around which enables the end-user to move safely through the village. The torch (i.e. flash-light) is a small hand held portable lighting device that has a narrow and strong lighting beam. It is used at night to move around the village or when one is looking for something specific. The task/study light is used for a specific task requiring a narrower beam of focused light. Examples of the lanterns are given in Figure 9.

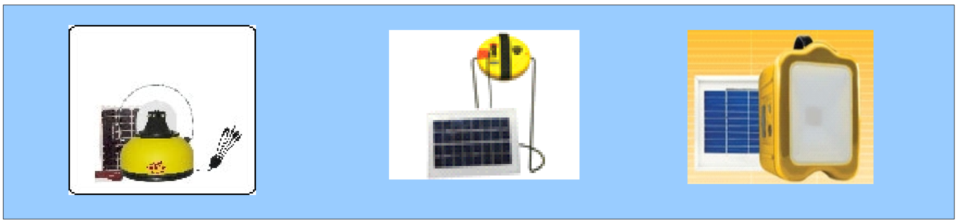

Figure 9: Examples of lanterns respectively ambient lantern (Gautum Polymers, 2012), task light (GreenLight Planet, 2012) and a torch (SunTransfer, 2012).

These systems are usually stand-alone systems at the household level or application level and can provide light for households, shops or schools. These systems may have separate power generating components such as outdoor photovoltaic panels and small wind turbines or built-in power sources such as photovoltaic panels constructed into the body of the lantern. The different components of the lanterns are the casing, the battery, the Printed Circuit Board (PCB), the lantern and the photovoltaic (PV) panel. The contemporary solar-lanterns often include a mobile phone charging option.

Solar Home Lighting System (SHLS)

The SHLS provides the household with multiple lighting points and typically has additional power points for mobile phone charging as shown in Figure 10. The larger systems can also provide

Figure 10: Solar Home Lighting System (Barefootpower, 2012)

sufficient energy for black and white televisions. The lighting points could be a set of LED lights or multiple lanterns. This system is ideal when multiple rooms in a household need to be lit up. A typical SHLS consists of multiple lighting sources, a battery, distribution wires, a junction box and a PV panel.

Disadvantages of the small-scale stand-alone systems are the low-capacity factor, excess battery costs and finite capacity. The latter implies wasting extra energy generated beyond the total capacity. The main advantage of the mini-grid is a better exploitation of the energy resources. Also, utilization of the power generating equipment is higher compared to stand-alone systems.

4.3 Delivery models

The delivery models for off-grid lighting products are either business models[8] or participatory models[9]. A distinction in off-grid lighting delivery models can be made between small-scale solutions and large-scale solutions for power generation (Palit and Chaurey, 2011). This is the main division between the delivery models discussed in this section and shown in Figure 11. Implementation models can be driven by different stakeholders: by regional governments in order to increase economic activity, by communities looking for access to modern forms of energy and by private entrepreneurs creating for-profit energy businesses (Krithika and Palit, 2011).

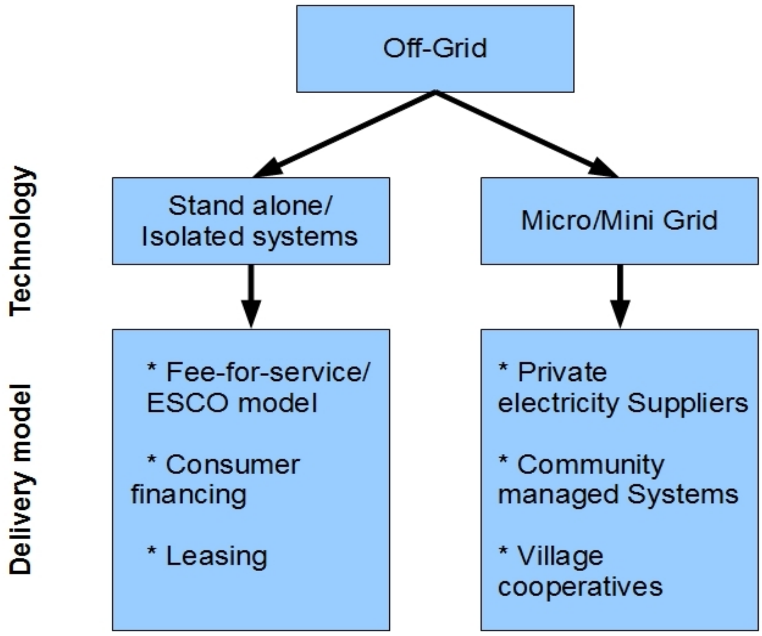

Figure 11: Delivery models for off-grid technology based on (Krithika and Palit, 2011).

Different challenges and opportunities apply to different mechanisms, also different social and technical scales are involved. The insights obtained from the use and implementation of SHLS projects are not directly relevant for understanding an alternative model including a mini-grid system as there are different social organisations and institutional frameworks required. Therefore, different delivery models should be considered when deploying the different solutions. These have been schematically illustrated in Figure 11 where the different implementation mechanisms are named per technology size. The delivery models are elaborated further in the next paragraphs.

Stand-alone/Isolated systems

In Figure 11 by consumer financing is meant that solar lanterns or SHLS are obtained by cash sales through dealers with or without commercial banks. Other delivery models for isolated systems are

[8] The business model for an off-grid electrification project is basically an overall framework within which the project operates including the choice of technology, financial viability of the model, institutional set up, role of various stakeholders and the regulatory&policy framework. In a business model, the underlying motive for an investor is profit which assumes central importance.

[9] In a participatory model the underlying objective is to create access to a lighting service or electricity through sustainable partnerships with the local communities. Participation of the communities is the centrepiece in a participatory model.

the fee-for-service model and leasing arrangements. These delivery models are further elaborated below.

- **Fee-for-service/ESCO models**

The local energy service companies (ESCO) owns, installs and operates electricity systems and provides other energy services to consumers (Lemaire, 2009). The company or village level entrepreneur (VLE) is responsible for repair and maintenance of the systems and providing replacement parts over the life of the service contract. The users/beneficiaries are charged a fixed monthly fee or the consumers lease the equipment for a fixed rental fee, which is why the model is also known as fee-for-service model. In this model either the ownership of all hardware is with the entrepreneur and users rent the charged solar lantern every night or the users own the lantern and pay a fee for charging the lantern (Chaurey and Kandpal, 2009).

Example: In Zambia, some of the challenges in servicing remote rural areas have been the long distances from power stations, low population densities in rural areas, high poverty levels, availability of technical skills, stormy weather conditions, vandalising of electricity infrastructure, lack of awareness of alternative technologies and the high initial costs of decentralised technologies (Haanyika, 2008). In order to address these challenges, ESCOs have been setting up the distribution of SHLS. The ESCOs have requested the government to no longer donate the PV systems, but to sell them to the ESCOs over a 20-year period. The ownership is transferred at the end of the sale. The PV systems are installed for a fee by the ESCOs at households and small shops. In addition a monthly payment is made by the end-user to the ESCO.

Initially a diverse group of end-users were served by the ESCO, but a study stated that many farmers and entrepreneurs have withdrawn from the scheme (Lemaire, 2009). This was due to the irregular income streams of this group of consumers and the scheme was not designed to take that into account. Therefore the ESCO in Zambia has catered mainly for civil servants as they had a steady income stream. Table 2 shows strengths and weaknesses of the fee-for-service delivery model.

Table 2: Strengths and weaknesses for fee-for-service/ESCO models

Strengths	*- The end-user does not have to raise capital upfront, as the ownership rests with the entrepreneur/ESCO* *- Customer service can work well as the responsible entrepreneur/ESCO is in the vicinity of the consumer* *- If centrally organized, the ESCO can obtain favourable financing terms from donors, market based credit organizations, which could result in lower tariffs for end-users*
Weaknesses	*- Risk of limited number of technical service personnel in the distribution channel* *- Theft risk is carried by the ESCO/entrepreneur* *- Withdrawal of end-users or short contract period can lead to loss of capital of the ESCO/entrepreneur* *- Irregular income end-user leads to inconsistent service level of lighting in household*

- **Consumer financing/Leasing/Micro-credit**

The lighting solution can be obtained by consumers by buying the product through the rural retail network. The direct sale is facilitated in a village or region, when a manufacturer expands its range and actively promotes his products. A pre-requisite is that the target households have sufficient funds to buy the lantern/SHLS from the shop or manufacturer. The uptake of the technology can be enhanced when manufacturers apply for a subsidy from the government. This can result in lower investment cost for the end-user.

In the case that the household does not have sufficient funds to buy the lantern/SHLS directly or is not willing to pay the price, financial arrangements should be facilitated. Credits should be made available by financing institutions. The rural consumer could pay off the lighting device with monthly instalments. There are several reasons why rural banks could be hesitant in providing these loans. Firstly, the investment for small-scale systems like the solar lantern/SHLS gives low returns on investments (Khanna, 2012; Mohanka, 2012). Secondly, the rural bank is not familiar with solar products and therefore refrain from providing loans (Chaurey, 2012). Although some private companies or banks use the opportunity to enhance the uptake of lighting systems. The Grameen bank in Bangladesh provides loans especially for SHLS (Grameen Bank, 2012).

Example: In 2006, Aryavart Gramin Bank, Uttar Pradesh introduced the scheme of financing SHLS. Its mission is to overcome the problem of power shortage that is being faced by the public, particularly in rural and semi-urban areas and to exploit available solar energy as much as possible to preserve fossil fuel (AGB, 2012). The bank together with National Bank for Agricultural and Rural Development (NABARD) and the Government of India are disseminating the programme across India (Pillarisetti, 2011). The bank has designed the project in such a way that households can repay the SHLS within 5 to 7 years. It was able to negotiate with a manufacturer to reduce the price of the product. From the banks perspective it only takes around 5% of its loan portfolio minimizing the risk for the bank, while from the consumers perspective accessibility to financing solutions for clean lighting technology is increased. The strengths and weaknesses of the consumer financing delivery model are shown in Table 3.

Table 3: Strengths and weaknesses of consumer financing/leasing/micro-credit

Strengths	*- The users of the lighting solution become the owners of the product*
	- Low financial risk for the lighting solution provider
	- Control of type of product by the credit provider
	- Private sector competition could lead to innovation
Weaknesses	*- There is a high initial cost and a limited market potential*
	- Identifying proper financial institutions
	- Danger of absent after-sales service
	- For-profit companies could be initially dependent on support of government

Micro/Mini-grid

For the mini-grid the methodologies of implementations are through multi-stakeholder programmatic models, utility models, grant based models. These could be either community managed systems and village cooperatives or the commercial led models (UNDP, 2004).

- **Village cooperatives/community managed systems**

A cooperative is an enterprise, legal entity that is democratically controlled by its members (ICA, 2012). It promotes equal participation and empowers rural people to shape the course of local development. It is an alternative to public sector management or principally profit-motivated private sector. The involvement of the members results in a participatory approach to meet their common economic, social and cultural needs. In addressing the lighting needs, cooperatives can select different technologies to meet the energy needs. In the case of community managed systems a village energy committee (VEC) is created to manage a mini-grid based project. The energy is delivered to a single village or a cluster of villages. The difference in definition with the village cooperative is that the VEC is compiled of representatives of the local community, but it is not obliged to be registered under law.

Community-based mini-grid management mostly occurs if a mini-grid in isolated areas does not attract private-sector or utility interest. In this case, the community becomes the owner and operator of the system and provides maintenance, tariff collection and management services. This delivery model has the benefit that it increases community self-sufficiency and self-governance. It could provide operation, management and maintenance jobs in the community and offer the possibility to apply tailor made tariffs.

However, there are some challenges when setting up community based implementation. There is usually lack of technical skills to design, install and maintain the systems. The lack of business skills to develop sustainable tariff plans and additional added value to increase the positive outcomes. The availability of financial resources is often absent. In addition the lighting system is often vulnerable to the "tragedy of the commons"[10]. In order to prevent potential conflicts within the community demand side management (DSM) should be initiated. During the implementation of the lighting system introduction of individual meters or other methodologies to measure and limit the consumption of each user could address the regulation of energy use.

Examples: a) On Sagardweep Island in West Bengal, the solar mini-grids are operated by co-operatives societies formed by the people using the grid (Iyer et al., 2010). Billing, collection and the discipline in maintenance is done by the society which remits the collection to West Bengal Renewable Energy Development Agency (WBREDA). This initiative was taken by the state government and started a solar PV programme benefiting 30% of the 6000 families. A dozen mini-grids (25-28.5 kWp), each costing Rs. 10 million have been built and are supplying 4-6 hours of grid power. The project was financed through a government subsidy and a loan from WBREDA at one percent interest.

An increase in demand is observed after introduction of the solar mini-grids. More households want a connection and the demand by the households that already had a connection has also increased. Due to the modularity of the solar mini-grids they were able to adapt to a certain extent (Ulsrud et al., 2011).

b) The village energy security programme (VESP) is promoted by Ministry of New and Renewable Energy (MNRE) to set up VECs to manage off-grid projects at the village level (IRADE, 2007). A subsidy of 90% of actual system cost or Rs. 2.25 million per system per village of 100 households is provided by MNRE (Baker&McKenzie, 2008).

The community gets equity contributions in cash to bring in the ownership, required for success of community centric projects. Test projects by NGOs were better than those implemented by state departments when it came to social mobilization and leadership of VEC (Worldbank, 2011; Palit and Chaurey, 2011). Active involvement of Gram Panchayats[11] in projects helped in developing the required synergy in getting village development funds for VESP. These funds were used for project cost and operational expenses.

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[10] The tragedy of the commons is a dilemma arising from the situation in which multiple members of the community or group of individuals, acting rationally consulting their own self-interest, will deplete a shared limited resource. Despite that it is clear that it is not in anyone's long-term interest for this to happen (Hardin, 1968).

[11] At the village or small town level there is self governing structure, which is called Gram Panchayat.

In the majority of projects the uptime of the mini-grids was considered unsatisfactory as the utilisation factor was low. The challenges for the sustainability were found to be the less concentrated electricity demand in the villages, low economic activity implying lower electricity demand, less financial resources of the consumers, difficulty in operation and maintenance, limited technical knowledge of the VEC and weak fuel supply chain linkages in the case of biomass. From the literature and the examples of the village cooperatives and community managed systems the list of strengths and weaknesses is deduced and shown in Table 4.

Table 4: Strengths and weaknesses of village cooperatives/community managed systems

Strengths	*- Sense of ownership and accountability* *- Employment opportunities for local youth* *- Productive uses of energy supply can generate additional incomes for households*
Weaknesses	*- DSM absent* *- Sensitive to political interference* *- Productive end use applications essential on the village level, for sufficient revenue and sufficient load*

- **Private sector models**

Recent focus has been on scaling up off-grid energy services by involving private companies (WBCSD, 2012). It is considered to be the approach with the greatest potential, taking into account the capacities of private companies, the needs of consumers and markets of developing countries (Krithika and Palit, 2011). Due to the instability of the market and the associated high risk, the private-sector is not yet at its full potential when building rural energy infrastructure. In order to attract private investors/operators to mini-grid projects, information is needed on system location, scale, income profiles of potential customers and available subsidies.

A private-sector model can take different forms according to the type of contracts with end-users or the utility, and with the ownership of the system or the mini-grid, and the type of subsidies. The private-sector actors are looking for innovative ways to increase their market share and their profit, which can result in efficient delivery of electricity. Two private sector models are considered as appropriate delivery models for the lighting services.

Public Private Partnerships (PPP): A large number of private models implemented to date have used a private model paired with government resources to support their initiatives. These models develop a business plan with a financial model relying on government subsidies and is implemented privately (Krithika and Palit, 2011).

Purely Private Models: Lighting systems can also be implemented by a complete for-profit company, by introducing electrification through a mini-grid or disseminating lighting products. There are two primary revenue models: one which tries to profit from selling the lighting service to local consumers and another which tries to profit from capital costs of setting up off-grid energy infrastructure.

Example: A well-known private sector case is Husk Power systems in Bihar (Huskpower, 2012). The company uses rice husk as the main raw material to produce electricity. The biomass gasification plants use about 330 kg of rice husk per day to generate power for six hours of day. The users pay a monthly rate of Rs. 80-100 for a 30 watt connection, which is collected in advance by the Husk Power employees (Greenpeace, 2010). The cost of producing 32 kW of electricity is Rs.

22000. The owners expect to recover the cost of the investment within three years.

Initially, the company was built with the help of international agencies and government subsidies. Husk Power operates on the build-operate-distribute model with technical and equity support from international agencies. Husk Power has built its own distribution lines, with each line providing a fuse to prevent excess use of households and power theft.

This model is replicable to other parts of the country as the system of Husk Power utilises rice husk that is abundantly available. Using a waste material as biomass feed helps to achieve cost-effective operations. The company has also integrated the system with other externalities, like carbon mitigation, encouraging customers to use energy-efficient CFL bulbs, selling the ash residue to incense stick manufacturers and also selling the rice husk char to solar panel manufacturers.

From the example and the description of the implementation models several strengths and weaknesses have been identified. These are presented in Table 5.

Table 5: Strengths and weaknesses of private sector models

Strengths	*- For-profit model can upscale if solution is viable* *- Single companies can become a driving force for initiating new projects* *- Innovations and ability to experiment can lead to new models*
Weaknesses	*- Risky investments, so few major investors other than social entrepreneurs are active* *- For-profit model could neglect community needs* *- Some dependence on governmental subsidy*

- **Hybrid models**

Combining different features of different models can lead to an improved hybrid business model. These solutions can be found in different forms, tending to adopt the different types of O&M contracts and combining different ownership structures. In order to illustrate this, two starting points can be considered. In some ways projects that do not have their origin in the private sector can attract a private actor which could generate sufficient cash flow for O&M and profitability. The projects can be built around existing business applications or public institutions in order to reach a critical mass, increase profits and local involvement. An alternative would be to support the development of a local private sector by concentrating energy loads or bundling projects together in attractive packages.

An example is Sunlabob in Laos, which plans to expand its local distribution network and connect it with a nearby grid in order to attract the interest from the utility (Sunlabob, 2012). Sunlabob has realized that small hybrid grids are an attractive addition for the main grid since they include existing generation infrastructure and social organization. Thus, if the grid gets connected the project could switch from a mainly private sector-based hybrid business model to a mainly utility-based hybrid model.

5 The Indian context

The off-grid lighting systems are considered in the Indian context. Therefore understanding of the local conditions are of importance. This will further limit the options of the lighting system in order to select the most appropriate.

5.1 Local conditions

Expenditure end-users

Income disparities between urban and rural household do to a certain extent explain the energy choices and consumption patterns. However, these differences could also be attributed to the variation in the ease of access. Statistically it was shown that the expenditure level, nature of surroundings and the rural-urban divide are significant energy consumption determinants for households (Pachaury, 2004). There is a difference in energy requirements between urban and rural residents. The choices households make regarding their energy use are dependent on their different socio-economic status, access and availability of resources. The average urban household has higher energy needs in every income decile class compared to the average rural household. The access to fuels and higher expenditure levels are the main reasons for fuel choices. The difference in indirect energy[12] consumption between households in different expenditure classes is much larger than the difference in direct energy[13] consumption.

The NSSO uses the monthly per capita consumer expenditure (MPCE) as the main indicator of the standard of living. The higher the share of expenditure of the households spent on energy, the higher is the vulnerability of the households to the prices of energy fuels. Although urban households spend more in absolute terms compared to rural households, in relative terms this is not so for every MPCE class. A UNDP report shows that the expenditure on fuels for cooking and lighting is not increasing with income (Gangopadhyay, 2003). Notably, the top percentile in urban areas has relative to their income lower expenditures as the lighting service is provided by the main electricity grid.

In the NSSO report of 2011 the spending capacity of Indian households is reported (NSSO, 2011). Estimates of the average MPCE in 2009-2010 gave Rs. 1053 in rural India and Rs. 1984 in urban India. The analysis of the linkage between the energy use and the economic affluence are based on the assumption that total household expenditures are an indication of the Indian household income (Pachauri and Jiang, 2008). Thus the per capita expenditure level of the urban population was on average about 88% higher than that of the rural population. The poorest 10% of India's rural population had an average MPCE of Rs. 453. The poorest 10% of the urban population had an average MPCE of Rs. 599. The top 10% of the rural population, ranked by MPCE, had an average MPCE of Rs. 2517 about 5.6 times that of the bottom 10%. The top 10% of the urban population had an average MPCE of Rs. 5863 – about 9.8 times that of the bottom 10%.

An illustration of the rural-urban divide can be observed when analysing NSSO data, which shows that although 72% of the households live in rural areas only 56% of these households use electricity as their primary source for lighting. Comparing this to urban areas 90% or more households use electricity as their primary source of lighting. In rural areas kerosene is mostly used to meet the lighting need (NSSO, 2008; Gangopadhyay, 2003). Many households in the survey have indicated that they use electricity as primary source for lighting supplemented with kerosene lamps. The data provided in this section endorse the energy ladder model as it shows the strong income dependence

[12] Indirect energy requirements are embodied in consumer goods such as food and services
[13] Direct energy requirements are in the form of natural gas, electricity and petrol

of fuel choices.

Table 6: Percentage wise division of primary lighting energy sources

Census	Electricity	Kerosene	Solar Energy	Other oil	Any Other	No Lighting
2011	*67.3*	*31.4*	*0.4*	*0.2*	*0.2*	*0*
2001	*60*	*39*	*0*	*0.2*	*0.3*	*0.4*

In Table 6 a comparison is made between the usage of lighting sources based on census data of 2001 and 2011. It shows that the primary lighting energy source is shifting from kerosene to an increase of electricity and solar energy. In the case certain rooms do not have a connection for modern lighting or the electricity grid fails, traditional lighting is the alternative. However, from this data it can not be deducted that households use kerosene as a secondary lighting source. Poorer households face a higher financial burden in meeting their energy needs (Jain, 2010). This decrease in access to modern fuels has as a consequence energy poverty. This acts as an obstacle to an improvement of the income level, as energy provides a basis for economic activities. This creates a vicious cycle of income and energy poverty.

Culturally acceptable

The market acceptance by end-users can be achieved when taking several specific aspects of the implementation of different lighting systems into account. Firstly, expectations should be aligned with the delivery of the energy service provided. Villagers in Tamil Nadu were disappointed with the light output and overall functionality, which led to the rejection of the technology (Dekker, 2007). In the same line solar PV lighting introduced in a village in China was not accepted by some families as there was a limited level of applications (Yuan et al., 2011).

Secondly, one must take into account the tradition and hierarchy present in the region/village where the modern lighting technology is introduced. There have been observations in rural areas of India that delivery models have failed because of caste relations in the village (Jaisinghani, 2012; TERI, 2012a). A lower caste was not allowed to cross a line in the village. In Papua New Guinea a field survey in villages where the modern lighting was introduced, showed that one of the reasons for failure was the sense that everything belongs to everyone (Sovacool et al. 2011). People feel very connected to their tribes and clans and the introduction of modern lighting in an individual household or community was sensed as an intrusion. During a field visit in Odisha villagers were encountered who refused to pay. The argument was that the sun is a common resource and all people share the same sun, so why should there be a financial transaction. In a field survey executed for TERI the suggested ideal operating conditions were not being followed. This led to lower overall performance of the lighting system.

Thirdly, often the technology is still unknown and differences between good quality products and poor products are not known (Dekker, 2007). Therefore education on the lighting solution should be part of the implementation mechanism (Chaurey, 2012).

Lastly, there have been indications that the shape and form of the lighting technology can enhance the acceptance. In the context of Ethiopia, users have preferred dark coloured lanterns as the dirt can hardly be noticed, or certain colours are negatively associated with a political party (Müggenburg, 2011). A preference in this report was also noticed for lanterns that were similarly shaped as the kerosene lanterns that they had already used .

Policy environment in India

There have been several policies in place in the last few years that have pushed the need and priority to promote renewable energy. The majority of acts focus on the generation by renewable means and the obligation of the state to buy generated electricity.

These policies have been set out by the central government of India, but there is still a degree of freedom in the implementation on the state level. The state government can set the feed-in tariffs and degree of subsidy that could apply to a certain solution. Initiatives to disseminate renewable technologies are done by state level organisations, which are usually renewable energy development agencies. The first four policies in Box 1 support mini-grid lighting systems as these generate electricity. An added benefit is that mini-grids are more viable with these policies as there is a future option to become on-grid and sell the excess electricity generated. Also part of the policies are exemptions of concessions. The JNNSM described in Box 1, provides financial support to lighting solutions that are based on solar. These policy acts and missions of the central government are not directly supporting lighting services however they do support the feasibility of off-grid lighting projects in India.

Box 1: Indian policies increasing viability projects

National Electricity Policy 2005: Allows SERCs to establish preferential tariffs for electricity generated from renewable sources. The National Electricity Policy 2005 stipulates that gradually the share of electricity from non-conventional sources would need to be increased; such purchase by distribution companies shall be through a competitive bidding process; considering the fact that it will take some time before non-conventional technologies compete, the commission may determine an appropriate price adaptation to promote these technologies (Singh and Sood, 2011).

National Tariff Policy 2006: Mandates that each SERC specifies a renewable purchase obligation (RPO) with distribution companies in a time-bound manner with purchases to be made through a competitive bidding process.

Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) 2005: Supports extension of electricity to all rural and below poverty line households through a 90% subsidy of capital equipment costs for renewable and non-renewable energy systems (RGGVY, 2005).

Eleventh Plan 2007–2012: Establishes a target that 10% of additional power generating capacity shall be from renewable sources by 2012 (a goal that has already been reached); supports phasing out of investment-related subsidies in favour of performance-measured incentives.

Jawaharlal Nehru National Solar Mission (JNNSM): The MNRE has launched the JNNSM in the month of January, 2010. The Government of India will provide the subsidy of 30% of system cost. 20% of system cost is to be borne by the user as down payment. 50% of system cost will be available from the bank finance with low interest loan through NABARD (MNRE, 2010).

These policies have resulted in some successful implementations. Solar energy has reached 3600 remote villages/hamlets, including those in Sunderbans, Bastar, Ladakh and the North-East (Sharma et al., 2012). These policies contributed to the scaling up of renewable energy, but the exact improvements in livelihood are difficult to measure. However, the different actors participating in the implementation of various policies have in some cases been hampering the market of solar lighting (Natarajan, 2012). For example, the introduction of JNNSM in Karnataka through NABARD, disturbed a functioning solar lighting market for several months, through unclear procedures and responsibilities. There is an indication that policies are enabling implementations, but when they are not carefully implemented they inhibit dissemination efforts of solar lighting solutions.

Resource availability

In the case of the dissemination of a lighting solution for the rural end-users, different resources can be considered. The most abundant energy resource on earth is solar energy. It is available for us through solar radiation and indirectly through wind, biomass, hydro and others. India has a good environment for the utilisation of this solar energy as shown in Figure 12. In the majority of regions the solar radiation is between 4-7 kWh per square meter and there are 250-300 sunny days per year (Kumar et al., 2010).

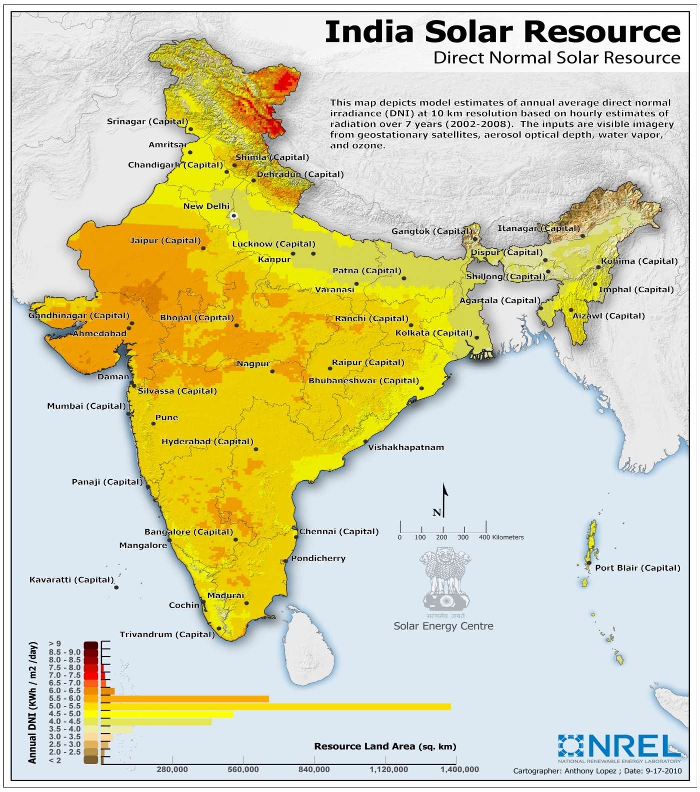


Figure 12: Indian Solar Resource Map (NREL, 2012)

Another option that can be considered is hydro-power. The potential of off-grid small-scale hydro-power has been estimated at 15 GW (Saxena, 2012). This estimation is based on the potential of Small Hydro Power (SHP) in the Himalayan states. Here the dominant energy source is the run of the river based model[14]. In the estimation of the suitability of SHP for off-grid lighting delivery two things must be taken into account. First, there must be sufficient demand for electricity generated. Secondly, there must be sufficient discharge and head[15] to be a feasible option for a project implementation.

Biomass resources are suitable for energy production using a wide range of materials, from firewood collected in farmlands and natural woods to agricultural and forestry crops grown specifically for energy production purposes. The resources are widely available, however the supply of the biomass to a gasifier is not as straightforward as expected (Kumar, 2012b; Mande, 2012). The delivery channels are not always effectively used and the seasonal availability of the resource should be taken into account. Another aspect that needs to be considered is when using biomass as a resource for lighting, the load factor of the plant has to be sufficient. In the case that the demand is too low, the plant operates with lower load, which is harmful to the gasifier. This is an issue as the energy demand for the lighting service alone in one village is too small to make the biomass plant feasible.

[14] The run of the river based model is the utilization of hydro-power by creating a diverted water stream from the river. This water is collected in a tank, which is elevated above the main river. Through a pipe the water is discharged and drives the watermill at the river level, which generates the desired power.

[15] Head is the height difference between the inlet (the water-tank) and the outlet (at generator level). The discharge is the flow of water that is redirected to turn the generator.

The majority of the generated electricity by wind is grid-connected and not used for decentralised generation of electricity or directly for the lighting services. The advantage of using wind power is that the cost per unit of electricity generated can be less than other resources available for decentralised power generation, but this is only valid when the estimated electricity demand is enough (Nouni et al., 2007; Nouni et al., 2010).

5.2 Solar most appropriate

Biomass mini-grids are highly dependent on technical skills and sufficient load to operate the gasifier successfully. Decentralised wind power is not yet in the stage to be widely implemented, similar to biomass sufficient load must be present to make the lighting systems feasible. Large and small-scale hydro-power are mature technologies, but are highly dependent on the geographical location of the need for lighting. In addition hydro-power requires sufficient load to be feasible.

In India there are a lot of sunny days and the intensity of the solar radiation is high. From the resource perspective solar seems to be the most appropriate for the dissemination of the lighting devices. An advantage is that the solar solution can be scaled to the need, because the number of PV panels can be varied accordingly.

The following reasons favour the solar resource for lighting:

- The lighting solutions are modular and therefore scalable to the need of the end-user.
- The availability of the solar resource is the most reliable.
- There are no additional costs for delivering the resource.
- Minimal amount of maintenance is needed as the lighting solutions based on solar hardly uses moving parts.
- In the majority of the used solutions for remote rural areas the energy is generated at the point of use, minimizing the need for transmission lines.
- Availability all over the country.

The remainder of the thesis will focus on lighting systems based on solar PV, either in stand-alone implementation or as part of a mini-grid.

5.3 Solar Challenges

Important challenges need to be addressed in lighting systems based on solar PV. These are the high investment costs, limited power demand and the awareness of the options and the use. In this section these challenges are introduced and the remainder of the thesis will consider solutions to overcome these challenges.

High investment costs

From the implementers perspective large capital investment is needed to set up projects for mini-grids and LaBL. An implementation of LaBL for 50 households has a total cost of Rs. 200000 for hardware, training and O&M (Prashant, 2012). The hardware of a solar mini-grid of Mera Gao Power (MGP) costs per household Rs. 1500-2000 (Jaisinghani, 2012). The solar mini-grid also provides the option of mobile phone charging. The total investment for the project implementer is Rs. 100000 for servicing 50 households .

Limited power demand

The operation of a lighting product does not require a lot of power. This means that a project only focussing on lighting must deal with excess power generated. This power could be diverted for other productive purposes or lighting points could be provided to multiple settlements.

Awareness

There is limited awareness of the technologies available. An anecdotal observation made in many rural areas is that lighting appliances are not used efficiently. Lighting sources are left on during the day-time or at night and households still use inefficient incandescent light bulbs. This results in a reduction of the economic benefit for the households. So together with the cost advantages of mini-grid electricity or other modern lighting solutions, complementary services should inform the households about the proper use. The households can then benefit fully from the saving potentials of a solar lantern or mini-grid connection.

6 Stakeholders criteria modern lighting systems

The different stakeholders in the Indian context have different ideas and demands of the lighting systems. First of all, ideas of the stakeholders on the lighting systems are presented. Followed by an overview of the criteria of the lighting products and concluded with the criteria of the delivery model.

6.1 Stakeholders in modern lighting systems

The success of project implementations, business models or retail channels is dependent on its stakeholders. The delivery model is characterised by the different information, capital and product streams. There is a capital flow, which is considered to be the financial support through subsidies and financial products like loans and credits. There is a product flow of the lighting device and corresponding spare parts and there is an information flow between the stakeholders. The latter enables the stakeholders to tune their policy decisions, product improvements, financial solutions and their implementation strategies. Ideally this feedback leads to the acceleration of the uptake of the chosen lighting solution.

Governmental body

In this analysis, the MNRE is considered to be the government body responsible for development of light applications in remote rural areas.

Opinion on method of lighting remote rural areas:

The interviewees from MNRE all feel that connection to grid electricity is the goal for every household in India. The point of view is that solar lanterns and SHLS are temporary solutions. Decentralised lighting systems are only to be implemented if they have the option to connect to a future grid extension.

Three preferred systems of delivery have been identified by the government, the fee-for-service system, village cooperation with government subsidy and PPP. They all have their advantages and disadvantages and must fit the local circumstances. In order to successfully address the implementation of decentralised lighting system projects, the central government facilitates technological training on ITI level[16].

There are already support mechanisms available through policies and laws in place, which should enhance the dissemination of the solar lighting technologies. Examples of these are: the possibility to sell the electricity to the grid, concessions on imported items, central excise duty tax, fixed tariffs and accelerated depreciation of installed projects.

Opinion on financing lighting in remote rural areas:

The financing of lighting in remote rural areas is often accomplished through subsidies. To make it economically attractive different subsidies have to bridge the gap between expensive technologies and poor customers. Financing is considered to be essential for uptake and there should be sufficient rural banks that provide seed capital for new businesses in the off-grid lighting sector. There must be more institutional support in place to provide incentives for these banks to accomplish an increase in lighting product businesses. The support can be provided by other partners, market players and NGOs. It is still a problem that banks do not find the companies credit worthy, which is

[16] ITI stands for Industrial Training Institutes of which around 5000 are present in India. Improving their skill level would be a channel of advancing India's technical/manufacturing capabilities.

partially caused by the unfamiliarity with the renewable energy technologies. To familiarise the banks with the technology, they should be engaged in the development of renewable technologies.

A solution proposed by MNRE is to refinance renewable energy through NABARD or by creating off-grid initiatives with financial support from the government. An example of the latter is that the banks will see the credit worthiness of these initiatives and subsequently might be willing to provide loans.

Opinion on type of solution for lighting in remote rural areas:

A problem of the Indian PV market is that R&D and production of PV cells is not fully developed and still the majority of PV panels in India are developed in China. It was opined that people do not initiate R&D, although it would bring down the costs. Somehow people and institutions do not feel the urge to invest in this technology.

The selection of the delivery model is challenging, because it is not an easy to task to fully understand the specific demands and needs in remote rural areas. It was opined that decentralised generation are temporary solutions, and mini-grid implementations can only survive if it is connected to the main grid. The chosen solution must be made configurable such that it can connect to the grid.

Financial Institutions

A financial institution interviewed is the Aryavart Gramin bank. This bank provides the financial means to buy a SHLS. It has set up contracts with a manufacturer, which enables them to address a scheme that takes into account the purchasing power of the poor.

The other financial institution interviewed is the Small-Scale Structural Infrastructural Development Fund (S^3IDF) based in the state of Karnataka. They provide the pre-investment to the entrepreneur, which makes the business plan of the entrepreneurs become more attractive to the rural banks.

Opinion on methodology of lighting remote rural areas:

Aryavart Gramin bank stresses the importance of understanding the circumstances related to the financing options, selling points, technical support and availability of lighting services. The bank stressed that creating awareness is an important aspect. On one hand within the villages through demonstrations in cooperation with teachers, existing customers and village heads. On the other hand it is needed to get the banks to understand that renewable technologies can be a viable market. Therefore, it is important to find the right incentives for the banks, and find ways for companies to participate and address the budget of their CSRs[17].

Besides that a manufacturer must be found who can support a product which is in the customers interest. It has to be an affordable, reliable product which includes a fair warranty and guarantee. If sufficient scale is reached, it could become attractive to provide more sales and service points.

The perspective of S^3IDF is that there should be a real pro-entrepreneur model which initiates projects for small improvements in the energy services. The financial means of these entrepreneurs must be achieved through investors like S^3IDF and regional rural banks (RRB). A clear understanding of the local situation is essential and therefore multiple small-scale initiatives are the

[17] CSR stands for corporate social responsibility, especially large companies reserve a percentage of their profit to invest in a social need.

methodology to go forward. At the moment only social entrepreneurs are active in this market, they do not have the direct goal to make money but instead look to address a social need.

Opinion on financing lighting in remote rural areas:

Financial institutions must be in place to support payments in instalments. The Gramin bank provides medium term loans repayable in 5 to 7 years for the purpose of implementing SHLS. These loans can be paid in Equated Monthly Instalments (EMI), after an initial down payment, 60 months of payments are required to repay the loan. The view is that the renewable energy technology has to be financially more attractive than other lighting solutions lower on the energy ladder.

Two suggestions in financing are made to upscale the dissemination of the lighting technologies: improving the accessibility to financial options for end users and by economies of scale to bring down the cost. The latter is achieved by having a preferred partner for delivering one lighting solution. The benefits are the revenues of carbon credit earned by the bank along with the incentives received from MNRE, Government of India. These can be used for after-sales service, maintenance of the systems financed, publicity, creating further awareness and employment opportunities for local youth.

According to S^3IDF, funding for small-scale infrastructural development should be done independently of the government. Therefore, banks must gain trust in these small enterprises. The distrust is caused by the unfamiliarity with the technology and how the enterprises are organised. Solar power that is grid connected is provided a Power Purchase Agreement[18] (PPA) with a term of 25 years, while the off-grid solar lighting solutions are required to be paid of in 5 years, even if the load might be the same. The problem is that it is viewed as a small individual investment with a high credit risk, rather than an infrastructural improvement. Therefore, there is a need to send a signal of trust to the rural banks.

Opinion on type of solution for lighting in remote rural areas:

Aryavart Gramin bank has the aim to provide SHLS where the grid is not present or where the electricity supply is erratic. They have identified challenges in creating demand, awareness, proper after-sales, repairs and maintaining the systems. The methods have been considered a success and NABARD issued a circular to RRBs to replicate the scheme of the bank.

The bank focused on promoting SHLS as it brings certain advantages from the perspective of the bank and the customer. The bank was able to make a deal with a preferred supplier, which brought the cost down and made technical support in the region more feasible. On the other hand, a disadvantage of having one partner could be the inability to meet customer specific demands.

NGOs and Non-profit organisations

The opinions of the NGOs are based on interviews within TERI. For a perspective outside India an interview has been conducted with a representative of ETC Netherlands.

Opinion on methodology of lighting remote rural areas:

From the perspective of TERI the promotion of modern lighting systems must be done in a sustainable manner. This sustainability is done through capacity building, improved after-sales

[18] Power Purchase Agreement is an agreement on the price that is paid by the utility to the power producer for a number of years.

service and the simplicity of the model.
There are several options for the LaBL campaign to start in a certain village. For example, a local NGO can initiate the campaign in a village and after several criteria have been investigated by TERI before the project is started. These criteria are: in which past activities has the NGO been active, what was the length of presence in the area and what type of funding was used. The aim is to obtain an agreement between the local stakeholders and the NGO for 3 years.

ETC Netherlands gives advice on energy services and is supporting local businesses and NGOs in the developing world in addressing energy services. ETC claims the most significant improvements can be found in scaling the business models.

Opinion on financing lighting in remote rural areas:

As part of the programs of TERI the financing comes from different sources. Firstly, companies donate a percentage of their profit as part of their CSR campaign. Secondly, as part of different Indian policies a percentage of the project cost is funded by the Indian government. This can come down to Rs. 81 per Watt (Prashant, 2012). Thirdly, individuals can sponsor a household or a family. Fourthly, to give ownership to the individuals and the community a percentage of the price of the lighting solutions must be borne by the end-user or indirectly by the community. The price of the lantern is Rs. 800. Partly the price is paid by the household, partly paid in instalments and partly funded by donations. Observed trends of the small-scale lighting solutions are the better affordability of the technology and a shift in focus on transaction enabled services.

Opinion on type of solution for lighting in remote rural areas:

There is no real preference stated in what type of solution should be used for lighting. TERI promotes the solar lanterns and the mini-grids driven by solar. The choice of selection depends on the local condition.

Entrepreneurs

In the LaBL concept the entrepreneur is selected by the community/local NGO or TERI, while in TERI mini-grid implementations the entrepreneurs are the one who come forward to initiate the project. In MGP the entrepreneur is the owner of the company that delivers solar mini-grids to villages meeting the social need of lighting and mobile phone charging.

Opinion on methodology of lighting remote rural areas:

In a village where both the LaBL project and a mini-grid was deployed, entrepreneurs and end-users preferred the mini-grid solution as there are several advantages to it: the possibility to have regular payments once a month, less work for the entrepreneur and battery charging is done centrally.

The entrepreneur responsible for the mini-grid stressed the importance of the exemption of the license for off-grid energy provision. A desire was expressed to see the exemption of concessions extended to areas where electricity supply is erratic. As this would enlarge the market opportunity and create growth opportunities. There is a marginal profit per household so the profit must be made by increasing sales volume. Therefore, the model must be simple and cheap. The entrepreneurs find the effort to obtain the subsidy too costly to be worth while. The entrepreneurs generally only consider applying for subsidies when a sufficiently large number of mini-grids can be implemented or sufficient solar lanterns can be sold.

Opinion on financing lighting in remote rural areas:

From the entrepreneur's perspective the investment made is a costly affair and they would like partners who could share the risk. Partnering with MFI is not considered attractive as a large part of the revenues go to the MFI. The pay structure of the users of the mini-grids is a weekly or monthly fee and they have to pay a certain amount for getting a connection. There were cases observed where the entrepreneur does not put money aside for urgent maintenance issues.

Opinion on type of solution for lighting in remote rural areas:

The entrepreneurs all point out that their solution is a better option than the main grid of India, as it is cheaper, more reliable and of better quality.

For other solutions like biomass, wind and hydro to be successful, sufficient scale is needed. This would imply that the project needs to become larger and subsequently more complicated. Sufficient support is then needed to implement such projects and the entrepreneurs spoken to, consider themselves too small to focus on these technologies. Therefore, solar is in their opinion the most appropriate. It is is also the cheapest option for small-scale clean lighting implementations. To make the other technologies more attractive it is important to enable them to connect to the grid on a fixed tariff. If a simple solution is chosen, it must be cheap enough to be within the price range that villagers are willing to pay.

Manufacturers

The manufacturers that were interviewed are mainly in the domain of solar lanterns and SHLS.

Opinion on methodology of lighting remote rural areas:

All the manufacturers realise the importance of after-sales service and try to provide it through a local technical service provider. These are entrepreneurs that are trained by the manufacturer or a technical partner in the region. The solutions that are needed should be simple. It is opined that the the distribution of the products are not really a problem. The entrepreneur is creative enough to find ways to bring the lighting appliance to the customer. The different manufacturers indicate that the accessibility to financing and creating awareness are the real challenges. The advantage of having a VLE in the distribution channel is that it supports raising awareness for end-users of lighting applications. A threat caused by using a VLE is that they can obtain a monopolistic position, which can drive up the cost of after-sales services.

Several of the manufacturers partner with preferred NGOs that will guarantee them a reasonable market share. They seem to prefer business models without subsidies as the business must be sustainable without grants. The manufacturers expressed a preference to do business without the support of the government. The market can not wait on the policies, as the application is an administrative bureaucracy. They would like to react to a changing market and the policies are simply too slow. The manufacturers do see a role for the government to assure the quality of products.

Opinion on financing lighting in remote rural areas:

The manufactures state that they keep the costs low for the end-user, but that they largely depend on the remoteness and the implementation mechanism chosen. The problem of financing is primarily that of lack of trust in the solar lighting. It is still considered as a weak product. Banks simply do not have faith in the technology. So they suggest that financial intermediaries are needed in order to guarantee secure investments.

Opinion on type of solution for lighting in remote rural areas:

The production of the SHLS and solar lanterns is done differently by the manufacturers. As the objective of the interviewed manufacturers is to address a social need, they prefer to construct/ assemble the solar lighting solutions locally and bring the cost down by re-using multiple components across designs.

All the manufacturers indicate that improvements in the battery can lead to greater acceptance by the end-users as costs would be reduced and there would be longer light provision. Also the manufacturers try to look at inclusion of other functionality alongside the solar lighting solution, like mobile phone charging or by including weather data for farmers. This added value makes end-users willing to pay more for the technology. Also, the improvement of LEDs have made the products cheaper and financially more accessible to the end-user.

End-Users

The end-user interviewees were users of mini-grids, solar lanterns, SHLS and the non-users. A general perception from these interviews was that they were satisfied with the solution provided. However, experiences from staff of TERI tell a different story. Problems that were identified ranged from technical issues of the solution to not willing to pay for solutions like fee-for-service.

Users that had positive experiences with their lighting solution indicated that they still want more energy services in addition to lighting. Also, it was found that when performance of lanterns or mini-grids decreases during winter, there is an increase in the use of kerosene.

Opinion on methodology of lighting remote rural areas:

The end-users that were interviewed had a preference for the implementation of the mini-grid technology, because the lighting service did not require bringing a lantern to a solar charging station (SCS). Also from the entrepreneur's perspective it was expressed that it is less effort to maintain and collect the money. Once a mini-grid is in place, it generates interest from people who see it work. A prerequisite for the entrepreneur before extending the mini-grid was that sufficient households or shopkeepers are willing to participate.

Opinion on financing lighting in remote rural areas:

The end-users that were interviewed had a willingness to pay for improved lighting. From interviewing non-users, the desire was expressed to have improved lighting if they could afford it. They would like to use it for studying and cooking in those hours.

Opinion on type of solution for lighting in remote rural areas:

In the interviews it became apparent that the people like the solutions provided. This is illustrated by the fact that more people want to participate once they have seen the lighting solution operating. Lanterns were considered to be good and supporting their livelihood work. There were shopkeepers that did not want to participate in the set up of the solar mini-grid as they do not trust the technology and they generally close their shop at 6 pm anyway.

Researchers

Three researchers have been interviewed of whom two were experienced researchers in the field of deploying lighting solutions in remote rural areas. The other researcher was implementing a project and shared the issues that he had encountered. In general the role of researchers in solar lighting in India is learning from experiences in the field. Fundamental technical research is not the main priority of the Indian researchers.

Opinion on methodology of lighting remote rural areas:

Beliefs amongst the researchers is generally that a bottom-up approach is the best way forward. This development is facilitated by the right signals given top-down. The right signal refers to policies set out by central and regional government. These policies could accelerate the availability of financial support and awareness campaigns. It was pointed out that the majority of successful initiatives were cases where ownership was taken care of.

The signals that are expected from state bodies or large organizations is that there is a coordination between the different programmes present in a region. These programmes should have a common goal alleviating poverty. This is expected to be achieved through better energy provision, improved health care and education.

The project implementer focusses on the development of a market and providing proper after-sales mechanisms. The challenge remains in finding interested, willing and capable entrepreneurs. In order to give the entrepreneurs the responsibility of ownership, they must provide a large part of the investment. In general, he/she will only invest if he/she is assured that the end-users have enough paying capacity.

The primary finding distilled from these interviews is that involving the community in the development and implementation will be the way forward. It will result in capacity building and creates awareness. The smart young leaders of districts must be encouraged to inform the people on the options of lighting solutions. All technologies must be promoted and preconditions must be set by the central government.

Opinion on financing lighting in remote rural areas:

Financing is partially done by available government subsidies. This support is only available in case the initiative complies to certain guidelines. It has been observed that these have been too stringent and has limited innovations. The policies have not been investor friendly. Successful businesses were able to innovate without governmental support. Nevertheless, a way must be found to provide basic funding through a central organization supported by polices. These policies transmit the message of trust in the technologies.

A warning was made that a general strategy to enhance uptake of the technology is to make the lighting devices cheaper, but that the quality of the solar technologies is being compromised. Also the researchers point out that in order to upscale the dissemination of lighting solutions, investors are needed. A precondition to achieve scaling is by getting the initiatives to be successful and independent of the subsidies.

Opinion on type of solution for lighting in remote rural areas:

As been pointed out by the researchers some technologies are not yet ready for large-scale dissemination. For example, biomass is not yet technically robust and it is not that easy for a single entrepreneur to initiate such a project. Also a micro-hydro solutions is not attractive for a single entrepreneur, because of the scale of implementation and the financing structure needed. Even in a mature renewable market like solar, where entrepreneurs can buy these products and initiate businesses with these technologies, disadvantages remain.

One is that the market and distribution channels are not properly developed. Another disadvantage is that there are no regulations and quality controls in place related to the assembling of lighting solutions. It was opined that the central government should promote all technologies as for every region a different solution might be feasible.

General

It is not surprising that opinions of the stakeholders are not aligned, which makes it hard to define 'the ideal methodology' to disseminate lighting products and services in India. The approach should be technology-independent, and should cater to local circumstances. However, from a financial and after-sales support perspective it is beneficial to use only one lighting system. The financing of the dissemination effort has several important concerns, on one hand the end-user must be willing and able to buy the product or service. This can be through financial support of rural banks or others. On the other hand, financial strategy must also address the capital of new businesses in renewable technology as currently banks are still hesitant to provide start up loans as working capital. The credit and financing capability together with the post-sales service capability are considered the most important aspects in delivering and disseminating the lighting service. In summary, the content of these interviews are given in Table 7 on the next page.

6.2 Technical appropriateness

In order to successfully implement a project there are several technical criteria that are important for the acceptance of the end-user and the project implementers. In this section the different technical criteria and how they might effect decisions during a project implementation are discussed. The criteria are divided according to the operation of the lighting solution by the end-user, the cost of the lighting system, the robustness and lifetime aspects of the solution and technical preferences of the manufacturers and project implementers. This section is concluded with a guide to use these criteria in different evaluation phases of a project implementation.

Operational criteria

The purpose of the introduction of the lighting technology is to address several needs during the evening, night and early morning. In an Indian fishing community there were complaints received, regarding the operation of the lighting solution that was used. It operated for one hour, while more operation time was desired (Apte et al., 2007b; Dekker, 2007). In this case a simple modification solved the problem. A small adjustment of the orientation of the solar panel increased the operation time. This example illustrates how the run-time of the lighting solution is important to the acceptance. The end-users of solar lighting appliance expressed to be satisfied with an operation time that lasts two days, which would exempt the end-users of daily charging and sensitivity to unfavourable weather circumstances. They would also like a daily operation time as long as possible, and the end-users indicate it as an important aspect of quality of the lighting solution (Müggenburg, 2011; Müggenburg et al., 2011). The desire is expressed that the minimum autonomous runtime should be between sunset and bed time, which corresponds approximately with 4-5 hours (Jaisinghani, 2012; Mohanka, 2012; Chaurey, 2012; Reiche et al., 2010; Crawley et al., 2009; Ochieng et al., 1998). Some users have indicated an additional lighting need in the morning of 1 or 2 hours. However, the majority of users are satisfied with at least 4 hours. Therefore, in the remainder of this thesis 4 hours of lighting are assumed as the minimum requirement of a lighting system.

Operation time can be reduced due to external factors. This can happen with a solar lighting solution during winter when the battery can not be fully charged during the day (Lighting Africa, 2008a). It is important to note that end-users tend to accept an occasional operation time that is less than the required minimum, as long as this has been communicated upfront before they agree to buyor to use the lighting solution (Jagdishpur, 2012).

Table 7: Stakeholders views on improving the dissemination of lighting solutions

Stakeholders	Method of operation	Financing strategy	Type of solution for addressing lighting
Governmental institute	*- Grid connection is the ultimate goal*	*- Subsidies*	*- Down-scale biomass plants*
	- Proper after-sales due to technical training	*- Banks providing loans*	*-Should be made configurable and able to connect to future grid*
Financial institutions	*- Creating awareness financial means*	*- Monthly instalments*	*- One technology enables partnering with one provider*
	- Creating awareness through demonstrations	*- Achieving scale enables governmental subsidies and carbon finance*	*- One technology enables economies of scale*
	- Small improvements in energy services	*- Create awareness local banks about technology*	*- One technology makes technical support feasible*
NGOs	*- Sustainability through capacity building, improved after-sales, simplicity of model*	*- Address the 2% of CSR companies*	*- Technology independence*
	- Initiative should come from the ground	*- Project cost partially from Indian Government* *- Private sponsorship*	
Entrepreneurs	*- Model should be simple and cheap*	*- Partners need for funding*	*- Small-scale solution leads to solar technology*
	- A local team should provide sales and technical maintenance	*- Users should pay a small price, profit is made through scale*	*- Other technologies might be attractive if it can be connected to the grid*
	- Erratic electricity supply is a market opportunity		
Manufacturers	*- After-sales service through a local technical service provider*	*- Low cost for end-users, but depending on remoteness and delivery model*	*- Improvements in battery and LED technology can lead to greater acceptance*
	- Local entrepreneur should take care of raising awareness	*- Lack of faith of banks, need for financial intermediaries.*	*- Add functionality to create added value for end-user*
	- Preference to operate without interference government		
End-Users	*- Preference for mini-grid implementations as it is less cumbersome*	*- There is a willingness to pay for improved lighting*	*- More people want to participate in initiatives*
	- Due to awareness of technology the desire was to have more lighting connections	*- Non-users stated insufficient funds for not using improved lighting* *- For SHS and solar lanterns a preference is made to pay at once if they could*	*- Several shopkeepers preferred not to participate as they did not need it and they did not trust it*
Researchers	*-Bottom-up methods initiated through signals from government*	*- Through subsidy government*	*- Micro-hydro, biomass are technologies that are not attractive for a single entrepreneur*
	- Importance of ownership	*.- Investors are needed to enhance uptake technology*	*- Solar technologies are mature, but the market is not well developed*
	- Challenge in finding interested, willing and capable entrepreneurs	*- Technology is made cheaper, but compromises quality, therefore certification needed*	*- No regulation and quality control in place*
	- Coordination of signals from central government		*- Government should promote all technologies*

The lighting solutions that are dependent on batteries need to be considered based on charging time. The battery needs to have the capacity to store the power sufficient for the required period of lighting and it has to be suitable to withstand the daily charge and discharge cycle (Crawley et al., 2009). Lighting solutions have been tested at different labs measuring the time before the battery is full or that the solar day has passed (Lighting Africa, 2011; TERI, 2012b). However, in order to make a fair comparison between the different lighting systems on the charging time, the appliances must be tested in the field, as the lighting intensities in the target areas of the project implementation can differ significantly and cannot be simulated in the testing labs.

In the usage of the lighting appliance the amount of light has been considered as an important factor. For the different needs like reading, cooking and simultaneous use with other family members the light output must be sufficient (Müggenburg, 2011; Dekker, 2007). In several cases, a task light had not provided sufficient lighting for the different needs of the end-users (Lighting Africa, 2008a). Therefore the end-users perceived it as an inappropriate lighting solution and remained with fossil-fuel based lighting solutions. At the other side of the spectrum, the light output must not be to strong as it might cause glare (Müggenburg et al., 2011).

Users should be sensitized on how to take steps to make the whole system perform better. This could have a major impact on the general performance of the system and the acceptance of the end-user (Nijhawan, 2012).

The benefits of consumer with one additional unit of luminosity is huge in the case where one switches from poor lighting of a kerosene lamp or candle to a small electric light (GTZ, 2010). In the case the consumer already has a modern lighting source the gains, when he moves up the energy ladder with the same amount of lumen-hours from low-to a higher intensity lighting, are much lower. In other words, the marginal utility for the first lumen-hours is highest and reduces with increasing amount of light consumed. Solar lanterns that provide luminance levels which lie below 80 lumens have been considered to have little potential to replace kerosene-run hurricane lamps (Mills, 2003; Brüderle, 2011). Needs above this level depend on specific use and this can be best evaluated taking the local conditions into account.

Research has shown that people who switch from fuel-based to modern lighting can do with lighting services lower than the standards in industrialized countries (Alstone et al., 2010). This implies that new efficient lighting technologies not necessarily need to meet the developed countries illuminance benchmarks. Policy makers should revisit the subject of recommended illumination levels regularly as LED technology advances and the price/service balance point evolves.

Additional features

There have been cases where solar lanterns were dismantled to find innovative ways to charge the mobile phone. A non-user stated that she would only start using a solar lantern in the case a mobile phone charging option is included (Jaisinghani, 2012; TERI, 2012a). Showing that additional features contribute to the user's acceptance of solar lighting solutions. Several surveys have indicated that additional features that come with a lighting solution are important for the uptake. The most important one is the mobile phone charging facility (Müggenburg et al., 2011; Komatsu et al., 2011).

Another option is the mode of dimming. This gives the user the option to run the lantern at different lighting intensities depending on the task, which could give the added benefit of longer run times. The users can adjust the level of brightness according to the activity. This gives end-user the control to save energy and influence the operation time (Müggenburg et al., 2011). Other desired features are an indicator showing that the lamp is charging, a warning light to show that the lamp is about to switch off and a power socket to allow a small radio to be connected (Crawley et al., 2009).

As already discussed in evaluating the previous criteria different tasks have different demands of the lighting source. Such as the intensity of light, modes of light and also the amount of degrees that are covered by the lighting beam. One specific preference for hand tasks and reading is a sharp focused beam with concentrated levels of light output (Tracy et al., 2009). End-users have shown a preference for a lamp in the middle of their house or main room. Therefore, the lighting solution should have a wider cone of light (Müggenburg et al., 2011). Households indicate that the angle of radiation is an important quality as the light spread covers more area (Lighting Africa, 2008a). If a choice needs to be made between a large angle of radiation and a high number of lumen's, a wider beam is preferred (Müggenburg, 2011). These observations indicate that the light output spread is a task related requirement and the preferences of the end-users must be well understood before project implementation.

Robustness and lifetime criteria

Experience in development cooperation shows that one thing must be avoided at the outset: that users of cheap and inadequate devices should become so disillusioned that the entire technology is discredited. It should be prevented that badly performing lighting devices are introduced. This spoils the market and affects the financial livelihood of people with low income (Mink et al., 2010). Therefore, it is essential to take care of the repair and maintenance.

The manufacturers indicate that the poor quality products are a threat to the small-scale lighting market (Mohanka, 2012; Kumar, 2012c). A proposed solution is that important components of the lighting system like batteries, PV-panels and lanterns are certified by an independent party (Brüderle, 2011). Firstly, the durability of the lantern is very important as the components that most often cause lamps to fail are cables, plugs, input jacks and switches. These parts are typically under extreme stress through everyday use (Lighting Africa, 2008a). Complaints of end users have been the common failure of LEDs, water leakage leading to corrosion and failure of the electronic component (Mink et al., 2010). In addition the modules are vulnerable when they are put on the ground during charging.

In many cases, the battery life time is reduced by misuse through the lack of knowledge of the user or entrepreneur. Manufacturers and entrepreneurs of lighting solutions in India indicate that the battery is the crucial component for improving the quality of their products (Mohanka, 2012; Jaisinghani, 2012; Rao, 2012; Saini, 2012; Sekhsaria, 2012).

In order to support the technical robustness manufacturers give a substantial warranty period for the battery and the lighting system. Customers have expressed the desire to have at least a 6 months or a 12 months warranty for the lighting solution (Crawley et al., 2009). The majority of the Indian manufacturers give a warranty on their products in this range (Mohanka, 2012; Jaisinghani, 2012; Rao, 2012; Saini, 2012; Sekhsaria, 2012).

When the technology fails, spare parts in remote rural areas are not easy to obtain. It is in the interest of the manufacturer that the appliances stay in operation. As this will result in positive publicity and acceptance of the end-user (Mohanka, 2012). There have been many complaints on unqualified technicians sent by the suppliers trying to repair lanterns. In the case that the material and processing is done in the region where the technology is disseminated, it automatically leads to improvement of the skills of the technicians and the availability of spares (Chaurey, 2012). Another advantage is a cost reduction when local materials are used. In order to avoid levy import taxes on finished products as has been done in the project of Grameen Shakti in Bangladesh (Wiese and Steidl, 2011).

Cost

The costs of the lighting product must be affordable for the end-user. In Malawi the shift from modern lighting had a strong impact on the households fuel expenditure. In grid-comected African villages half of the connected households continued to use kerosene lanterns (Peters et al., 2009). Altogether, the average electrified household still consumed 3 litre of kerosene per month compared to 8 litre before electrification. In a study investigating the introduction of solar lanterns, the expenditure per lighting source was shown for school children in 100 rural families across Dahod District in Gujarat State, India (Agoramoorthy and Hsu, 2009). It showed that the household expenditure on kerosene and electricity reduced as seen in Figure 13. However, after the solar lantern introduction, the households kept using the kerosene lantern in other rooms. These two examples show that despite the introduction of modern lighting the utilisation of fuel based lighting remains.

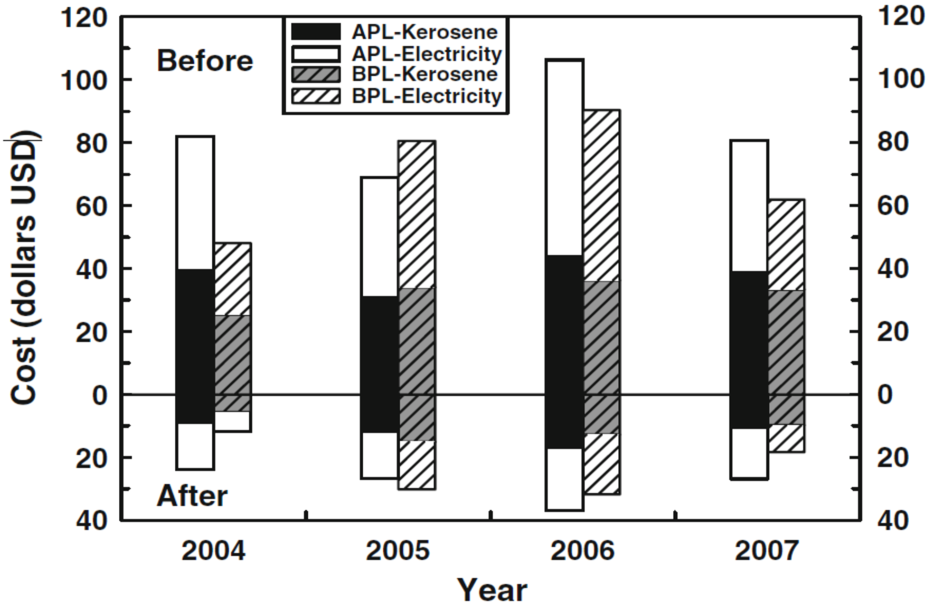


Figure 13: The average cost of kerosene per household before and after the use of solar lanterns in villages of western India. APL above poverty line; BPL below poverty line (Agoramoorthy and Hsu, 2009).

The target audience finds most of the costs too expensive, because the upfront costs are high and are amplified due to high discount rates that apply for poor consumer investments (Apte et al., 2007b; Adkins et al., 2010). This generally leads to the rejection by the user as the solutions are perceived to be expensive (Lighting Africa, 2008a; Jaisinghani, 2012). However, the willingness to pay may shift if additional functionalities are included and the quality of the product is better. So when analysing the cost aspect, the robustness and all functionalities must be taken into account. It is likely that the user will compare the costs of different options if given the choice. The potential end-user must find the lighting solution economically attractive based on the costs and other factors. The financial attractiveness enhances the uptake of the modern lighting solution and the movement of the household up the energy ladder.

Manufacturers and project implementers criteria

In addition to the end-users perspective, there are some additional criteria that are mainly of interest for manufacturers and project implementers. Firstly, past selections of modern lighting and current practical experience show a preference for LED lighting in newly made lanterns (Gaur and Marcus, 2008; Gaur and Thakur, 2010). Also within the scientific literature there is general consensus that the shift to LED lighting is the way forward, reducing energy use, pollution and improving affordability (Khan and Abas, 2011). The CFL lanterns are therefore not considered to be the most attractive option. Although the light output is considered to be better than LED, the energy consumption is also a lot higher. Nevertheless, it is the end-user who has to decide which lamp type is preferred.

Secondly, the contemporary shift in battery type from solid lead acid to lithium battery is an aspect that could be taken into account. It is projected that Li-Ion batteries will become the dominant battery used by the manufacturers due to its light weight, expected cost reductions, being more environmental benign and the expected improved delivery channels (Mohanka, 2012; Sekhsaria, 2012). The Li-Ion battery type is predicted to be the fastest growing battery segment in the portable electronics segment, with a projected price decline of 13% annually, and a lower price than NiMH batteries (IFC, 2010). The manufacturers and project implementers prefer that a small-scale lighting solution comes with a Li-Ion battery.

6.3 Criteria delivery model

Economic viability

The economic viability of a project, scheme or private dissemination initiative of a lighting system is dependent on the costs and price of the lighting device. The gap between the expensive renewable solution and the low purchasing power of the consumer can be met by a subsidy or an investor. For the project implementation and the end-users additional money is important during the start-up. However, if the project is not self-sustaining, there is an associated risk of withdrawal, which could lead to the cessation of the dissemination effort.

In assessing the economic viability of the lighting system, it should not only be limited to the end-users (Chaurey and Kandpal, 2009; Chaurey and Kandpal, 2010a). It should also be economically viable for the whole supply chain (Heierli and Polak, 2000). In this thesis the economic viability is limited to the end-users and project implementers.

Manufacturers

To evaluate the position of the manufacturer and the chance of successfully deploying the solar lighting device the following aspects can be considered: The geographical location of the manufacturer in the targeted area is of interest. The marketing spread considers the operational areas of the manufacturer and the potential market growth of this organisation. Therefore the current presence in the region and the promotional activities to increase their market share are important criteria. The delivery models that have been employed by the manufacturer in the targeted area or in other regions. In judging whether the manufacturer is the appropriate partner these models are compared with the expected delivery model of the project. In order to enhance the sustainability of a project the after-sales services of the manufacturer should be available. This can be provided for example by a local or regional technical service station.

Distribution challenges

Often stakeholders in the implementation of lighting have to overcome distribution challenges. The delivery models need to take into account these challenges during the project design phase. The challenges are addressed through capabilities[19] of the distribution system.

[19] A capability is used in this context as resource of a business, institution to create a certain outcome. In this case businesses, MNRE, manufacturers use the capabilities to reach out to the BoP end users in remote rural areas to provide them with a lighting service.

One can imagine that lighting solutions for the BoP is potentially a large market and there is a challenge in servicing this consumer base. In order to achieve a successful distribution of a product through a supply chain every stakeholder/participant has its own needs, objective and ability to deliver the energy service. The delivery models that disseminate the different lighting systems should comply with these capabilities.

The SHLS and the solar lanterns are considered durable consumer goods. These goods provide a lighting service or utility over time and have a relatively high price for BoP consumers. Three capabilities have been identified as essential for the lighting systems taken into consideration. These are the physical distribution, financing and promotion. These aspects should be taken into account when attempting to initiate projects or businesses in this domain. The policies should be designed to support the physical distribution and financing by providing working capital. As part of a government programme the promotion capability can be taken care of through awareness campaigns, which will increase the user acceptance of the pushed technology.
Looking specifically at challenges in distribution channels of the discussed delivery models it is possible to identify characteristics a delivery channel should have. The array of observations and key-points are given in Table 8.

Table 8: Capabilities credit and financing, post-sales services addressed in the delivery models

	Credit and financing	**Post-sales service**
Fee-for-service/ESCO	*- Regular income stream expected from end-user*	*- Centrally organized by VLE or ESCO*
	- Potentially favourable financing terms for ESCO	*- Extended lifetime products through controlled charging*
	- Small fee is paid by the end-user	
Consumer financing/ leasing	*-Sufficient paying capacity end-users*	*- Credit solution provider could also take care of after-sales service*
	- Credit solutions provided directly by rural banks or through intermediaries	*- Could be neglected by rural retail*
	- Rural retail need sufficient working capital to start up business	*- Monopoly position of technical support provider*
Community managed systems/Village cooperatives	*- Large-scale solution need more funding, so support of large financial bodies required*	*- Development technical skills within the community*
	- Ownership is facilitated by community contributions through payment and/or labour	*- Sufficient scale of mini-grid solution needed so technical teams can operate in the region*
Private sector models	*-Through government subsidies*	*- Could be provided by the delivery channel of products or services*
	- Community pays fees for the service of light	*- Support by technical operator mini-grid*
	-Working capital needed, which could be delivered by banks	*- Sufficient scale can lead to regional technical teams*

7 Case studies delivery models

In this chapter case studies illustrate the financial and post-sales solutions of different delivery models. More information on the case-studies can be found in appendix D.

7.1 Description case-studies

SELCO: The target population resides in remote rural villages that are either off-grid or connected to an unreliable power source. SELCO views a product as a combination of technology and finance . There the delivery model uses the approach of door-step service and door-step financing to overcome several barriers of modern lighting dissemination (SELCO, 2012).

NEST: The Noble Energy Technologies (NEST) was initiated by Mr. D.T. Barki in 1998 to end light poverty in India. In the beginning loans were needed by NEST to have seed capital to start the company and credits were obtained from local banks to buy materials and assemble the solar lanterns. The products were sold on credit and it became almost impossible to recover the money from the market (IBS, 2009). The flow of the products and credits were out of NEST's control, which almost led to bankruptcy. However, the founder decided to continue as his aim is to address a social need. This perseverance was ultimately rewarded as NEST became a successful enterprise learning from the lessons of the initial years (Jolly et al., 2011).

LaBL: The campaign LaBL is an initiative that is targeting a billion rural people improving their lighting sources by replacing kerosene/paraffin lanterns with solar lanterns (TERI, 2011). The model is based on the rental scheme or the fee-for-charging service for solar lanterns. A local entrepreneur is selected and responsible for the solar panels and the O&M of a SCS.

Bushlight India: The NGO Cat Projects in collaboration with the NGO Gram Vikas had done an extensive survey to investigate villages that have been expropriated from their original settlement (Cat Projects, 2012). The focal point of the implementation of a solar powered electrification project was the village Maligaon of 48 families of mixed casts.

Ramgad: In the eighties the state owned Non-conventional Energy Development Agency (NEDA) of Uttar Pradesh aimed to electrify rural areas. One of the projects was a SHP of 100 kW at Ramgad, which utilized the discharge of the Ramgad river. The project was initiated in 1988 and was finally commissioned in 1990 (Kumar, 2012c). In 2000 the state of Uttarakhand was formed and the project came under control of the Uttarakhand Renewable Energy Development Agency (UREDA). In those days it provided 6 villages electricity in an area that was completely off-grid. It was initially only used for lighting at the household level, but now there are 1000 LED based lamps at the household level and 100 LED based street lights installed. In total it provides to 373 households electricity.

Jagdishpur: The solar mini-grid replaced a lighting service that was running on a diesel generator set in the village Jamo in the Chhatrapati Shahuji Mahara Nagor district, Uttar Pradesh. The village is officially grid connected, but the electricity supply from the main grid is cut off between 6 pm. and 10 pm.

7.2 Credit and financing

SELCO: The SHLS provided by SELCO range in price from Rs. 7,000 to 20,000 (Bairiganjan et al., 2009). The majority, around 90% of the products are purchased on credit through financing agreements with local banks. SELCO has formed a steady relationship in Karnataka and Gujarat with regional rural banks, commercial banks, NGOs and rural farmer cooperatives to develop financial solutions, which matches the cash flows of the targeted rural population. Some end-users work directly with the finance organisations, while others work through SHGs. For the bank this provides an added benefit as it gives additional security that a loan will be repaid. Also rural banks often require a minimal deposit before providing a loan, it is here where SELCO steps in as poor households often don't have this amount of cash. The funding of the margin money is possible with support from external investors like Renewable Energy & Energy Efficiency Partnership (REEEP).

NEST: In the first three years of the existence of NEST the end-user paid Rs. 1500 for the lantern without the battery (Karamchandani et al., 2009). This price was too high for the end-users.

The company was initiated with seed capital provided from banks and friends. This enabled the company to start an assembling factory and the possibility to buy material on credit. The income stream of the company was based on the sales of the products, services and O&M fees paid by end-users. The profit obtained per solar lantern could rise up to Rs. 500 through the recycling of used material.

LaBL: The user pays a daily or a monthly fee for charging or renting the solar lantern. The entrepreneur has the freedom to chose how to use the additional income, e.g. 90% of the monthly fee could be income and 10% can be set aside for maintenance. The rent or charging fee is between Rs. 2-10 per day. This is determined by the paying capacity of the villagers and their willingness to pay. From the project implementation perspective funding can be provided through the LaBL fund, private investors and corporate funding. The SCS in remote areas is mainly funded by grant supported by the LaBL fund and co-financed by a partnering organisation (Krithika and Palit, 2011). If the entrepreneur has sufficient money and wants to participate in the project, he initiates a partnership with LaBL. The partnership enables the entrepreneur to obtain a loan for the projects. He/she will pay back the loan after a number of years, which will free the money for new LaBL initiatives. This makes it from the LaBL perspective a perpetual methodology to finance SCSs.

The LaBL fund can be raised from corporate, private and government schemes. First of all, companies can use their CSR, which is often 2% of their profit. Secondly, as part of different Indian policies a percentage of the project costs are funded by the Indian government. Thirdly, individuals can sponsor a household, a family or a village. Fourthly, the most important one for ownership is the community contribution. A portion of the price of the lantern is paid by the household, partly paid in instalments and partly funded by donations. The total costs for the SCS is Rs. 200000, which can be split up according to 70% on hardware, 7-8% on training and the remaining on O&M, costs for monitoring, project activities and profit (Prashant, 2012).

Bushlight India: After the energy assessment on household level, the households were given the liberty to plan their own energy need and the tariff they would be willing to pay.

The funding of the capital cost was done by the Bushlight India Project by the Australian government for 3.2 million US$. The costs for the meetings for community and capacity building were taken care of by Bushlight India Project and Gram Vikas. The powerhouse and the system compound were paid by Bushlight India Project, Gram Vikas and a contribution by the community. The total costs of the implementation was Rs. 5.1 million.

Ramgad: The governmental bodies paid for the SHP. The total cost of the installation was Rs. 5.2 million of which 60-70% went into construction/civil works, 10-15% into distribution works, 5-10% into the maintenance costs and the remainder went into equipment. An additional Rs. 3.7 million was needed for grid synchronization and overhauling of the system.

The tariff in Utterakhand is around 2 Rs./kWh and if excess electricity is sold to the grid the price is 2.85 Rs./kWh, according to a PPA. The cost of generation is 0.70 Rs./ kWh, which provides a significant margin for the VEC. Initially the households paid a fixed tariff per month depending on the number of light points. However, inefficient use of the power delivered led to the installation of energy meters. The monthly tariff was based on the energy consumption pattern of the household.

Jagdishpur: These end-users pay the entrepreneur Rs. 6. per night. The entrepreneur pays 55% of the investment and 45% is borne by the NGO. A contract between the NGO and the entrepreneur supports the request of the entrepreneur for a loan at a rural bank. Other financial support comes from the government as similar implementations are done by the same NGO, which makes it viable to request for subsidies.

7.3 Post-sales

SELCO: In the lease to own programme the focus is on establishing a steady long-term relationship with the customers and building their trust and confidence. Initially SELCO provided, along with the financing scheme, different type of warranties to end-users. These were additional one-year guarantee to the manufacturer's warranty and a 9-day money back guarantee along with a year free service. Currently, SELCO provides a free service for 1 year and after that the consumer has the option of availing an annual maintenance contract or a pay per service contract.

NEST: In the initial phase of the company the after-sales service and battery delivery was done by the salesmen and dealers. This meant that the salesman/dealers obtained an important role in the business plan of NEST.

LaBL: The entrepreneur raises capital to financially support the after-sales service. In addition to his income, he builds up an O&M fund that can be utilized when the warranty of the systems has passed. TERI monitors and tracks the different projects on the performance of the VLEs. The lanterns are procured from regional manufactures, which preferably have technical teams in the region. The TRCs visit the villages on advice of the entrepreneur when repairs are needed. On these visits they collect the logbooks of the entrepreneurs, which are given to the NGOs to observe the performance of the charging stations.

Bushlight India: The technology was delivered by Tata BP Solar. A maintenance contract for 5 year is in place, while the system has a lifetime of 15 years.

Ramgad: The O&M is paid indirectly by the users through the VEC. The revenues made from the collection of bills of the end-users and the selling of electricity to the grid are kept in a separate bank account. The last major maintenance was in 2003. Small maintenance issues are ongoing like greasing the turbines and maintaining the water pond.

Jagdishpur: The contract between the NGO and the entrepreneur entails the availability of a regional technical team.

7.4 Observation case studies and example implementations

Looking at these case studies and some examples from previous chapters some generic observations are possible. In Table 19 an overview is shown of the different lighting systems and their different characteristics.

It can be observed that with increasing size of the system the applied service delivery model and therefore also its corresponding stakeholders change. In the case of servicing a cluster of villages or multiple households clearly shows the role of government and also large financial donors/partners. When shifting to a smaller system of mini-grid the influence of the entrepreneur becomes more prominent on how the service delivery model is applied. The directly purchased SHLS are paid

Table 9: Different lighting solutions and their corresponding delivery models

Lighting System	Solar lanterns	SHLS	Solar Micro grid	Solar Mini-grid	SHP
Power range	*1-10 Wp*	*10-100 Wp*	*2 kW*	*25-50 kWp*	*100 kW*
Number of target users	*- 1 room in 1 household*	*- 1 household*	*- 50 households*	*- 6000 households*	*- 6 villages*
Service delivery model	*- Fee-for-service, direct sales , leasing*	*- Direct sales, government subsidised programmes*	*- Subsidised through government, partially subsidised initiative by entrepreneur*	*- Subsidised through government, local co-operative societies for operation*	*- VEC, Community initiative*
Credit and financing	*- Community contribution, subsidy*	*- Bank loans, MFI*	*- Government subsidy*	*- Government subsidy*	*- Government subsidy*
Case Study	*- LaBL, NEST*	*- SELCO, JagdishPur*	*- BushLight, Jagdishpur*	*-Sagardweep Island*	*- Ramgad*

with credits For the smallest scale there is space for individual purchases or ESCO/fee-for-service initiatives. Also it can be seen that the ownership changes, an AC mini-grid is typically community owned. A DC mini-grid is an initiative typically owned by the entrepreneur. In the fee-for-service the entrepreneur is responsible for the implementation. The ownership resides more with the individual end-user when shifting to the smallest scale of lighting solutions.

Providing financial solutions is done by providing collaterals, small daily payments and through trust building between end-user and local banks. In order to keep the mini-grid implementation feasible it was observed that fixed-tariffs on the household level led to inefficiencies. Therefore, in different case-studies metering was introduced, paying more attention to DSM.

The experience and lessons from the case studies reveal key elements for success that are common for delivery models of lighting solutions. It would be beneficial to have these elements enhanced through the right policy measures. In the case of mini-grid sized solutions, measures should be taken to ensure the solution is capable of synchronizing with the main grid. This will increase the financial feasibility of the project. Another incentive for project implementers could be to relax the concession regulation for electricity generation for officially grid connected villages. This would enlarge the market of private investors.

The trust between rural banks and lighting end-users must be strengthened to enhance the uptake of small-scale lighting solutions. This can be achieved by providing financial incentives to the rural banks when loans are provided to customers that purchase a lighting system or by setting an example to support initiatives in this market. Another option could be to have the population get acquainted with the rural banks and vice versa, which will pave the way for the lighting solutions. Another aspect that needs to be addressed is the provision of affordable after-sales. This can be achieved through sufficient regional technical support. The different case-studies had their own approach in addressing the post-sales service. As the lighting system increases in size, more technical staff is needed to cope with the increase in work. This could for example be achieved by providing incentives to future students for obtaining an engineering degree.

From the observations and examples of previous chapters it can be observed that the end-user has a limited choice in the array of modern lighting solutions. On one hand the choice in system of lighting is dictated on the governmental or community level. On the other hand the full market of modern lighting solutions is not available in many remote regions. In this way the market can not address the lighting need efficiently. Here is where challenges lie that the government must tackle. How to achieve sufficient competition in remote rural areas in order to have efficient markets operating or have a company achieve enough scale to be able to reach the consumers with sufficient profit-margin.

8 Lighting system project considerations

8.1 Selection of lighting product

In the initial phase an inventory of lighting appliances is made to obtain an overview of the different options, this is so-called the survey phase by the office of the initiators of the project. Prior to this phase, the lighting requirements and needs of end-users have already been distilled. However, progressive insight from users and project implementers require different evaluation phases to improve the project result. So after the survey phase some lighting solutions arise as the best option or the most convenient appliance to be used in a certain implementation region. In the next phase these solutions are tested in the field. Feedback on the performance could result in other lighting appliances to be taken to the field. These solutions are tested in the target area, where other aspects

Table 10: Criteria for determination technical appropriateness of lighting solutions

Technical appropriateness criteria	Description	Survey criteria	Field test criteria	User criteria
Autonomous run time	*One charge must result at least in one night+morning operation and preferably 2 nights and 2 mornings.*	√		√
Charging time	*Must be able to fully charge a lantern within 12 hours.*		√	√
Cost	*Research has shown that there is willingness to pay for quality*	√		√
Light Output (Lux/lumens)	*Intensity must be of sufficient high level to light up a room. Dependent on local condition and the specific activity.*	√	√	√
Additional features	*Especially the mobile phone charging and the dimming function has been shown to the most important functionality desired by end-users*	√		√
Battery protection	*To prevent deterioration of the battery capacity, the battery must be prevented to discharge completely or to become overcharged*	√		
Light Output spread	*Difficult to determine upfront what is suitable for the local condition.*		√	
Warranty	*Preferably the manufacturer provides for certain period of time a warranty. Also after warranty technical service is desired.*	√		
Durability	*The product has to be robust, failure of the light is detrimental for large-scale dissemination. Therefore the durability in the field is essential.*		√	√
Certification	*To prevent poor products to be deployed the lanterns are preferably certified.*	√		
Material(Supply chain profitable)	*Preferably locally available, must also be profitable for the different stakeholders in the supply chain.*		√	√
Lighting Type	*A preference among manufacturers and scientists for LED lights*	√		
Lighting Need	*Dependent on the task for which the lamp is used*	√		
Battery Type	*According to manufacturers there will be a shift LI-Ion batteries.*	√		

can be more important, for example a political agenda. This is the so-called the 'field test'. After some iteration the best lighting solution according to the field test criteria, is implemented. A critical phase as the target population begins to use the technology more intensively and apply their own criteria. In this final phase the so-called user criteria are applied. If these are fulfilled, an important step is taken for the user acceptance of the technology, which leads to further dissemination of the lighting solution in the region. The overview of criteria of the previous sections is given in Table 10 and is divided according to which phase the criteria can be tested and evaluated.

All these criteria together are needed to guarantee a high quality product with a good light output that will gain acceptance once consumers have experienced and tested the lamps for several weeks in their homes. Sustainable light output, i.e. consistent lighting duration at sufficient illuminance, and robustness of all components are the key factors for user satisfaction. An extensive overview of lighting solutions is given in Appendix C. It can be observed that the majority of the lighting solutions are using LED lanterns. Several criteria can be selected as the most important in the initial phase of the project. For example the desire to have a autonomous run-time high-setting larger than 6 hours, the cost lower than Rs. 2500 including the solar panel and a light output larger than 80 lumens. Applying these criteria results in a short list of small-scale lighting solution shown in Table 11 on the next page.

In the project implementation and the selection of the lighting solution, the position in a country of the potential manufacturer and the stakeholders must be taken into account. As the targeted remote rural areas are characterised by dispersed settlements and poor infrastructure. A preference can be made by the project implementer for a manufacturer that already has a strong foothold in the region. The current situation of the manufacturers can be evaluated based on the relation they have with the different stakeholders, local entrepreneurs, distribution channels and technical service teams.

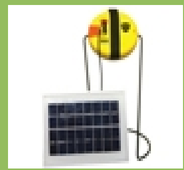
8.2 Financial impacts different modern lighting systems

End-users

The fuel costs are low for solutions based on solar and hydro. In order to analyse the economic benefits of the introduction of the modern lighting system, the type of lighting should be considered. In general, the operating costs of the modern lighting solutions are lower than the traditional fuel-based lighting solutions.

The solar lantern, SHLS and a mini-grid light point are compared with the hurricane lantern and a lighting point connected to the electricity grid. The latter is included in the analysis to illustrate the price difference for end-users of lighting in on-grid areas and off-grid areas. The purchase decision of the end-user is dependent on the trade-off between in cost and quality. Therefore the costs of the end-user are given in costs per lighting point and also the costs per lumen-hours. The former is chosen because cost is often a primary factor for the end-user. The latter is defined so that the quality of the light output is taken into account, when evaluating the cost of a product.

Table 11: Small-scale solar devices

Application		**Ambient lantern**	**Task light**		**Torch**	**SHLS**
Product name		*LED solar lantern*	*SHL2*	*Sun King Pro*	*Suntransfer2*	*Barefoot PowerPack 5W*
Picture						
Manufacturer		*Solid Solar*	*Global Telelinks*	*Greenlight Planet India Pvt. Ltd.*	*Suntransfer*	*Barefoot Power*
Source		*LaBL Test Lab Reports*	*Solar Quarterly*	*Lighting Africa*	*Lighting Africa*	*Lighting Africa*
Warranty		*1 year*	*1 year*	*1 year*	*1 year*	*1 year lamp, 2 year PV*
Autonomous	*High setting(hr)*	*7.15*	*8*	*6*	*17*	*19*
Run Time	*Low setting(hr)*		*60*	*15*	*28*	*77*
Lamp type		*LED*	*LED*	*LED*	*LED*	*LED*
Light output	*High setting*	*5 horizontal, 25 vertical lux at 3 feet*	*100 lumens*	*110 lumens*	*70 lumens*	*190 lumens*
	Low setting			*44 lumens*		
Light distribution		*360*	*120*	*Wide*	*Wide*	*Wide*
Battery protection		√	√	√	√	√
Easily replaceable battery			√		√	
Battery indicators	*Status*	√		√		
	Charging			√		
Special feature	*Phone charging*		√	√	√	√
	Dimming	√				
	Others				*Remote on/off switch*	*Power output for radio*
Price (Rs.)		*1500*	*2200*	*1550*	*1600*	*7000*

The definition of the levelized annual costs per lighting point is given by equation[20] 2 and 3.

$$annual\ cost\ per\ lighting\ point = \frac{\alpha * I + OM + F}{number\ of\ lighting\ points} \tag{2}$$

$$\alpha = \frac{r}{1-(1+r)^{-L}} \tag{3}$$

α = capital recovery factor
I = initial investment
OM = annual costs for operation and maintenance
F = annual fuel costs
r = discount rate
L = depreciation period of the equipment

with the definition of the annual cost per lighting point, the costs per lumen-hours can be found according to equation 4.

$$annual\ costs\ per\ lumen\ hours = \frac{annual\ costs\ per\ lighting\ point}{lumens\ per\ lighting\ point * hours} \tag{4}$$

To compare the different technologies several choices and assumptions are introduced to obtain a fair comparison. The evaluation of the costs of the lighting solution is not taking into account the financial tools that might be present. This is considered to be part of the delivery model and this is part of the local availability of financial solutions and the policy regime at the state level. An assumption is that the minimal amount of lighting delivered is 4 hours per day, 365 days a year, which means 1460 hours per year. Another assumption is that the annuity factors are 1 when there are no investments depreciated from the end-user perspective. Hurricane lanterns have a lifetime less than 1 year and for rental solutions or lanterns, there is no investment depreciated.

The hurricane lantern is included in the analysis to illustrate the economic consequences of a kerosene lighting device. In India kerosene is typically used by households in rural areas, where the grid and clean lighting services are absent (Bhattacharyya, 2006). A typical lifetime of 400 hours and an average light output of 45 lumens is assumed (Jones et al., 2005). The costs of the hurricane lantern on the market is Rs. 120, which comes down to a yearly investment cost of Rs. 438 (Apte et al., 2007b). Kerosene distribution pricing is built up in different ways. Subsidy is provided with the aim to promote the usage of kerosene as a cooking fuel, but a major portion of the subsidized kerosene is used for lighting. The kerosene as provided through Public Distribution System (PDS) has the subsidised price of 14.83 Rs./litre, after removing the government subsidy for the customers the price becomes 15.65 Rs./litre (Indian Oil, 2012). The government also provides a subsidy of 31.48 Rs./litre to the oil companies to keep the prices low. The actual price of kerosene is 45.28 Rs./litre excluding VAT, excise duty, wholesale and retailer commission. The total subsidy provided by the government is 32.3 Rs./litre. These numbers are based on the Delhi kerosene price break-down, which gives an indication of the magnitude of the subsidy.

Another price taken into consideration is the black market price of kerosene, which was previously estimated to be 35 Rs./litre (Pattanaik, 2012; Apte et al, 2007b). Now all the variables are known to determine the annual costs per lighting point and costs per lumen-hours when including the usage of kerosene 0.03 litre/hour (Mills and Jacobson, 2007).

[20] This equation is based on the definition of costs of electricity given by Blok (Blok, 2007).

One of the options for a clean lighting solution that is considered here is the solar lantern. One of the delivery models considered is via a fee-for-service scheme like LaBL In the calculations a rental fee is chosen of Rs. 5. In this evaluation the end-user does not take care of the investment costs and O&M costs as this is incorporated in the daily fee.

Secondly, the rural customer can buy the solar lantern including a small solar panel at full or subsidised cost. In the analysis below the subsidy is not taken into consideration. The life time is assumed to be 3 years with a discount rate of 20%, which is a low estimate for poor customers (Reddy and Reddy, 1994). The operation and maintenance costs are considered 10% as is the case in several LaBL cases (TERI, 2011).

Another option to address the lighting need of the poor remote rural customer is the SHLS. In this scenario the SHLS is disseminated according to the partnership between Aryavanath Gramin Bank and Tata BP Solar (Pattanaik, 2012). The lifetime of the system is 5 years and the same discount rate of 20% as the solar lanterns is used. The maintenance cost is assumed to be 5%. The system includes 2 lighting points and additional options for running a small black-and-white TV and a mobile phone charging device, which will give the solution added value for the end-user. For the sake of simplicity of the analysis this added value is ignored and only the lighting points are considered. In the case of decentralised generation through PV, the mini-grids promoted by MGP are considered (MGP, 2012). The connection fee of a household is Rs. 40, and there is a weekly charge of Rs. 25 (Jaisinghani, 2012).

Applying the data of Table 12 to the equations 3 and 4 the following results are shown in Table 13

Table 12: Data on different lighting technologies

	Solar lantern		Solar Home Lighting System	Mini-grid	Hurricane lantern			Main grid connected
	Stand -alone	LaBL			Subsidised Kerosene	Unsubsidised Kerosene	Black Market Kerosene	
Investment cost[Rs.]	*1750*	*0*	*13650*	*40*	*438*	*438*	*438*	*203*
Annuity factor[1/yr]	*0.48*	*0*	*0.24*	*0.24*	*1*	*1*	*1*	*0.24*
Operation and Maintenance[Rs./yr]	*175*	*0*	*683*	*0*	*0*	*0*	*0*	*0*
Fuel costs[Rs./yr]	*0*	*1825*	*0*	*1325*	*650*	*1983*	*2847*	*350*
Number of light points	*1*	*1*	*2*	*2*	*1*	*1*	*1*	*1*
Light output per point[lumen]	*100*	*100*	*450*	*75*	*45*	*45*	*45*	*450*

Table 13: Annual unit costs per lighting technology

	Solar lantern		Solar Home Lighting System	Mini-grid	Hurricane lantern			Main grid connected
	Stand -alone	LaBL			Subsidised Kerosene	Unsubsidised Kerosene	Black Market Kerosene	
Annual unit cost per lighting point[Rs./yr]	*914*	*1825*	*1969*	*667*	*1088*	*2421*	*3284*	*399*
Annual unit cost per lumen [Rs./lumen hour]	*0,01*	*0,01*	*0*	*0,01*	*0,02*	*0,04*	*0,05*	*0*

The annual unit cost per lighting point of the different cases, shows that the hurricane lantern using kerosene from the black market, unsubsidised kerosene, SHLS and the solar lantern through LaBL are the most expensive. However, looking at the annual unit cost per lumen-hour, the hurricane lantern is in all cases more expensive compared to the other cases. So although the kerosene lighting solution is cheaper when considering initial and running costs, when taking into account the quality of light, it is more expensive. The calculated costs per lighting point of the hurricane lantern are estimates. In reality the price paid for the kerosene bought by the household is a cumulative of subsidised, unsubsidised and black market kerosene costs. As in first instance the household will buy subsidised kerosene, which will be complemented with the unsubsidised and black market kerosene.

The cheapest solution for end-users seems to be the mini-grid and the main-grid. From the latter this can be expected taking into account economies of scale. Looking at the annual unit cost per lumen the SHLS, the incandescent light bulb, the stand-alone solar lantern and the solar mini-grid score relatively high. The SHLS and incandescent light bulb have a higher lumen level. It is debatable whether the additional price paid is worth the quality increase. In the case of the SHLS the annual costs are double as the SHLS consists of two lighting points. This means that the end-user must have more purchasing power.

Investment costs

The end-users with low purchasing power do have problems with the investment costs given. The discount rate for poor end-user tends to be higher than the 20% used in the calculations, which makes the investment costs a significant barrier to overcome. This can be achieved by intelligently designed financial solutions.

Multiple solutions have been suggested by the stakeholders to overcome the investment costs. Also the case studies showed the diverse solutions to address the challenge of the investment costs. Another previously not mentioned option is to decrease the investment cost could be a financial injection by the central government. Money can be diverted from the government funds spent on the kerosene subsidy. It is estimated that more than 67.6 million Indian households still are dependent on 1 or 2 kerosene lanterns for lighting (NSSO, 2008). The annual usage per household is 43.8 litres when assuming a usage of 0.03 litre per hour and 4 hours per day. This gives a total of 3.0 billion litres that is annually consumed for lighting. Together with the subsidy 32.3 Rs./litres gives a total burden for the Indian government of Rs. 96 billion annually. Diverting the subsidy on kerosene to promote solar systems for lighting would in theory be enough to provide 20 million households a solar-lantern of Rs. 1750. In this simplified reasoning the aspects like dissemination costs, technical service and operation and maintenance, availability of supplier, willingness to adopt, adequate solar radiation, are not taken into account. Also the kerosene subsidy is provided to the oil companies, so removal of the subsidy will have impacts on employment within the companies and on the distribution channels of oil. Another point to consider is that the amount of kerosene per month distributed by the PDS to a household is limited to 4 litres, which finds its use not only in lighting but also in cooking.

8.3 Environmental impacts

In this section an assessment is done of the environmental impacts of the discussed lighting technologies. The two major aspects that have impact on the environment of the proposed lighting solutions are the CO_2 emission that can be avoided and the battery usage.

Potential CO_2 emission

In the dissemination of lighting systems a significant contribution could be made to the CO_2 emission reduction, as kerosene is replaced with a cleaner technology. In assessing the potential of

CO_2 emission reductions two cases are considered:

- CO_2 emissions avoided by replacing kerosene lanterns with clean lighting solutions
- CO_2 emissions avoided by replacing kerosene lanterns with the main grid.

In assessing the potential of CO_2 emission reductions the methodology is similar as specified for the application of carbon credits within Clean Development Mechanism (CDM) (UNFCC, 2006). The lighting solutions taken into consideration are the solar lantern, SHLS and solar mini-grid. As the lighting service is addressed, the amount of kerosene that would be needed to generate a similar level of lighting service is determined. Other important parameters are the luminous efficacy (lumen/W) of kerosene lanterns and the energy content of the amount of kerosene, that would have been consumed in absence of the solar lighting solution. Multiplying this with the emission factor of kerosene the emission avoided for implementing a clean lighting solution can be calculated. This gives equation 5, which is an adopted version of the equation used for the application for carbon credits.

$$BE_v = N_v * L_n * d_v * h * \frac{1}{LE_{ker}} * EF_{ker} * 10^{-6} \tag{5}$$

Another scenario would be if these households were connected through extension of the main grid of which the calculation is based on equation 6. In this case the grid-connected households are assumed to have an incandescent lamp of 60 W, such that the lumen output is 450 lumens. The efficiency of the distribution and the transmission is based on T&D losses in the country for the year 2003-04 (CEA, 2006).

$$BE_v = N_v * L_n * d_v * h * \frac{1}{LE_{incandescent\ lamp}} * \frac{EF_{main\ grid}}{\eta_{T\&D}} * 10^{-6} \tag{6}$$

The parameter descriptions and values relevant for equation 6 are given in Table 14 on the next page. The annual emission reduction for the different scenarios are given in Table 15 on the next page, when introducing one lighting point. The emission losses replacing grid without transmission losses are given to see the potential gains that can be achieved when improving the transmission of electricity in India.

From these results estimates could be made how much CO_2 emission could be avoided if 20 million below poverty line households using kerosene lanterns are addressed by a combination of innovative implementation schemes supplying solar lanterns. In the case the households need 2 solar lanterns for education, cooking and productivity activities, the potential total emission reduction could be 15.1 $MtCO_2$/year.

The emission reductions using solar technology for lighting purposes have a large potential for buying carbon credits if coordination between the projects can be accomplished. The project can claim carbon credits through CDM, when sufficient scale is achieved. An example is the implementation of the Gramin Aryavanat bank, that reached sufficient scale by selling more than 33600 SHLS (Pattanaik, 2012). This resulted in an emission reduction of 57.1 $ktCO_2$/year for which the bank obtained a carbon credit agreement. This additional financial resources supports the after-sales service. If other initiatives or projects obtain sufficient scale or there is a coordination between the small-scale implementation projects, there is an opportunity for additional funding by CDM. However, up to now, cooperation between the small-scale players have not yet been successful (Mohanka, 2012).

Table 14: Parameters for calculations of the baseline emissions of kerosene lanterns avoided and of the incandescent lighting avoided

Parameter	Description	Value	Unit	Source
Be_v	*Emissions generated in the absence of the project activity in period v*		CO_2	
N_v	*Number of lighting points added in period v*	*1*		
d_v	*Average number of days lamps have been deployed in period*	*365*	*day/yr*	
h	*Average number of hours solar lamps are used per day*	*4*	*hours/day*	
LE_{ker}	*The specific light output of kerosene of a hurricane lantern*	*0.1*	*lumen/W*	*(Apte et al., 2007b)*
EF_{ker}	*The specific CO_2-emissions of kerosene*	*259*	*CO_2/MWh*	*(UNFCC, 2006)*
$L_{solar\ lantern}$	*Lumen output of solar lantern deployed as part of the project activity*	*100*	*lumen*	*Section 8.2*
L_{SHLS}	*Lumen output one lighting point of SHLS deployed as part of the project activity*	*225*	*lumen*	*Section 8.2*
$L_{mini\ grid}$	*Lumen output of one lighting point in the mini-grid deployed as part of the project activity*	*75*	*lumen*	*Section 8.2*
$LE_{incandescent\ lamp}$	*The specific light output of kerosene when burnt in a kerosene lantern*	*7.5*	*lumen/W*	*Section 8.2*
$EF_{main\ grid}$	*The specific CO_2-emissions of main grid*	*790*	*CO_2/MWh*	*(CEA, 2006)*
$\eta_{T\&D}$	*Efficiency main grid, taking transport and distribution losses into account*	*67.5*	*%*	*(CEA, 2006)*

Table 15: Emission reduction per lighting point after introduction of the modern lighting solution

Implementation type	Baseline emissions replacing kerosene[CO_2/year]	Baseline emissions replacing grid without transmission losses[CO_2/year]	Baseline emissions replacing grid with transmission losses [CO_2/year]
Solar lantern	*378*	*15*	*23*
SHLS	*850*	*35*	*51*
Mini-grid	*283*	*12*	*17*

Battery usage

Additional cost in the project implementation could be essential to incorporate recycling of materials. As the interest and importance of batteries in the evolution of clean lighting technologies is increasing, pressure on the environment due to increase in production of batteries is also increasing. Batteries are very important for small-scale lighting products, but the production and discarding are detrimental for the environment. In order to improve the environmental profile adequate battery waste management should be implemented well.

China is a main producer of batteries and a recent tightening of environmental legislation led to the closure of multiple Lead-Acid factories. This resulted in a shortage of Lead-Acid batteries, the advantage was that more attention was paid to alternatives, like the Lithium battery. Different manufacturers suggest that it has the greatest potential for future development and optimization (Divya and Østergaard, 2009). The benefits are its low weight and small size, which makes the battery ideal for portable devices. The disadvantages are the high costs and the sensitivity to improper discharging.

The mining process of the material for the batteries has shown significant damage, to human health, land degradation and social impact (McManus, 2012). This was largest for the production of Lithium battery. However, the assessment did not take the lifetime of the battery into account. It was pointed out that large-scale use of batteries should incorporate proper recycling processes, which will ultimately lead to a reduction in mining the resource. In the disposal phase of the small sized lighting solution the batteries are the largest contributor to environmental damage compared to the other components (Durlinger et al., 2012).These life cycle analyses of the different battery types have shown that the environmental profile of small size PV lighting products can be improved by 50% when waste management or recycling of the batteries becomes common.

Another environmental consideration is the step from kerosene lanterns to clean lighting solutions results in an increase in usage of other materials. An increase in PCB, casing materials, LEDs and batteries lead to additional waste, that nature can not decompose.

9 Discussion

The research has provided an overview and characteristics of lighting systems that are available for introducing lighting in remote rural areas. The technology and delivery model are intertwined and dependent on the regional context. In order to address the limited quality of lighting in off-grid regions in India a synergistic approach is desirable, but a coherent strategy has not come forward. Solutions are provided on the regional level, which should be supported on the governmental level.

In order to obtain good results, care was taken during the interviews to cover the important topics. The same general topics are addressed, but space was left for variation and conversation. The results were used to obtain understanding of the Indian implementation strategies to provide the lighting and energy services in off-grid regions. The stakeholders provided an Indian perspective, however it would have been interesting to obtain more perspectives from stakeholders outside India. Preferably those who participate in addressing lighting or other energy services in off-grid regions in the developing world. In this research only one NGO in the implementation of energy services was considered, which is not enough to confirm the perspective on the implementation of energy services in India.

The analyses showed that the majority of stakeholders have a limited view of what the possibilities are of the different lighting systems and the accessibility of financial support. Awareness campaigns should be able to widen the perceived array of options. End users of a certain modern lighting solution do not have a similar experience with another technology. Entrepreneurs promoting or participating in the deployment of a certain technology could be limited in their perception due to their own preference.

Case studies in this research were not all in off-grid regions. Some of them were connected to the grid, but were cut-off in the evening. The feasibility of the delivery models in these villages are valid as well, as there is sufficient customer base for the introduction of an alternative lighting solution. The case studies selected contributed to understanding of the Indian context in relation to the delivery models discussed. The observation of multiple cases provide more robust information about relationships and characteristics of an implementation of a lighting system. The number of case studies to grasp the regional and social diversity was limited. Increasing the number of case studies would have provided more robust information on the stakeholders interactions and delivery mechanisms.

In assessing the lighting needs the assumption is made that it is not relevant how the lighting need is met. This is true when looking on the level of well-being, however a village that is connected to the main grid generally has a different demographic composition and economic circumstances compared to an off-grid village. The change in lighting needs might be supplemented by the introduction of other energy services.

Men have started to read and do more productive work, while for women the domestic work has shifted from the morning to the evening hours. It is debatable whether the lighting has improved the lives of the women, on the one hand the women have the liberty to spread their daily activities over the extended days and on the other hand women are in fact starting to do more domestic work as the improved lighting condition has given them the opportunity.

The delivery models were discussed with the historical and current backdrop of the policies in India. The policy impact on the delivery models are indirect as they are not specifically designed for off-grid lighting solutions, but targeted at electrification for poor households and the promotion of solar technology. The policy measures discussed focused on the technology and not on the social measures to reduce poverty. In order to get a complete picture of the well-being of households it would be important to consider measures of the central government that address poverty in India, of which the lighting service could be one aspect enhancing the well-being.

In this research the central power utilities were not considered as an initiator of off-grid projects. Nevertheless, the largest power generation company in India has been setting up model distributed generation projects for village electrification based on renewable energy sources to demonstrate the techno-commercial viability and sustainable operation of such projects. Even if a project is successfully deployed and is in operation there is still a risk of being rejected by the local communities. The utilities biggest strength, namely its centralisation is also its biggest weakness. The central utility is not flexible enough to address unique features of the energy needs.

The research focused on lighting systems that serviced the lighting needs at night. This is often assessed as the most urgent need in remote rural areas. However, during the day storage rooms or houses without windows also require lighting. In these situation different type of lighting solutions that uses the sunlight directly can be considered.

10 Conclusions and recommendations

The aim of this research has been to gain insights from different implementations of lighting solutions and provide recommendations for appropriate lighting systems in remote rural areas. As previous researches have focused either on small-scale lanterns or on mini-grid systems supplying electricity, this research considered a more extensive spectrum of the different solutions and delivery models. The following research question is answered within this research:

What are appropriate modern lighting systems for the rural consumers in off-grid regions in India?

Different lighting systems are available, but the answer to this question is that there is not a single lighting system that has been identified as being the most appropriate. The various lighting solutions meet different local circumstances. Several systems have been identified and can be divided in their technological characteristics and their associated delivery models.

The lighting system comprises of a technology part where alternatives for traditional lighting are considered. These are solar lanterns, SHLS and mini-grid based solutions. The mini-grid can be powered by several means, which are solar, biomass, hydro power and wind.

In evaluating the technical criteria of the lighting devices, the lighting duration at sufficient illuminance and robustness of all components are the key factors for user satisfaction and willingness to pay. Improving the environmental profile of the lighting solution attention must be paid to adequate battery waste management. Modern lighting solutions have a lower of carbon footprint compared to traditional lighting solutions. An assessment of the potential showed that in the hypothetical case of introducing solar lanterns to 20 million households replacing kerosene, the emission reduction would be 15.1 $MtCO_2$/year. These emission reductions could support acquiring additional funding by carbon credits by aligning multiple projects.

The lighting systems in this research are also defined to include the delivery model as different means are available to bring the solution to the end-user. The following delivery models have been identified for small-scale solutions: fee-for-service, leasing and consumer financing. For mini-grids these are: community managed systems, village cooperatives and private models. The models are appropriate depending on local conditions. A partnership between a private actor and a public institution can be beneficial for the project implementation. Innovation is driven by private sector management and the public institution can provide sufficient financial capital and influence the distribution channel. Policies should be designed in support of facilitating essential capabilities for lighting delivery models like physical distribution, financing and after-sales.

The case studies revealed contributors to the success of implementation models for lighting solutions. The financial feasibility of mini-grid sized solutions for lighting services is increased when having the technological possibility to synchronize with a future main grid in the region. The market for private investors could be enlarged by relaxing the concession regulation for electricity generation of officially grid connected villages. An enabler for projects to become successful are financial incentives for rural banks to provide loans to customers who want to purchase a lighting system. Another option is governments are willing to set an example by supporting project implementations in this market. The uptake of small-scale lighting solutions will be enhanced as the trust between rural banks and lighting end-users is strengthened. Another enabler is the provision of affordable after-sales, which can be achieved through sufficient regional technical support.

Rural consumers in off-grid regions can be characterised by their need and behaviour in relation to the lighting service. Changes in the provision of lighting include improvements in the quality of light, output of light, and longer operation time. These aspects enable productivity opportunities, longer study times, better comfort and protection, reduction in time to collect fuels and entertainment. The modern lighting solutions also provides health benefits for the end-user as the indoor-air quality is improved.

High investment costs can be overcome by including a financial solution in the delivery model. Cleverly designed delivery models showed that modern lighting technologies can be cheaper than kerosene lighting. Including the quality of light in the comparison favours the households even more when comparing the running costs of low carbon lighting technologies with the hurricane lantern.

The differences between small-scale and large-scale lighting systems show a shift in ownership from individuals to community based models. As the size of the delivered lighting system increases, shifts are observed in the funding. Also stakeholders change in the business model promoted.

As there is not one technical solution/delivery model that can grasp the distinct contexts of implementations, lessons must be taken from past experiences, which can improve future projects and scale up lighting initiatives in remote rural areas. The characteristics for successful lighting systems implementations are:

- In India, solar is recommended as the most appropriate solution. The focus in this research has been on solar, because of its scalability to the end-user needs, its availability across the country and its reliability. Other resources may be considered appropriate depending on demand and geographical characteristics.
- Viewpoints on how to address the dissemination differ significantly between the stakeholders, which makes a central and synergistic approach in addressing the scaling of the lighting solution in remote rural areas harder. This in fact suggests that the solution must be found at the regional or village level where directions are set out by a central government supporting these local initiatives.
- As the end-users have limited purchasing power, expectation management of implementations of small-scale solutions becomes more important. The business plans should take into account the social impact as disappointment in the technology can result into rejection.
- When implementing large-scale lighting systems more focus must be on DSM. This improves energy efficient behaviour of the end-user, thereby supporting the feasibility of the project implementation. It was observed that fixed-tariffs on the household level led to inefficiencies and losses in the project implementations.
- In order to improve feasibility of a micro/mini-grid solution it should be designed to be connected with a central grid. The priority is to cater to the local demand, but the surplus generation should be fed into the central grid.
- Barriers to information on the technology can be overcome by education and raising awareness. This can be a result of projects where the community becomes educated and information can trickle down through effective involvement and participation in the implementation process. A large-scale attempt to address poverty and well-being in the country a government programme should especially address the promotion capability, as campaigns can increase the user acceptance of the pushed technology.
- From the technical criteria perspective the evaluation during a project implementation should be done in several phases. In consecutive order these are at the offset of the project, during the field-tests and after the implementation. Feedback mechanisms will facilitate fine-tuning the delivered lighting systems.

However, certain grounds for failure transcend the local circumstances and can be generalized. The hallmarks of failed lighting system implementations are:

- The lighting solution is too expensive for the targeted population and no financial solution is provided.
- The lighting intensity delivers a low light output or has a limited runtime.
- The project implementation does not take into account after-sales and technical support, causing limited availability of technical service personnel in the distribution channel.
- Absence of a supply chain of components of the lighting solution.
- Increase in demand of end-users is not taken into account during the design of the lighting system.
- The implementation of the off-grid lighting system is done without taking into account future grid-extension in the region.
- Policies are unrolled without preparing the implementing agencies on procedures.
- The stakeholders in the distribution channel do not benefit.
- Energy demand based on lighting in a mini-grid implementation is too low

From these conclusions and the content of the different chapters the following recommendations for project, policy implementations and future research are made:

- Policies should be designed to facilitate trust between regional rural banks and end-users. This will facilitate the private-sector as consumers will have access to loans.
- Quality control should be promoted on the technical solution level and also on the project implementation level. The increased quality controls should improve the robustness of the implementation. This will come with a price tag, so it is necessary to find a balance between the cost of implementation and the quality control.
- Exemption of territorial concessions given by a state government are an option but in order to attract the private sector, the cost and time involved with the application need to be reduced.
- Manufacturers and project implementers should align their efforts to qualify for available subsidies.
- In order to understand changes in lighting needs, it is desirable to have a quantitative measurement. The literature survey showed that most of the projects and reports on the topic had their own unique methodology to quantify these needs, which obstructed the cross-cut comparison of different project implementations.
- The end-user in off-grid areas has a limited choice in the array of modern lighting solutions. On one hand the lighting system is enforced on the governmental or community level and on the other hand the market of modern lighting solution in the region is only sparsely represented. In this way the market can not address the lighting need efficiently. In order to have efficient markets operating, policy action should encourage competition between different brands of solar lighting solutions in remote rural areas.

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APPENDIX A Modelling impacts after introduction modern lighting

The quantification and comparison of different researches on how much lighting is required for a specific task is challenging. There are distinctions observed in the methodologies used. This means that one to one comparison between gains in well being cannot be done without large assumptions. In modelling attempts are made to quantify the lighting needs, which can be achieved by certain modelling assumptions. The energy requirement for lighting or other energy services can be estimated by for example using the acreage of the house (van Ruijven et al., 2011; Daioglou et al., 2011). Another methodology would be the assumption that the energy use for lighting is based on income, which holds until a certain level (Reddy and Balachandra, 2006). Fuel requirements are expected to rise with increasing household size, but also economies of scale holds for household lighting. For example the cost of lighting per household member reduces as the size of the household increases, as one lamp can light up a room whether one person or five people are trying to read. Also the energy use for lighting is not expected to increase endlessly with income as there will be a limit in the demand.

The poor consumers that have a limited budget for energy consumptions are forced to use a less convenient fuel for lighting as long as it is cheaper. The intangible factors like the mentioned higher time consumption for fuel collection and exposure to particulate matter, lead to a non-monetary burden or an inconvenience cost for the households. Attempts to include these inconvenience costs in modelling have been made to analyse impacts of policy measures on the diffusion of modern energy sources in India (Ekholm et al., 2010). These models are limited in the way they can differentiate the local situation in every case. The lighting service needs are highly contextual; the requirements for a school-aged child doing homework are different from their mother in a night market kiosk and from the night watchman who patrols a gate.

APPENDIX B List of institutions and people interviewed

The interviews were conducted with a selection of the identified stakeholders. In the list below the interviewees related to a registered organisations are mentioned.

Governmental bodies
MNRE: Maithani, P.C.
Raza, A.
Khare, D.K.
Saxena, P.

Manufacturers
Global Telelinks: Rao, C.V.
Gautum Polymers: Mohanka, G.
Greenligh Planet: Sekhsaria, M.
Barefootpower: Kumar, P.
Hogan, E.

Researchers and NGOs
TERI: Chaurey, A.
Kumar, A.
Tiwari, J.
Prashant, V.
ETC: de Winter, J.
Alternate Hydro Energy Centre: Kumar, A.
Saini, R.P.
ABPS Infrastructure Advisory: Mande, S.

Financial institutions
S^3IDF: Natarajan, H.
Aryavart Gramin Bank: Pattanaik, P.K.

Entrepreneurs
Mera Gao Micro Grid Power: Jaisinghani, N.

APPENDIX C Inventorization small-scale solar lighting solutions

General Information					Warranty				Autonomous RunTime (full battery) [Hours]		Lighting System	Light output				Storage System			Battery Protection					Battery indicators		Certification				Extra		Price	
Source	Product Name	Manufacturer	Solar Lighting Device	Website	Not specific[months]	Lamp[months]	Battery[months]	Solar Module [months]	Low setting	High setting	Lamp type	[Lux at 3 feet, horizontal(h), vertical(v)]	[Lumens]	LightDistribution [degrees]	Charge type(s)	Storage Type Battery	Nominal Battery Voltage [V DC]	BatteryCapacity [mAH]	Active HVD	Active LVD	Reverse polarity	Others	Easily Replaceable Battery	Status	Charging	Battery	SPV	Lantern	Others	Mobile charger	Dimmer	Without Solar Panel [Indian Rupees]	With Solar Panel [Indian Rupees]
GIZ	Ammini	Ammini Solar Pvt. Ltd	Ambient lantern	www.ammini.com						3	CFL		380	360		Lead acid	12	7200														-	6500
Solar Quarterly	ALC7DC	Arsh Electronics Pvt Ltd.	Ambient lantern	www.grotal.com/arshelectronics						4-5	CFL		420	360	PV and AC		12	7000								X	X	X		X		1430	3400
Solar Quarterly	All3DC	Arsh Electronics Pvt Ltd.	Ambient lantern	www.grotal.com/arshelectronics						8-9	LED		90	360	PV and AC		6	4500								X	X	X				1045	2150
GIZ	AS018	Astral Solar Technology Co.	SHLS	www.astsolar.com							CFL				External PV and AC	Lead acid	12	12000												X		1100	-
GIZ	AS021	Astral Solar Technology Co.	Ambient lantern	www.astsolar.com	12					10	LED			360	External PV	Lead acid	6		X	X									X		X	-	825
TERI Solar Lighting Laboratory	LED Lantern	Avni Energy Solutions Pvt. Ltd	Ambient lantern	www.avnienergy.com						8.75	LED				PV	SMF lead acid	6	4500	X	X	X			X								-	-
TERI Solar Lighting Laboratory	LED Lantern	Avni Energy Solutions Pvt. Ltd	Ambient lantern	www.avnienergy.com						7.5	LED				PV	SMF lead acid	6	4500	X	X	X			X								-	-
Solar Quarterly	Electra	Avni Energy Solutions Pvt. Ltd.	Ambient lantern	www.avnienergy.com						12	LED		180	360	PV and AC	Lead acid	6	4500	X	X				X	X	X	X					1072	1650
Solar Quarterly	Electra Big	Avni Energy Solutions Pvt. Ltd.	Ambient lantern	www.avnienergy.com						12	LED		360	360	PV and AC	Lead acid	12	7200	X	X				X		X	X					1760	2750
Lighting Africa	Barefoot Firefly 12 Mobile	Barefoot Power	Task light	www.barefootpower.com		6		12	8.5	4.4	LED		25	Wide	PV	Rechargeable NiCd	3.6	680	X	X			No							X		-	1600
Lighting Africa	Barefoot PowaPack 5 W	Barefoot Power	SHLS	www.barefootpower.com		12		24	77	19	LED		190	Wide	PV	Rechargeable Sealed Lead Acid	12	4200		X			No							X		-	7000
Lighting Africa	PowaPack Junior 2.5W Matrix	Barefoot Power	SHLS	www.barefootpower.com	12				9.4	19	LED		25	Wide	PV	Rechargeable NiCd	3.6	3000		X		Passive HVD	Yes						X	X		-	3250
Solar Quarterly	KSSL 09 a/b	Bhambri Enterprises	Ambient lantern	www.bhambrienterprises.com						5-6	LED				PV and AC		6	4500									X					1155	1760
TERI Solar Lighting Laboratory	LED Lantern	BNK Energy Alternatives	Task light	www.ledon.in						14.45	LED	7h, 62v			PV	SMF lead acid	6	4500	X	X	X			X	X							-	-
TERI Solar Lighting Laboratory	LED Lantern	BNK Energy Alternatives	Ambient lantern	www.ledon.in						11.5	LED				PV	Lithium Ion	7,4	2200	X	X	X			X	X							-	-
TERI Solar Lighting Laboratory	LED Lantern	BNK Energy Alternatives	Ambient lantern	www.ledon.in						10	LED				PV	SMF lead acid	6	4500	X	X				X	X							-	-
GIZ	Mightylight 3040	Cosmos Ignite Innovations	Task light	www.cosmosignite.com						8	LED	Satisfactory			External PV	NiMH															X	-	3000
GIZ	Kiran	d.light	Ambient lantern	www.dlightdesing.com/home_global.php	6				8	5	LED			360		NiMH	3.6	300				overcharge protection										-	1040
GIZ	Solata	d.light	Task light	www.dlightdesing.com/home_global.php	6					4	LED			90		NiCd	3.6	400				overcharge protection										-	940
Website dlightdesign	S250	d.light	Torch	www.dlightdesing.com/home_global.php	12					12	LED		80-100	90	PV and AC	NiMH			X	X			Yes	X					X	X	X	-	2250
TERI Solar Lighting Laboratory	LED Home Lighting System	D.W. Power	SHLS							4	LED				PV	SMF lead acid	12	N.A.	X	X				X	X							-	-
TERI Solar Lighting Laboratory	LED Task light	ECCO Electronics	Task light	www.ecco.in	12					18.1	LED	5h, 25v			PV	Lead acid	6	4500	X	X	X		Yes	X						X		-	1695
Solar Quarterly	VII	Freeplay Energy India Ltd.	Ambient lantern	www.freeplayenergy.com						5	LED		240	360	PV, AC and manually operated	NiMH	6	4000						X		X				X		1815	-
Solar Quarterly	Sourapam – 10	Geetanjali Solar Enterprises	Ambient lantern	www.geetanjalisolarin.com						4-5	CFL		371	360	PV and AC	Lead acid	12	7000									X	X		X		2750	4400
Solar Quarterly	Sourapam -3	Geetanjali Solar Enterprises	Ambient lantern	www.geetanjalisolarin.com					8	4	LED				PV and AC	Lead acid	6	4000									X	X		X	X	1100	1650
GIZ	SL9000SW	Global Marketing Technologies Inc.	Ambient lantern	www.gmtems.com							CFL				Internal PV	Lead acid																-	-
Solar Quarterly	SHL2	Global Telelinks Ltd.	Task light	www.prakruthipower.com		12	12	12	60	8	LED		100	120	PV	Lithium Ion	3.7	1400	X	X			Yes				X			X		1430	2200
Solar Quarterly	SHL1	Global Telelinks Ltd.	Task light	www.prakruthipower.com					30	4	LED		100	120	PV	Lithium Ion	3.7	1400									X			X		1210	1650
Lighting Africa	Sun King Pro	Green Light Planet India Pvt. Ltd.	Task light	www.greenlightplanet.com	12				15	6	LED		110	Wide	PV	LiFePO4 Rechargeable	6.6	1450	X	X		Cell Balancing	No	X	X				X	X		-	1550
Lighting Africa/Solar Quarterly 2010	Sun King	Green Light Planet India Pvt. Ltd.	Task light	www.greenlightplanet.com	12				16	4	LED		46	220	PV and AC Grid	Rechargeable Lithium Ion	3.7	780	X	X			No			X			X		X	-	935
Solar Quarterly	Prism lantern	Halonix Ltd.	Ambient lantern	www.halonix.co.in						4-5	LED		225	360	PV and AC	Lead acid	6	4500						X		X	X					1650	4565
TERI Solar Lighting Laboratory	LED Lantern	Innovlite India Pvt. Ltd	Ambient lantern	www.innovlite.com						22	LED	2.2 h, 22.8 v			PV	XL power SMF lead acid	6	4500	X	X	X			X	X							-	-
Solar Quarterly	JJL-2	Jain Irrigation System Ltd.	Ambient lantern	www.jains.com						4-5	CFL		371	360	PV		12	7500								X	X	X			X	3355	4560
Solar Quarterly	JJL-3	Jain Irrigation System Ltd.	SHLS	www.jains.com						2.5-3	CFL		558	360	PV		12	7500								X	X	X			X	3575	4785
Solar Quarterly	JJLL-1	Jain Irrigation System Ltd.	Ambient lantern	www.jains.com						4-5	LED		42	360	PV		12	7500								X	X					1210	1980
Lighting Africa	Sunlite Solar Light	Kingfisher Consultants Ltd.	SHLS	www.sunlite.co.ke		12	6	12		10	LED		85	Wide	PV	Rechargeable Lithium Ion	3.7	3000		X			Yes						X	X		-	2500
GIZ	MS01	Macro-Solar Technology Co. Ltd	Ambient lantern	www.macro-solar.com							LED				Internal PV	NiMH																-	-
TERI Solar Lighting Laboratory	LED Lantern	Moser Baer India Ltd.	Ambient lantern	www.moserbaer.com						9.5	LED				PV	SMF lead acid	6	4500	X	X				X								-	-
Solar Quarterly	SL03–SL05	Moser Baer India Ltd.	Lantern	www.moserbaer.com					12	6	LED		128	360	PV and AC	Lead acid	6	4200								X	X			X	X	2200	2750
GIZ	Aishwarya NEST-6543	Noble Energy Solar Technologies Ltd.	Ambient lantern	www.solarnest.net						7-9	CFL	Very Good		360	External PV	Lead acid	6	4000														-	4700
Lighting Africa	SHLS+mobile charger	Philips	SHLS	www.philips.com/offgridlighting	12				11	5.3	LED		38	Wide	PV	Sealed Lead Acid	4	4000		X			Yes						X	X		-	-
Lighting Africa	Uday Mini	Philips	Ambient lantern	www.philips.com/offgridlighting	12					6.6	CFL		120	Omni	PV	Rechargeable Sealed Lead Acid	6	4400	X	X			Yes						X			-	3650
Solar Quarterly	Arushi	Reliance Industries Ltd	Ambient lantern	www.relsolar.com						12	LED		200	360	PV	Lead acid	6	4500									X					-	3520
Solar Quarterly	CFL-lantern	Reliance Industries Ltd.	Ambient lantern	www.relsolar.com						10	CFL		371	360	PV	Lead acid	12	7000									X	X				-	4920
Solar Quarterly	HUTLITE-006A	Ritika Solar System Pvt. Ltd.	Ambient lantern	www.ritikasystems.in						3-4	LED		180	360	PV and AC	Lead acid	6	4500/7200									X	X				1100	1760
Solar Quarterly	HUTLITE-006F	Ritika Solar System Pvt. Ltd.	Ambient lantern	www.ritikasystems.in						3.5	LED		350	360	PV and AC	Lead acid	6	4500									X	X				1540	2200
Solar Quarterly	HUTLITE-006G	Ritika Solar System Pvt. Ltd.	Ambient lantern	www.ritikasystems.in						3	LED		330	360	PV and AC	Lead acid	6	4500									X	X				1700	2354
Solar Quarterly	HUTLITE-952A	Ritika Solar System Pvt. Ltd.	Ambient lantern	www.ritikasystems.in						3-4	CFL		427	360	PV and AC	Lead acid	12	7000									X	X				1375	2860
Solar Quarterly	HUTLITE-954A	Ritika Solar System Pvt. Ltd.	Ambient lantern	www.ritikasystems.in						2	CFL		250	360	PV and AC	Lead acid	6	4500									X	X				770	1500
Solar Quarterly	HUTLITE-006E	Ritika Solar System Pvt. Ltd.	Ambient lantern	www.ritikasystems.in						4-5	LED		280	360	PV and AC	Lead acid	6	4500									X	X				1320	1980
Solar Quarterly	Kirandeep	Ritika Solar System Pvt. Ltd.	Task light	www.ritikasystems.in						4-6	LED		110	180	PV and AC	Lead acid	6	4500									X	X				990	1320
GIZ	Solar 2007-1	Solarprojekt Freilassing e.V.	Ambient lantern	www.solarprojekt-freilassing.de						8+	LED	Poor		360	External PV	NiMH	3.6	4500				overcharge protection										3250	5525
GIZ	Wuara 2212SL	SolEnergy Africa PTY Ltd	Ambient lantern	www.solenergycc.com							LED				PV																	-	-
TERI Solar Lighting Laboratory	LED solar lantern	Solid Solar	Ambient lantern	www.gautampolymers.com	12					7.15	LED	5h, 25v		360	PV	SMF lead acid	6	4500	X	X	X			X					X		X	-	1500
TERI Solar Lighting Laboratory	olar Lantern(Micro Controller B	Solid Solar	Ambient lantern	www.gautampolymers.com	12					8.5	LED	3.3v, 25.6h			PV	SMF lead acid	6	4500	X	X	X			X								-	-
Solar Quarterly	SS-1001	Solid Solar	Ambient lantern	www.gautampolymers.com	12				14	6	LED		120		PV and AC	Lead acid	6	4500									X				X	1713	3100
Solar Quarterly	SS-1002	Solid Solar	Ambient lantern	www.gautampolymers.com	12				12	6	LED		120		PV and AC	Lead acid	6	4500									X					1876	3250
Solar Quarterly	SS-1003	Solid Solar	Ambient lantern	www.gautampolymers.com	12				12	6	LED		120		PV and AC		6	4500									X					2053	3400
Solar Quarterly	SS-1007	Solid Solar	Ambient lantern	www.gautampolymers.com	12					7-8	LED		100		PV and AC	Lead acid	6	4500									X	X				1777	2700
Solar Quarterly	SS-1008	Solid Solar	Ambient lantern	www.gautampolymers.com	12				14	6	LED		150		PV and AC	Lead acid	6	4500									X	X		X	X	1881	2800
Solar Quarterly	SS-1009	Solid Solar	Ambient lantern	www.gautampolymers.com	12				14	6	LED		100		PV and AC	Lead acid	6	4500									X	X		X	X	1881	2800
Solar Quarterly	SS-1010	Solid Solar	Ambient lantern	www.gautampolymers.com	12					3-4	CFL				PV and AC	Lead acid	6	9000									X					1020	2000
Solar Quarterly	SS-1011	Solid Solar	Ambient lantern	www.gautampolymers.com	12					2.5	CFL				PV and AC	Lead acid	6	4500									X					1143	2121
Solar Quarterly	SS-004	Solid Solar	Ambient lantern	www.gautampolymers.com	12					3-4	CFL				PV and AC												X				X	2043	4700
Solar Quarterly	Wonderlite	Solkar Solar Industry Ltd	Ambient lantern	www.solkar.in					13	6	LED			180	PV and AC	Lead acid	6	4500								X	X	X			X	1430	2200
Solar Quarterly	Sunshine	Solkar Solar Industry Ltd.	Ambient lantern	www.solkar.in					12	6	LED			360	PV and AC	Lead acid	6	4500								X	X	X			X	1540	2540
GIZ	Glowstar GS7	Sollatek Ltd	Ambient lantern	www.sollatek.com						Satisfactory	CFL	Very Good			External PV	Lead acid																-	19000
GIZ	Solux LED 100	Solux e.V	Ambient lantern	www.solux.org						7.5	LED		80-100	180	External PV		3.6	3500												X	X	-	3380
Lighting Africa, GIZ	Solux LED-50	Solux e.V	Torch	www.solux.org		12			44	5.6	LED		68	90	PV and AC Grid	Rechargeable NiMh	3.6	1700	X			passive LVD	No						X	X		-	3200
Solar Quarterly	IIA	Suntechnics Energy Systems Pvt. Ltd	Ambient lantern	www.conergy.com						3	CFL		371	360	PV		12	7000								X	X	X				1650	3276
Lighting Africa	Suntransfer1	SunTransfer	Torch	www.suntransfer.com	12				31	11	LED		67	Wide	PV and AC Grid	Rechargeable GEL Lead Acid	6	2900	X	X			Yes						X	X		-	-
Lighting Africa	Suntransfer2	SunTransfer	Torch	www.suntransfer.com	12				28	17	LED		70	Wide	PV and AC Grid	Rechargeable GEL Lead Acid	6	4500	X	X			Yes						X	X		-	1600
Solar Quarterly	SL01N Indoor	Suraj Solar System	Ambient lantern	www.surajsolar.com						5-6	LED		240	360	PV and AC	Lead acid	6	4500	X	X								X		X	X	990	1633
Solar Quarterly	SL01N Outdoor	Suraj Solar System	Lantern	www.surajsolar.com						7-9	LED		240	360	PV and AC	Lead acid	6	4500	X	X										X	X	990	1633
Lighting Africa	Sundial	Trony Solar Holdings Co. Ltd.	Task light	www.trony.com	24				23	6.9	LED		87	Wide	PV	Rechargeable LiFePO4	6.4	1600	X	X			No							X		-	2700
Lighting Africa	SolarMine Solar Lantern	Uniglobe HNT Co., Ltd.	Ambient lantern	www.solarmine.co.kr	24					13	LED		100	Omni	PV	Rechargeable Lithium Ion	3.6	5800		X			No									-	-
GIZ	Sun x-set mobile	Wurth Solergy	SHLS	www.we-online.de						Very Good	CFL	Very Good			External PV	NimMH/lead acid																-	26800

APPENDIX D Case studies

SELCO (Leasing/Purely Private Model)

General description: SELCO targets remote rural villages that are either off-grid or connected to an unreliable power source. SELCO views a product as a combination of technology and finance and hence uses the approach of door-step service and door-step financing to overcome several barriers of modern lighting dissemination (SELCO, 2012). SELCO has been able to assess the end-user needs and create a solution that fits best. Thereby focusing on distribution, sales and post-sales service. The sales force and associates promote the products that SELCO has to offer and are the link to the financing options, which can be through MFI, Self Help Groups (SHG), National Banks or Rural Banks. Another model supported by SELCO is where the entrepreneur obtains a loan to purchase a solar lantern charging system. He will repay the loan by the income he generates from renting out the solar lanterns to street vendors. SELCO is facilitating this loan as the intermediary between the entrepreneur and the local bank.

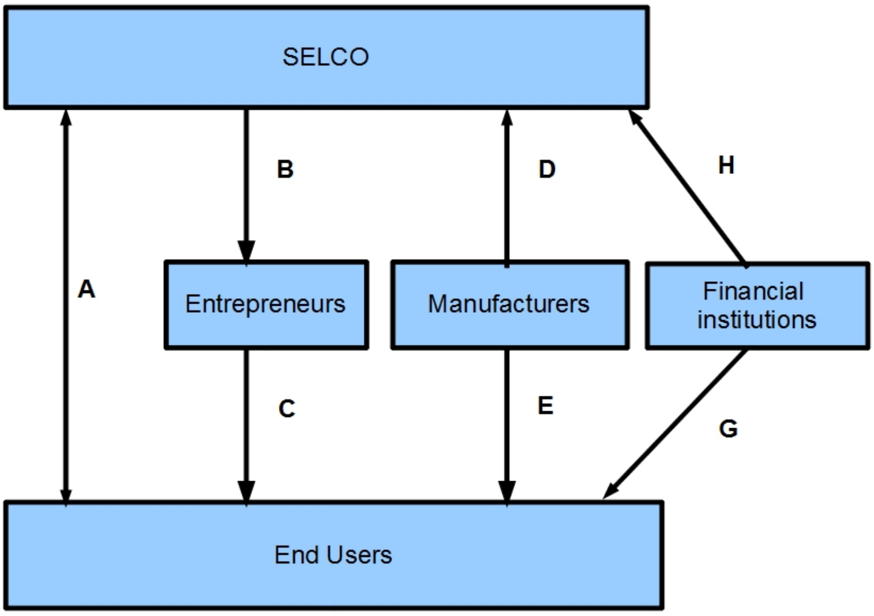

Figure 14: Stakeholders of the SELCO model.

Figure 14 shows the stakeholders in the SELCO business model. The NGO SELCO comprises of two parts, headquarters and direct sales force. Instead of the latter, business associates like the entrepreneurs are used for direct sale. Awareness is raised by sales executives that promote their products through wall paintings, banners and demonstration vehicles in remote villages and at local fairs. The manufacturers provide the solution and after-sales directly or via SELCO. The national/rural banks, MFIs, SHG provide financial support directly to the end-user or combined with a lighting solution. The arrows between the stakeholders represent the relations as follows: (A) between SELCO and the end-user contains the doorstep delivery of the lighting solution through the regional offices, retail offices and SELCO's direct sales and in the other direction the information/ financial stream is shown. (B), (C) Instead of the SELCO direct sales unit, the regional unit could have a business associate/entrepreneur as the sales person of the lighting solution. (E) The after-sales service provided by a technical team or by a representative of the manufacturer. (D) represents the stream of lighting solutions of the manufacturer that uses the distribution channels of SELCO to reach a customer base. (G) The financial solutions that are provided by the MFIs, national/rural banks and SHGs. (H) The indirect financial service that SELCO delivers to the end-user through international investors and banks. This also represents the trusting relation that SELCO builds with the rural banks in order for them to support poor rural customers. Providing the tailor made solution to meet the end-user needs can not be done on a large-scale. There are high investment costs which can hardly be paid by people living below the poverty line. SELCO has overcome this barrier by building a trust relationship with various banks.

Credit and financing: The SHLS provided by SELCO range in price from Rs. 7,000 to 20,000 (Bairiganjan et al., 2009). The majority, around 90% of the products are purchased on credit through financing agreements with local banks. SELCO has formed a steady relationship in Karnataka and Gujarat with regional rural banks, commercial banks, NGOs and rural farmer cooperatives to develop financial solutions, which matches the cash flows of the targeted rural population. Some end-users work directly with the finance organisations, while others work through SHGs. For the bank this provides an added benefit as it gives additional security that a loan will be repaid. For example: a local village bank arranged the loans which suited the cash flow of the customer with appropriate payments in instalments. Also rural banks often require a minimal deposit before providing a loan, it is here where SELCO steps in as poor households often don't have this amount of cash. The funding of the margin money is possible with support from external investors like Renewable Energy & Energy Efficiency Partnership (REEEP).

Post-sales services: In the lease to own programme the focus is on establishing a steady long-term relationship with the customers and building their trust and confidence. Initially SELCO provided, along with the financing scheme, different type of warranties to end-users. These were additional one-year guarantee to the manufacturer's warranty and a 9-day money back guarantee along with a year free service. Currently, SELCO provides a free service for 1 year and after that the consumer has the option of availing an annual maintenance contract or a pay per service contract.

Table 16: SWOT Consumer-Financing/Leasing, SELCO

Strengths	**Weaknesses**
- Ownership	*- Scalability of this private model, regional limitation*
- Private sector can result in innovation	*- Profit centred, thus at times households without paying capacity are left out*
- Building trust between end-users and rural banks	*- Reliance on external technicians*
Opportunities	**Threats**
- Model can be regionally expanded by other entrepreneurs/companies	*- Grid extension*
- Lowered hurdle to approach bank for other financial services	*- Investment partners controlling entrepreneurs*
- Coherence community through SHGs	*- Limitation in customisation with growth*

Strengths and weaknesses: In Table 16 the SWOT is shown of the SELCO model. The strengths are that the end-user becomes the owner of the product. The independence of external regulations for subsidy or others, pushes the company to continuously innovate to stay ahead in the field of private lighting service providers. Due to the tailor made solutions there are limitations to the growth of the model, which is a drawback acceptable for SELCO as a non-profit organisation. On the entrepreneurial level, there is an aim to make a profit, which could result in excluding the households with lower paying capacity. SELCO focusses on distribution and sales, so the model is dependent on external parties for technical development. Therefore it is vulnerable in the post-sales service as the manufacturer might change his mind.

NEST (Direct Sales)

General description: The Noble Energy Technologies (NEST) was initiated by Mr. D.T. Barki in 1998 to end light poverty in India. In the beginning loans were needed by NEST to have seed capital to start the company and credits were obtained from local banks to buy materials and assemble the solar lanterns.

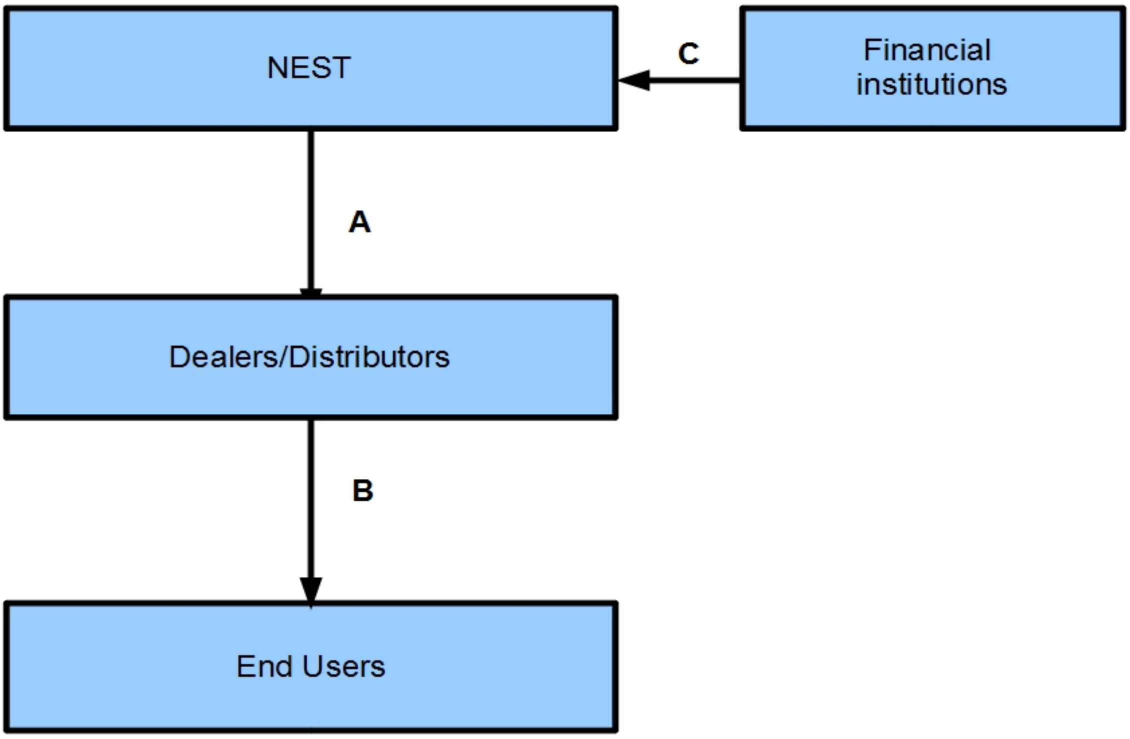

Figure 15: Stakeholders case study NEST

The initial sales of solar lanterns were disappointing as only 5000 units per year were sold. Several reasons were put forward: being a small beginning company in an unknown market and the retail price of the product was to high. It was pointed out that the majority of poor rural consumers have irregular and small cash flows, little savings and no credit options.

The arrows in Figure 15 represent the relations as follows: (A) NEST designs and manufacturers the solar lanterns, which they provide to dealers and distributors. (B) These dealers can be independent businessman, who are responsible for the sales, training, after-sales services and recycling of batteries. (C) The financial institutions and friends of NEST provided credit and financial support for the seed capital. Around 2003 NEST came into financial problems, through the limited screening of the dealers that were appointed. The products were sold on credit and it became almost impossible to recover his money from the market (IBS, 2009). The flow of the products and credits were out of NEST's control, which almost led to bankruptcy. However, the founder decided to continue as his aim is to address a social need. This perseverance was ultimately rewarded as NEST became a successful enterprise learning from the lessons of the initial years (Jolly et al., 2011).

Credit and Financing: In the first three years of the existence of NEST the end-user paid a price of Rs. 1500 excluding the battery (Karamchandani et al., 2009). This price was too high for the poor end-users.

The company was initiated with seed capital provided from banks and friends. This enabled the company to start an assembling factory and the possibility to buy material on credit. The income stream of the company was based on the sales of the products, services and O&M fees paid by end-users. The profit obtained per solar lantern could rise up to Rs. 500 through the recycling of used material.

Post-sales services: In the initial phase of the company the after-sales service and battery delivery was done by the salesmen and dealers. This meant that the salesman/dealers obtained an important role in the business plan of NEST.

Strengths and weaknesses: In Table 17 is the SWOT analysis shown. The strengths of the implementation of the direct sale is that there can be a large margin through recycling. Another strength is that the salesman/dealers for the sale have an existing distribution channel at their disposal into regions that are hard to attain. However, the use of external salesmen can also be considered as a weakness. Large margins on the lighting solutions are paid by NEST and there is the added risk of abandonment by the salesman of the project and thereby causing capital loss. The price of the lanterns was too expensive, despite the pay-back time being three years. Another weakness was the large dependence on credit during start-up. An opportunity to overcome high initial costs of the lighting solutions for end-users is by creating partnerships with financing institutions. Threats are the poor consumer has no paying capacity or has less willingness to pay.

Table 17: SWOT Direct Sales, NEST

Strengths	**Weaknesses**
- Large margin through recycling - Extensive distribution channel through salesman/dealers existing channels	*- Dependence on external salesman - High retail price product for poor consumers - The need to depend on credits for start-up*
Opportunities	**Threats**
- Create partnerships with financing institutions to enable credits	*- Rejection of the lighting solutions - No paying capacity poor consumers.*

LABL (Fee-For-Service/Public Private Partnership)

General description: The campaign LaBL is an initiative that is targeting a billion rural people improving their lighting sources by replacing kerosene/paraffin lanterns with solar lanterns (TERI, 2011). The model is based on the rental scheme or the fee-for-charging service for solar lanterns. A local entrepreneur is selected and responsible for the solar panels and the O&M of a SCS.

In this case study different stakeholders participate in providing affordable lighting to the rural communities, which is presented in Figure 16. The government is represented by MNRE, which provides the subsidy. TERI is responsible for the LaBL fund, while the grass root NGO is responsible for the implementation. The manufacturers represent in this figure the solar lantern providers and the TRCs that support the after-sales service. The entrepreneur is the one who is responsible for the SCS and the end-users are the ones who rent or charge for a fee. The relations between the different stakeholders are represented by the arrows as follows: (A) The partner organisation (PO) provides the direct link to the entrepreneur and the local community. (B) TERI works with different partners of which some players are in the lighting, the semi-conductor and the PV industry to customise and develop robust and reliable solar lanterns exclusively for the LaBL campaign. In this way the technical partners are guaranteed a market for their products and the project implementers can communicate the requirements of the villagers back to the manufacturers. (C) The product partner of TERI will provide the solar lanterns and the SCS to the VLE. They will take care of the installation and take care of initial technical hiccups. (A), (D) The LaBL partner

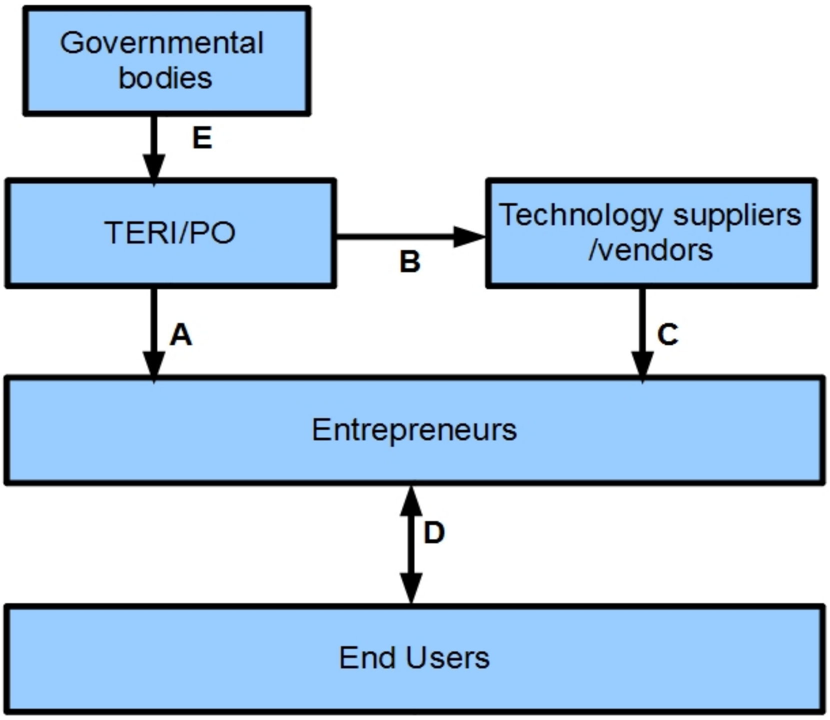

Figure 16: TERI's LaBL model (TERI, 2011).

organisation and the local community will select a VLE, which will take care of the SCS. The VLE has to guarantee the availability of land and building. (C) In the case that multiple SCS are installed in a region it is viable to have a TRC, which will take care of the after-sales service. The ownership of the SCS and lanterns should in the ideal case partially with the community to sustain the LaBL implementation. TERI is responsible for the LaBL fund, which receives financial support from private and corporate funding. (E) In addition subsidies are received from the government for providing the lighting service for poor households.

There are several reasons why a SCS can be preferred in small villages compared to individual purchasing of solar lanterns. In a theft prone area the VLE can lock up the solar lanterns behind closed doors and households in poor villages might be tempted to sell the lantern and solar panel that they own. Another advantage of a SCS is that the lanterns are structurally charged, improving the lifetime of the battery. However, in a village that is highly dispersed it can be more beneficial that each household obtains a solar lantern with an individual solar panel.

Credit and financing: The user pays a daily or a monthly fee for charging or renting the solar lantern. The entrepreneur has the freedom to chose how to use the additional income, e.g. 90% of the monthly fee could be income and 10% can be set aside for maintenance. The rent or charging fee is between Rs. 2-10 per day. This is determined by the paying capacity of the villagers and their willingness to pay. From the project implementation perspective funding can be provided through the LaBL fund, private investors and corporate funding. The SCS in remote areas is mainly funded by grant supported by the LaBL fund and co-financed by a partnering organisation (Krithika and Palit, 2011). If the entrepreneur has sufficient money and wants to participate in the project, he initiates a partnership with LaBL. The partnership enables obtaining a loan for the projects. He will pay back the loan after a number of years, which will free the money for new LaBL initiatives. This makes it from the LaBL perspective a perpetual methodology to finance SCSs.

The LaBL fund can be raised from corporate, private and government schemes. First of all, companies can use their CSR, which is often 2% of their profit. Secondly, as part of different Indian policies a percentage of the project costs are funded by the Indian government. Thirdly, individuals can sponsor a household or a family. Fourthly, the most important one for ownership is the community contribution. A portion of the price of the lantern is paid by the household, partly paid in instalments and partly funded by donations. The total costs for the SCS is Rs. 200000, which can be split up according to 70% on hardware, 7-8% on training and the remaining on O&M, costs for monitoring, project activities and profit (Prashant, 2012).

Post-sales service: The entrepreneur raises capital to financially support the after-sales service. In addition to his income, he builds up an O&M fund that can be utilized when the warranty of the systems has passed. TERI monitors and tracks the different projects on the performance of the VLEs. The lanterns are procured from regional manufactures, which preferably have technical teams in the region. The TRCs visit the villages on advice of the entrepreneur when repairs are needed. On these visits they collect the logbooks of the entrepreneurs, which are given to the NGOs to observe the performance of the charging stations.

Strengths and weaknesses: In Table 18 several strengths, weaknesses, opportunities and threats are identified based on the literature and the observations of implementations of LaBL in Jagdishpur, Uttar Pradesh and Mewat, Haryana. The strengths of the ideal LaBL implementation is that

Table 18: SWOT Fee-for-service, LABL

Strengths	Weaknesses
- Consumers do not have to raise capital *- ESCO O&M*	*- Risk of theft is mostly borne by ESCO* *- To achieve full cost recovery ESCOs might only target affluent households*
Opportunities	**Threats**
- Aggregating demand can result in favourable financing terms for donors *- Operation next to erratic supplying grid*	*- Limitations in resources of trained personnel with appropriate skills* *- Loss of capital of ESCO due to withdrawal of customers of the services* *- Grid extension*

consumers are not confronted with high investment costs to obtain a lantern. Also the entrepreneur and the TRC is taking care of the O&M. A weakness of a LaBL implementation is that the risk of theft is mostly borne by the entrepreneur. Some LaBL implementations do not have a proper TRC in place.

An opportunity is that aggregating demand can result in increased business for the entrepreneur, which will give him additional income. Threats are the limited trained technicians available, the loss of capital of the entrepreneur due to withdrawal of customers for the services. This can be induced through the introduction of the main-grid, micro-grid or mini-grid. This was for example observed in Jagdishpur, Uttar Pradesh.

BUSHLIGHT INDIA (Community Managed System)

General description: Cat Projects in collaboration with Gram Vikas had done an extensive survey to investigate villages that have been expropriated from their original settlement due to the building of a reservoir (Cat Projects, 2012). The focal point of the implementation of a solar powered electrification project was the village Maligaon of 48 families of mixed casts.

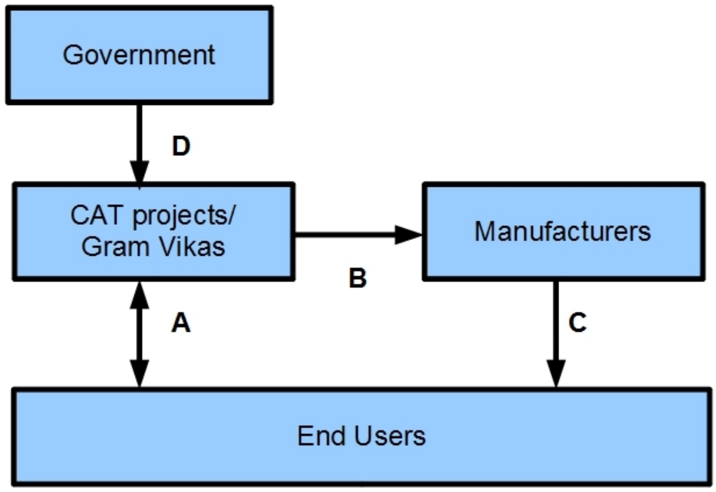

Figure 17: Bushlight India stakeholders.

Figure 17 shows the different stakeholders of Bushlight India. The government comprises of the Australian government largely responsible for the funding and WBREDA. CAT-projects and Gram Vikas, a grass roots NGO from Odisha, are the leading implementers. The manufacturer and system supplier of Bushlight India is TATA BP solar and the end-users are the villagers of Maligaon. The arrows represent the relations between the different stakeholders as follows: (A) Gram Vikas and Cat-Projects select an appropriate site to start the project and hold meetings with the end-users. The end-users support the project implementation with labour and financial support. (B) CAT projects contacts manufacturers for the technical implementation. (C) The manufacturers supply the technology to the household. (D) The government pays the largest part of the investment costs.

Initial meetings with the people of Maligaon were focused on understanding the community needs and the situation of the village. Subsequent meetings were held to inform the people about the contents of the solar electrification project. After agreement of the people to go forward with the project an energy needs assessment was conducted at household and community level taking into account an increase in demand and future expansion of the community. A review of the energy consumption showed that the total designed demand is 22.3 kWh/day, which includes currently unallocated capacity for growth. This estimate was done for 47 houses, 2 shops, 15 area lights and 2 community buildings. A selected energy committee was formed to design the implementation plan. Contributions were made by the people by donating land, bricks and stones for the construction. Some technical developments were done within the project like the Urja Bandhu[21] for the household and the system control board for the operator.

Credit and financing: After the energy assessment on household level, the households were given the liberty to plan their own energy need and the tariff they would be willing to pay.

The funding of the capital cost was done by the Bushlight India Project by the Australian government for 3.2 million US$. The costs for the meetings for community and capacity building were taken care of by Bushlight India Project and Gram Vikas. The powerhouse and the system compound were paid by Bushlight India Project, Gram Vikas and a contribution by the community. The total costs of the implementation was Rs. 5.1 million.

Post-sales service: The technology was delivered by Tata BP Solar. A maintenance contract for 5 year is in place, while the system has a 15 year lifetime.

[21] The Urja Bandhu literally means the Energy friend. It is installed in the connected household and measures the energy usage. Light indicators show how much is left according to their monthly payment.

Strengths and weaknesses: A strength of the implementation is the community commitment and participation (Tuckwell et al., 2011). Other strengths are the scalability of the project to the household and institutional energy demand and the availability of power 24/7. Weaknesses are the dependence on a lengthy preliminary phase and a large dependence on loans/investment. The implication is that the BushLight model is not available to implement on a large scale for many vulnerable villages/communities. Another noteworthy point is that the guarantee of 24/7 power supply is met by a diesel generator as back-up.

Table 19: SWOT Community Managed Systems, Bushlight India

Strengths	Weaknesses
- Community commitment and participation - Scaled to household energy demand - Availability 24/7	*- Lengthy preliminary phase - Large dependence on loans/investment - Diesel generator as back-up - Only in villages where they are the most appropriate technical and economic option, leaving out other vulnerable villages*
Opportunities	**Threats**
- Improved working environment for teachers can result in better education in the village - Longer study time - Additional income generating activities at night - Urja Bandhu can be used within other projects for DSM - Standardization project implementations	*- Increasing demand above the scaled 120% - Grid Electrification - Failure tendering process - Retain technicians willing to work as operator in village*

Opportunities are the improved working environment for teachers. The Urja Bandhu can be used in other projects for DSM. It could be included for the standardization of project implementations. A threat for the implementation is that the demand might increase above the scaled 120%. Another threat is the additional costs caused by a failure of the tendering process. Also the shortage of technicians willing to work as operator in village and the extension of the main grid if there is no option to synchronize with the mini-grid are also threats to Bushlight India.

RAMGAD (Village cooperatives)

General description: In the eighties the state owned Non-conventional Energy Development Agency (NEDA) of Uttar Pradesh aimed to electrify the rural areas. One of the projects was a SHP of 100 kW at Ramgad, which utilized the discharge of the Ramgad river. The project was initiated in 1988 and was finally commissioned in 1990 (Kumar, 2012c). In 2000 the state of Uttarakhand was formed and the project came under control of the Uttarakhand Renewable Energy Development Agency (UREDA). In those days it provided 6 villages electricity in an area that was completely off-grid. It was initially only used for lighting at the household level, but now there are 1000 LED based lamps at the household level and 100 LED based street lights installed. In total it provides to 373 households electricity. The responsibility of the SHP is given to the society/community after commission (Ramgad, 2012). In this case the ownership is taken care of by making the household financially responsible for the connection. The end-user paid Rs. 200 for the connection and initially paid a tariff of Rs. 20-40 per month. In 2004 in cooperation with the UREDA and MNRE the SHP became synchronised with the electricity grid. The connection to the grid made the project financially healthier. The demand initially was only during the evening and the morning, leading to a low load factor. After connection to the grid the load factor increased from approximately 15% to

80% and excess supply was sold to the grid.

In Figure 18 the different stakeholders of the Ramgad SHP are shown. The governmental body in the initial phase was NEDA Uttar Pradesh. In a later phase this became UREDA and MNRE. The technical suppliers/vendors were multiple companies providing the powerhouse and turbines. The VEC operates and maintains the project. The end-users utilize the electricity, the power-suppliers buy excess electricity generated and provide electricity in the case of shortage. The arrows show the relationships between the stakeholders as follows: (A) The funding was completely done by governmental bodies and invited technical suppliers/vendors to participate. (B) The governmental bodies supplied the technology through the VEC. (C) In case of maintenance issues, payments are made by the VEC to the technical suppliers and service is delivered by the suppliers. (D) The end-user pays a monthly fee to the VEC. (E) Since 2004 the region had become electrified and after investment of the governmental bodies, the VEC was able to sell or buy electricity from the grid.

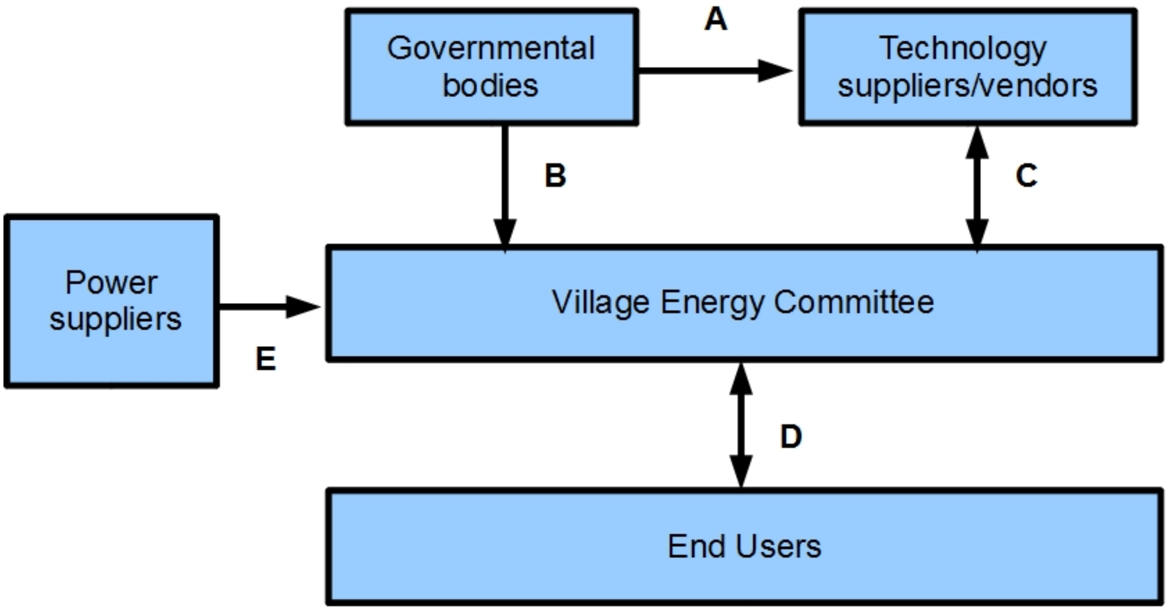

Figure 18: Ramgad SHP stakeholders.

Credit and financing: The governmental bodies paid for the SHP. The total cost of the installation was Rs. 5.2 million of which 60-70% went into construction/civil works, 10-15% into distribution works, 5-10% into the maintenance costs and the remainder went into equipment. An additional Rs. 3.7 million was needed for grid synchronization and overhauling of the system.

The tariff in Utterakhand is around 2 Rs./kWh and if excess electricity is sold to the grid the price is 2.85 Rs./kWh, which has been agreed upon through a PPA. The cost of generation is 0.70 Rs./ kWh, which provides a significant margin for the VEC. Initially the households paid a fixed tariff per month depending on the number of light points. However, inefficient use of the power delivered led to the installation of energy meters. The monthly tariff was based on the energy consumption pattern of the household.

Post-sales service: The O&M is paid indirectly by the users through the VEC. The revenues made from the collection of bills of the end-users and the selling of electricity to the grid are kept in a separate bank account. The last major maintenance was in 2003. Small maintenance issues are ongoing like greasing the turbines and maintaining the water pond.

Strengths and weaknesses: In Table 20 the SWOT of this implementation is shown. The strength of this project is a relatively cheap price of the energy service delivered to the end-user. Advantages of SHP are that the population is not disturbed and the benefits can be shared with the local communities. A weakness was that initially a flat tariff was set, which did not provide the incentives for users to switch off their light at home. This led to the need for energy meters on the household level. In this way the end-users were motivated to switch off the light or other electrical appliances. Also unpaid light bills and subsequent disconnections were a regular occurrence. Here the VEC stepped in to prevent these issues and communication with the concerned household often resolved the inability or the non-willingness to pay of the household. Prior to the solution being connected to the main grid the load factor was 15%, which made it a relatively expensive solution for lighting. The low load factor of the SHP was a major concern as it was only used for lighting at the household level. An advantage is that there is enough power supply to meet the growth in demand. A threat for the SHP is flooding, in order to mitigate the impact the power plant was elevated on a stable location. Another threat is that during summer the power supply might be low, due to less discharge.

Table 20: SWOT Village Cooperatives, Ramgad

Strengths	**Weaknesses**
- Cheap electricity price *- Sufficient scale to connect to the grid* *- SHP plants do not disturb communities*	*- Energy wastage due to the use of a flat tariff* *- Financial losses due to non-paying households* *- Low load factor lighting*
Opportunities	**Threats**
- Increase in demand household *- Additional income with mobile phone charging shops*	*- Damage due to floods* *- Low load factors due to dry spell*

Jagdishpur, Mini-grids (Public Private Partnership)

This implementation is an example of a PPP delivery model. The solar mini-grid replaced a lighting service that was running with a diesel generator set in the village Jamo in the Chhatrapati Shahuji Mahara Nagor district, Uttar Pradesh. The village is officially grid connected, but the electricity supply from the main grid is cut off between 6 pm. and 10 pm. For several years the shops in the village have used a diesel generator set to have light during the evening to do business or productive activities.

The different relations as shown in Figure 19 can be described as follows: (A) The entrepreneur provides the end-user the lighting service with LEDs in their shop. These end-users pay the entrepreneur Rs. 6. per night (B) The experiences of the end-users are collected by the researchers within TERI through surveys, (C) which is also the NGO that cooperates with the entrepreneur on the implementation. The entrepreneur takes care of 55% of the financial support and 45% is borne by the NGO. (D) A contract between the NGO and the entrepreneur (E) will support the request of the entrepreneur for a loan at a rural bank. (F) Other financial support comes from the government as similar implementations are done by the same NGO, which makes it viable to request for subsidies. This financial aid and the entrepreneurs and NGOs own capital enables the installation through a regional technical team, (G) which obtain the technology from the manufacturers. (H) These manufacturers might be eligible for subsidies of the government.

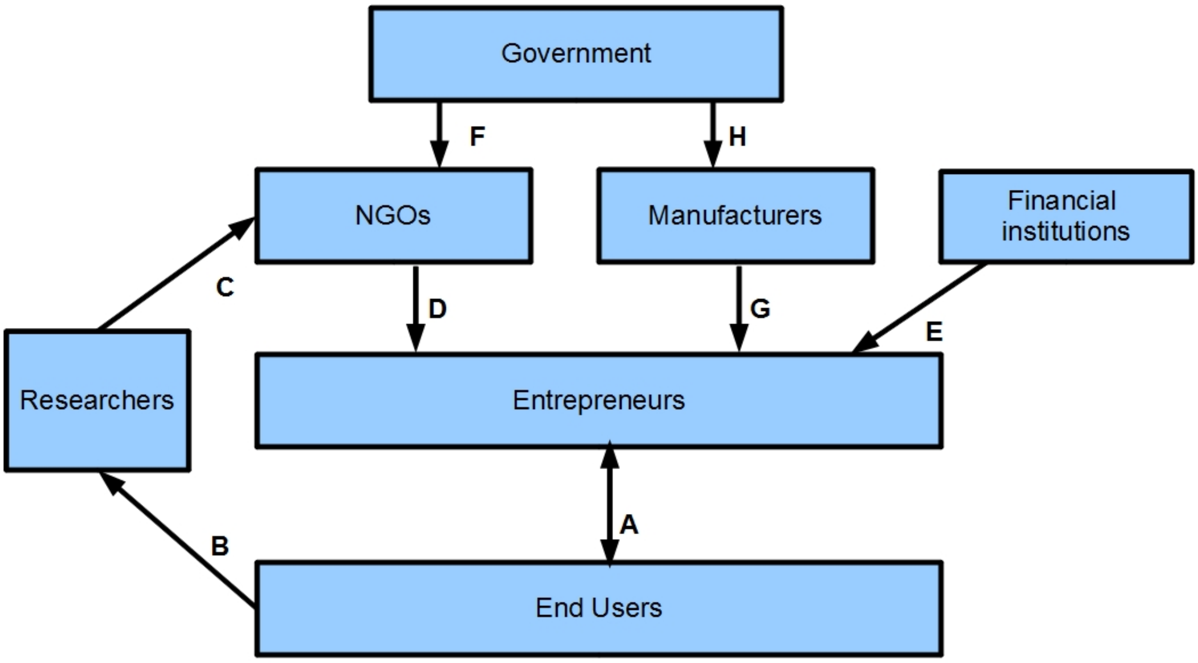

Figure 19: Stakeholders relation in the implementation of mini-grids in Jagdishpur, Uttar Pradesh