MASTER

An energy network of local energy suppliers in rural India
improving the Rural Spark energy kit on technical and social-economic aspects

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Award date:
2015

Executive Board

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Date
6 July 2015

Version
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Where innovation starts

Preface

Uden, 6th of July 2015

You are reading the final report of my graduation research done at the Eindhoven University of Technology. With the completion of this report I finish my Master's program. After three years of academic education I can proudly say that I've grown as a person and gained a lot of knowledge and experience.

The past year I have been working on the following subject: solar energy solutions in rural areas. PV panels give rural areas the opportunity to develop their own energy network. Unfortunately the PV panels only generate energy when the sun shines and therefore intelligent solutions are required to make the system more efficient. I hope my research helps to provide new insights to improve distributed energy networks with PV panels on technical, but also a little on the social-economic aspects part.

During my graduation project I had help from my supervisors Elphi Nelissen, Gert Boxem, Johanna Hoffkens and Evan Mertens to bring this project to a good end.
Elphi Nelissen has been a great support during my process and provide me with new practical insights to proceed with my project.
I thank Gert Boxem for his critical look at the process from begin till the end and for the many meetings and brainstorm sessions we had together.
Johanna Höffken I thank for her enthusiastic support and expertise about empirical research. She give me another perspective to look at technical improvements.
Last but not the least I want to thank Evan Mertens to set up this project, for his hospitality during my trip in India and being a great source of information about Rural Spark. I hope my research helps Rural Spark to take the next step in the right direction and provide everyone in rural India with electricity.
Not only my supervisors have been of great help, but also my family, friends and fellow students. Manny thanks go out to my parents for supporting, motivating and giving me all the space I needed. Also special thanks to my boyfriend who also listened to my endless complaints and helped me whenever he could.
All that remains is wishing you inspiring moments when reading this report. At the end I hope you can say it was" bohd atja"!

Christina Randjiet-Singh

Summary

Millions of people in rural India live with no or insufficient electricity supply. The Indian government failed to supply everyone with electricity before 2012. The traditional top-down approach has not been successful so far and another approach is required to electrify rural India. The bottom-up approach is suggested in literature. Rural Spark is a company who develops technical solutions to provide electricity for rural areas with a bottom-up approach. With the solar Energy Kit local people become local energy suppliers and provide electricity to everyone and earn a little money.

However, the Rural Spark Energy Kit only generates the minimum electric light demand for rural areas in India: the generated electricity is not sufficient for a whole year. In addition, the local people would like a higher electricity generation and not only for lights. The current Rural Spark Energy Kit is not large enough to provide the current and expected future demand. To improve the Energy Kit, technical and social-economic aspects of the system have to be explored, and must match the setting of rural India.

The goal of this research is to improve the technical and social-economic aspects of the Rural Spark Energy kit, in order to provide the current basic and additional electricity demand of the local people in rural India.

The main question of this research is:
How can the Rural Spark Energy Kit be improved in technical and social-economic aspects, in order to better provide the current and additional electricity demand in rural India?

To answer this question a preliminary research is conducted which consist of a literature study and a field trip. The preliminary study gives an description of the current situation regarding the Rural Spark Energy Kit. The literature study and the field trip result in two potential scenarios, which are further elaborated on four technical and social-economic key factors.

In the first scenario each local energy supplier has a large storage to cover the seasonal mismatch. This scenario is decentralized: each local energy supplier is a central point and connected to each other. The large battery is technically possible but energy distribution through cables results in more than 50% voltage losses over a distance of 500 meter or more. The wired connection is not suitable in this situation, however the battery has added value to cover the mismatch between the seasons.

In the second scenario local energy suppliers lend out small storage devices such as lithium battery packages or chargeable lamps. The local people can charge their own lamps and other devices. Battery package must be controlled to gain profit, which can increase from the current 600 INR to 1000 INR or more for the local energy supplier. Higher profit, more information regarding maintenance are made using smart technologies
More research is required to find the optimal capacity for the batteries, or to find a combination of large and small storage devices, because both scenarios show potential for rural India. The smart technologies have added value when it comes to information exchange and matching supply and demand However, it is not yet clear how this is implemented in the Energy Kit and how the local people will respond to the new technologies. As these technologies are new, the price is not known. The success of the new Energy Kit depends on the investment and profit the local energy suppliers have to make A good overview of the prices therefore is a necessary inclusion in the business plan.

Samenvatting

Miljoenen mensen op het platteland van India hebben geen of een ontoereikend elektriciteitsvoorziening. Het is de Indiase overheid niet gelukt om iedereen van elektriciteit te voorzien voor 2012. De traditionele top-down benadering lijkt nog niet succesvol en een andere aanpak is nodig om landelijke gebieden de beschikking over elektriciteit te geven De bottom-up aanpak wordt in de literatuur geprezen. Rural Spark is een bedrijf dat technische oplossingen ontwikkelt voor landelijke gebieden met een bottom-up aanpak. Door lokale mensen te voorzien van een Energy Kit worden ze energie leveranciers. Ze voorzien iedereen van elektriciteit en verdienen daar geld aan.

Hoewel de Rural Spark Energy Kit landelijke gebieden voorziet van minimale behoefte aan licht, is dit nog niet voldoende om aan de minimale energiebehoefte te voldoen voor een volledig jaar. Daarnaast hebben de lokale mensen behoefte aan meer energie en niet alleen voor lampen. De huidige Rural Spark Energy Kit is niet groot genoeg om aan de huidige en verwachte energievraag te voldoen. De Energy Kit moet verbeterd worden op technisch gebied, maar ook op sociaaleconomisch gebied om aan huidige en aanvullende energievraag te voldoen voor de situatie in landelijk India.

Het doel van dit onderzoek is om de huidige Rural Spark Energy Kit te verbeteren op technische en sociaaleconomische aspecten, zodat, voor landelijk India, nu en in de toekomst voldoende energie kan worden opgewekt

De hoofdvraag van dit onderzoek is:
Hoe kunnen de technische en sociaaleconomische aspecten van de Rural Spark Energy Kit verbeterd worden om beter in de huidige en aanvullende elektriciteitsbehoefte te kunnen voorzien voor landelijk India.

Om deze vraag te kunnen beantwoorden is een vooronderzoek uitgevoerd, bestaande uit een literatuuronderzoek en een veldonderzoek. Dit onderzoek resulteert in twee scenario's die verder worden uitgewerkt aan de hand van vier essentiële technische en sociaaleconomische factoren.

In het eerste scenario hebben de lokale energie leveranciers een grote batterij om de seizoensmismatch te overbruggen. De lokale energie leverancier is verbonden met andere lokale energie leveranciers. Dit scenario is technisch mogelijk, hoewel de distributieverliezen meer dan 50% bij een afstand van 500 meter. De verbinding tussen de lokale energie leveranciers is niet efficiënt, hoewel de grote batterij meerwaarde heeft voor het overbruggen van de seizoensmismatch.

In het tweede scenario verhuren de lokale energie leveranciers kleine apparaten zoals lithium batterijpakketten of oplaadbare lampen. De lokale mensen kunnen met de batterijpakketten hun eigen lampen en andere apparaten opladen. Door de batterij pakketten kan de omzet van de lokale energie leveranciers verhoogd worden van 600 INR naar 1000 INR. Smart technieken zorgen voor informatie over de prijs, aantal op te laden batterijen, onderhoudsinstructies en algemene informatie om de kennis van de lokale energie te vergroten.

Meer onderzoek is nodig naar het optimaliseren van de batterijcapaciteit of het combineren van grote en kleine batterijen. 'Smart' technieken hebben een toegevoegde waarde met betrekking tot informatie-uitwisseling, hoewel het nog niet duidelijk is hoe dit precies in de Energy Kit wordt toegepast en hoe de lokale mensen zullen reageren op de smarttechnieken. Daarnaast is de prijs niet bekend en dit is nodig om aan een goed businessplan te schrijven, want de lokale mensen willen graag geld verdienen en zij zijn bepalend voor het succes.

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1 Introduction

Millions of people in rural India live with no or insufficient electricity supply. The Indian government had the ambition to electrify every village and hamlet in 2012, but this goal has not been achieved (Kamalapur, Udaykumar, & Karajgi, 2008; Undp, Bank, Sector, & Assistance, 2004). The currently used, traditional, top-down approach has not been successful so far and another approach is required to electrify rural India.

Instead of the top-down approach, a bottom-up approach is suggested in literature (Bhattacharyya, 2013; S Groh, Philipp, Lasch, & Kirchhoff, 2014). With the bottom-up approach, rural people are encouraged to invest in rural electrification and build their own grid from the bottom up to the top. Several projects use this bottom-up approach, such as Greenpeace with the project Dharnai live!, Lightings a Billion lives and Rural Spark (Greenpeace, 2014a; “Lighting a Billion Lives - About us,” n.d.; Rural Spark, 2015b). These projects have shown the potential of the bottom-up approach.

The Rural Spark solution

Rural Spark developed a technical and social-economic solution to provide electricity for rural areas. The Rural Spark Energy Kit consist of a PV panel of 40 Wp or 80 Wp and a Spark Station which can charge LED lamps as shown in Figure 1-1.

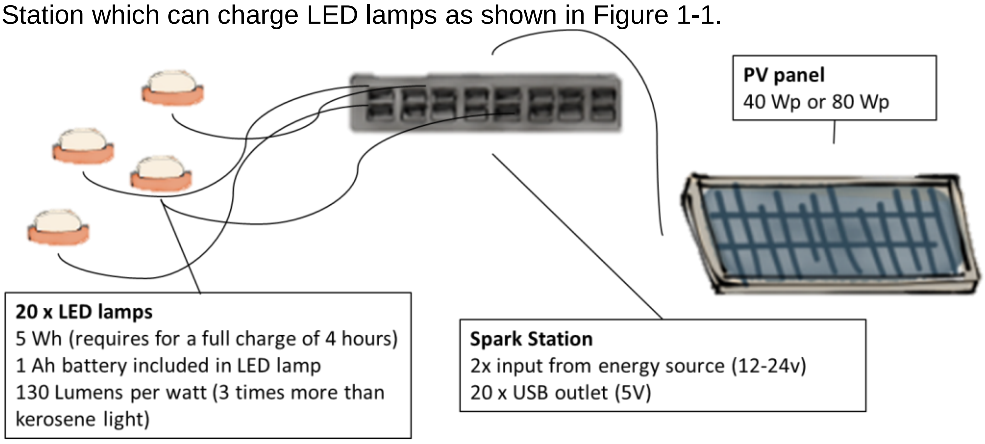

Figure 1-1 Illustration of the components of the Rural Spark Energy Kit and specifications

The Energy Kit illustrated in Figure 1-1 is sold to local agents who make the local people aware of the product. Local people who become interested in the Energy Kit can rent the kit every month. They have to pay the local agent and he will give an activation code for the Energy Kit. The local energy supplier charge the LED lamps and rent these out to other local people. This way everyone has access to electric lights, and the local energy suppliers also earn some money. More information about the Rural Spark solution can be found in paragraph 2.2.1.

The design approach of Rural Spark is unique because they take into account the wishes of the local people. This way Rural Spark develops not only a technical solution, but also social-economic.

1.1 Problem definition

Although the current Rural Spark Energy Kit is able to provide electricity in rural areas, the generated amount of electricity is, for large periods of time, lower than the minimum daily electricity demand for lighting. The local users desire a higher supply than just for lights. Probably the electricity demand will grow once the electricity supply has become more reliable.
The current Rural Spark Energy Kit is not large enough to provide the current daily lighting demand and the expected future demand. For the next generation of Energy Kits the social-economic aspects and possible improvements of the system have to be explored The Energy Kit needs to suit the setting of rural India.

1.2 Research goal

The goal of this research is to improve the technical and social-economic aspects of the Rural Spark Energy kit, in order to provide the current basic and additional electricity demand of the local people in rural India.

1.3 Research question

The main question of this research is:
How can the Rural Spark Energy Kit be improved in technical and social-economic aspects, in order to better provide the current and additional electricity demand in rural India?

In order to reach the goal the research main question is divided into three sub questions:
1. Which technical improvements are required to match the current basic electricity demand and to which extend can the additional electricity demand be covered?
2. How should the current social-economic approach be changed in order to cover the current basic and the additional demand?
3. What is the added value of smart technologies for the Rural Spark Energy Kit in rural India?

1.4 Methodology

First a preliminary research is conducted to get an understanding of the current situation in rural India and the experiences of the local people with the Rural Spark Energy Kit. This preliminary research consists of a description of the current electrification situation in India, interesting findings from literature and reference projects. More information can be found in Appendix I: Literature study.
The second part of the preliminary research is the field trip, which will be used to get a broader understanding of the context. During this field trip on the 6th and 7th of November, local energy suppliers of Rural Spark were interviewed in the village Guraru and the Bankey Bazar area. Guraru is used as case village and consists of 150 households, and is 1,5 to 1 kilometer wide and long. Further are the participants observed in their daily life. This all resulted in in empirical data about the context and will be used in addition to the findings from literature. The interviews and some pictures of the field trip can be found in Appendix II: Field trip. Findings form literature and the field trip are translated in technical and social-economic

key factors. The key factors are used to make an overview of limitations and opportunities for each for several scenario.

Using literature and field trip findings different scenarios are defined, which will be compared with the current situation. The three scenarios which are researched are:

1. The current situation

This is the situation during the field trip where the local energy suppliers use the old Rural Spark Energy Kit with a maximum of 20 LED lamps. This is a decentralized layout where each local energy supplier becomes a central point for energy.

2. Central storage (decentralized layout)

Literature and the field trip showed that a decentralized layout has potential for rural electrification. In the case village Guraru a decentralized layout is created with a central storage at each local energy supplier. The local energy suppliers are connected through wires to exchange energy. The potential of the technical and social-economic aspects are calculated and analyzed.

3. Small storage devices (distributed layout)

Literature also showed that a distributed layout has potential for rural electrification. The distributed layout differs from the decentralized situation, because more and smaller energy suppliers are connected with each other. In Guraru the local energy supplier will generate energy, but will also sell small battery packages or other devices which can store energy. The small devices can be traded with other local people which results in a distributed layout.

For scenario 2 and 3 the technical and social-economic aspects are calculated and analyzed for all the key factors. First, a description of the scenario is given. Next the calculations and findings from literature are analyzed to find the most suitable solution.
The next step is to improve the scenario by means of smart technologies as described by (Sinha et al., 2011).
The scenario with the smart technologies is compared with the current situation to clarify the improvements and to show which aspects Rural Spark should take into account to improve the Energy Kit.

1.5 Schematic research overview

Figure 1-2 gives a schematic research overview, which shows the different research steps.

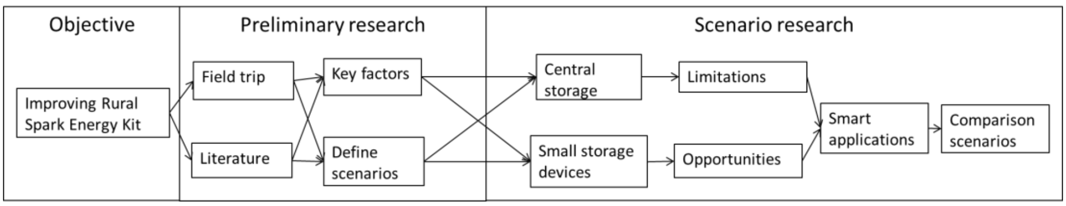

Figure 1-2 Schematic overview of the research

The field trip and literature study are the preliminary research which result in technical and social-economic key factors for rural India and the scenarios that should be investigated.
The researched scenarios are the central storage and small storage devices as mentioned in the previous section. For each scenario the technical and social-economic key factors are discussed based on literature findings, field trip findings and simple calculations. This result in an overview of limitations and opportunities.

The next step is applying smart technologies to exploit the opportunities. In the end, the scenario with the smart technologies is compared with the current situation to show the most suitable solution for rural India.

1.6 Research boundaries

In order to keep the research tangible and manageable, boundary conditions are applied:

- The research does not take small industries and electric cooking devices into account. It focuses on lights, mobile phones, fans and televisions which are home devices.
- The research focuses on local energy suppliers with a PV panel, other renewable resources are left out.
- This research only considers DC (Direct Current) appliances.

1.7 Report structure

The goal of Chapter 2 is to get a better and broader understanding of the current situation regarding the Rural Spark Energy kit. This chapters consist of four parts: literature findings, field trip findings, overview of the current situation and motivation of the choice of the scenarios.
The literature review describes the current situation in rural India. Interesting findings from literature and reference projects are used to get a understanding of these subjects as well the technical possibilities.
The field trip is conducted to get a broader understanding of the technical and social-economic aspect in rural India. First, Rural Spark and the other stake holders are explained. Secondly the findings from the field trip are given.
The findings from literature and the field trip are translated in technical and social-economic key factors and are used to make an overview of the limitations and opportunities of the current situation.
This chapter is ended with an argumentation of the chosen scenarios also emerged from literature and the field trip.

Chapter 3 describes the results of the three scenarios. First a short overview of the current situation is given. Next the first scenario with a central storage is discussed as well the second scenario with small storage devices. For each scenario an overview of technical and social-economic aspects as well as limitations and opportunities is given. The added value of smart technologies is discussed and a comparison with the current situation is made.

Chapter 4 contains the conclusions and recommendations. First, the research question is answered, followed by the research sub questions. In the recommendations aspects for further research are discussed.

Appendix I gives the literature study which is used for the preliminary research.
Appendix II describes the field trip. Discussed are the goal, the method and the results. Pictures and the interviews with the local energy suppliers can also be found here.
Appendix III gives a logbook of all the calculations.

2 Rural electrification

This chapter described the current situation regarding rural electrification in India and the Rural Spark Energy Kit. First literature findings are given discussing the electricity situation in India, interesting findings and reference projects.
The second part describes the Rural Spark solution with the information gained from the field trip. From literature and the field trip technical and social-economic key factors are created which are used to give an overview of the limitations and opportunities of the scenarios and an explanation of the chosen scenarios.

2.1 Literature findings

The literature background is divided in three parts. The first paragraph describes the general current situation regarding rural electrification in rural India. The second part describes interesting finding from the literature. The last part are reference projects to show the possibilities possible in rural India.

2.1.1 Current situation

India is the 5th largest energy producer in the world, but still millions of people live without access to reliable electricity. 70% of the Indian people live in rural area, but don't have a proper connection to electricity grid. Nowadays, electricity is a basic need just like water and food (Oda & Tsujita, 2011).
Literature states that the lack of electricity results in education level and economic development falling behind (Oda & Tsujita, 2011; Shailaja Rego, Naresh Kumar, 2013). Also electrification plays an important role in poverty reduction and a safer and healthier living environment (Chaurey, Ranganathan, & Mohanty, 2004; Palit, 2014).
The rural people survive by earning money with cultivate land, owning a small store or provide services such as making clothes. Other daily activities are searching for fuels and water which is heavy work (Undp et al., 2004).
An average household earns around 7000 INR per month, of which 1% is spend on electricity (Oda & Tsujita, 2011; Ram, Kumar, & Teske, 2012).
Literature shows that electrified villages mostly use electricity for lighting. The possibility to charge a mobile phone is also high priority, followed by a fan and a television (Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012). Annually a rural household uses 500 to 1000 kWh electricity (Ram et al., 2012).

2.1.2 Interesting findings

The literature study results in three interesting topics which are the technical solutions, involvement of the stakeholders and smart applications.

1. **Technical solutions**

Literature showed that the technical solution should be found in a bottom-up approach, because the top-down approach has not been proven successful so far (Bhattacharyya, 2013; G Upadhyay et al., 2012). These bottom-up approaches result in micro grids with a distributed or decentralized layout (Millinger, Mårlind, & Ahlgren, 2012; Palit, 2014; Sarker, Asare-Bediako, Slootweg, Kling, & Alipuria, 2012; Sen & Bhattacharyya, 2014). Figure 2-1 shows the difference between a centralized, a decentralized and a distributed network layout.

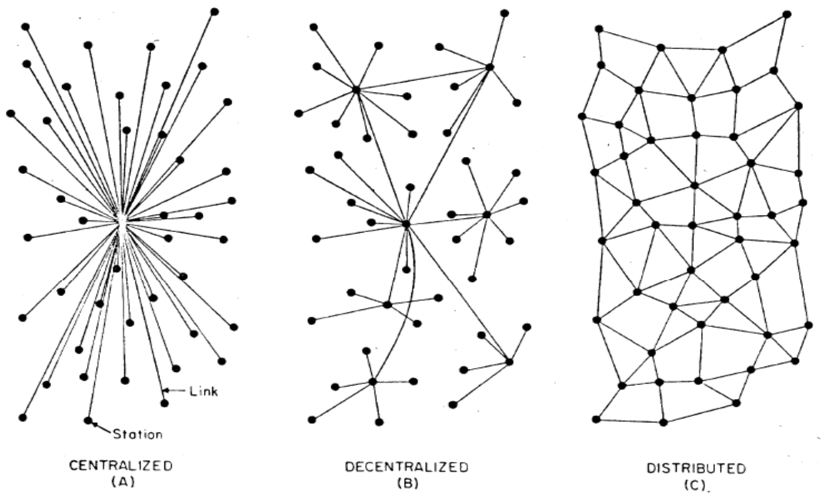

Figure 2-2 Difference between centralized, decentralized and distributed (Barn, 1962)

The traditional electricity grid is centralized: large energy plants generate electricity and distribute it to many end users. When the energy plant is failing, all end users lack supply. A decentralized energy grid makes use of smaller energy plants or energy sources which are connected to each other. When one of the energy sources is failing, others can take over and this makes the network less vulnerable to plant defects than the centralized grid. In a distributed energy grid all the end users in the area are connected to each other. The advantage of a distributed and decentralized grid are, compared to a centralized grid:

1. Generation source close the user (solar power)
2. The generation is mainly done with renewable sources: Distributed Energy Resources (DER).
3. Generation sources are connected to other sources and can operate when one failing.

Literature shows that the decentralized and distributed grids are mainly micro grids, which can operate independently from the national electricity grid. The micro grids uses renewable energy sources such as wind and solar power, but they are stochastic which mean there is a mismatch between supply and demand. Matching supply and demand with, for example solar power, is only possible with storage (Koen Kok et al., 2008).

2. Involvement of the stakeholders

Literature shows that not only the technical aspect determines the chance of success, also the interest of the stakeholders is of importance. Table 2-1 shows the four success factor for applying rural electrification.

Table 2-1 Success factors for rural electrification adopted from (Heist, 2011; Kamalapur et al., 2008; Martinot, Chaurey, Lew, Moreira, & Wamukonya, 2002; Mertens, 2011; Sen & Bhattacharyya, 2014)

Success factor	Explanation
1. Temporary subsidies are undesirable	“Subsidies are unlikely to lead to sustainable markets unless they explicitly create the conditions whereby they are no longer needed (i.e., smart subsidies)” (Martinot et al., 2002).
2. Economic benefit for local people	Loans are only interesting when there are no

	other cheaper solutions. For example: paying a fee for a product is not interesting when other people get a solution for free or cheaper. There is no economic benefit for the local people (Martinot et al., 2002). This occurred in the Greenpeace Dharnai Live project, where the solar powered system became unused after the Indian government extended the national grid to this village and provided cheaper electricity than with the solar power ("Electricity Access and Renewables Integration | The Energy Collective," 2014).
3. Involvement of the final users	(Kamalapur et al., 2008) state that the customer is the key stakeholder and an active member. Projects have proven that self-involvement and a self-invested, self-designed, self-maintained and self-,managed system is more efficient.
4. Education, information and maintenance information for the final users	Training and educating local people on how to use the products, result in lower cost and limit the operational risks (Sen & Bhattacharyya, 2014).

It is notable that the economic aspects play a big role in the success of the solution. Without enough benefit, local people will lose interests in the products. In addition, the local people should be involved and informed from the beginning, but also be educated to maintain the product by themselves to limit the risks.

3. Smart technologies

Literature about rural electrification and micro grids come along with terminology like intelligent energy trade, power matching, energy balancing, energy matching and demand site management. As described above, literature made clear solar power is related to matching supply and demand. Sinha introduces smart grid technologies as described in Table 2-2 which can help to achieve a balance between supply and demand (Sinha et al., 2011).

Table 2-2 Smart grid technologies according to Sinha (2011)(Sinha et al., 2011)

Smart grid technologies	Description	Source
1. Smart Meters	*"The smart meter is an advanced energy meter that obtains information from the end users' load devices and measures the energy consumption of the consumers and then provides added information to the utility company and/or system operator for better monitoring and billing"*	(Zheng, Gao, & Lin, 2013).
2. Meter Data Management	Implementation of a multi-location instance that would allow individual utilities to take advantage of the system by allowing them to view a subset of the collected data from all of the locations after integration with Advance Metering Infrastructure system.	(Sinha et al., 2011)

3.	Field area networks	Network for data transmission between users. Most important functionality is communication and connection between different users.	(Baig, Das, & Rajalakshmi, 2013)
4.	Integrated communications systems	Standards, protocols, network, and computer systems that help to be "the brains" of the smart grid.	(Ellis, 2012)
5.	IT and back office computing	Information technology.	
6.	Data Security	Protection and reliability of the data.	(Ellis, 2012)
7.	Electricity Storage devices	For example batteries.	
8.	Demand Response	"Demand Following Generation". This can be realized by intentional modification in electricity consumption pattern by reducing or rescheduling instantaneous electricity demand, called demand response (DR).	(Bhattarai, Bak-Jensen, Mahat, & Pillai, 2013)
9.	Distributed generation	An electric power generation within distribution networks or on the customer side of the network-	(Ackermann, Andersson, & Söder, 2001)

Table 2-2 mainly shows technologies to match and trade energy. Smart meters are required to measure the energy demand, which is communicated with meter data management trough field area networks. An IT and back office computing manages the data and decides what the energy price will be. Integrated communication systems exchange the right information about price, supply and demand with the users.

For rural India it is important to match supply and demand because of the stochastic behavior of solar power (K. Kok, Warmer, Kamphuis, Mellstrand, & Gustavsson, 2005). It is not clear which smart grid technologies are required to create a smart decentralized or distributed micro grid, but the focus lies on matching supply and demand.

The smart technologies are a necessity to make the micro grids efficient. Together with the social-economic aspects, this could be a potential combination to successfully electrify rural India.

2.1.3 Reference projects

Four reference projects are reviewed in the literature research which are shown in Table 2-3. These reference project are chosen because of their technical layout. They either have a distributed layout or a decentralized layout. According to literature (Millinger et al., 2012; Palit, 2014; Sarker et al., 2012; Sen & Bhattacharyya, 2014) these are the two layouts with great potential for rural electrification. In Table 2-3 the technical specifications are given, as well the social-economic aspects and whether smart technologies are applied or not.

Table 2-3 Overview of reference projects specifications regarding rural electrification (Greenpeace, 2014a; S Groh et al., 2014; Kaas, 2012; "Lighting a Billion Lives - About us," n.d.)

Aspects	Lighting a Billion Lives	Dharnai Live	Swarm electrification	SOPRA
Lay-out	Decentralized	Decentralized	Distributed	Decentralized
Scale	50 lamps (small	450 homes, 2400	Unknown	

	village)	residents		
Capacity	5 x 50 W= 250 W	100 Kw	20 to 85 Wp	60 kW
Storage capacity	100 Ah 24Volt 240 Wh	60 kWh 140 Ah 12 V	34 kWh 80 Ah 12 V	53 kW
Wired	Not wired	Wired	Not wired/wired in future	Wired
Lamps	Solar LED. Burns for 4 to 6 hours, or 8 hours when dimmed	60 solar street lamps	unknown	Unknown, but a whole village can be supplied of electricity.
How does it work	A solar charging station consisting of 5 PV panels of 50 WP. Each panel has a junction box with 10 connections for solar LED lamps. These lamps are charged and rented out to people in the village	Different packages are rented out to local people or commercial packages. These packages consist of a PV panel and a converter.	The local people buy their own Solar Home System. With a battery storage energy can be stored which is not directly used. The people provide themselves with electricity.	The SOPRA is installed and connected to all the households and industries who want to use it. The advanced metering system measures the price for the energy and the costs every household has to pay.
Benefits for local people	The local people have access to payable electricity. Even the poorest can pay for it.	The local people have access to electricity. Schools and other public place have electricity which improves the quality of living.	The local people generate their own electricity. When swarm are created and connected to each other, they can exchange surpluses of energy.	The local people generate their own energy at a central point.
Financing	Fee for service model: solar charge station is financed by funds. Local people pay a small amount of money for the lamp renting service. Loan finance model: The solar charging station operators start their own business with a loan	Each package has its own price. More devices result in higher monthly cost. They also pay for every unit (Wh) they use.	The local people lease a Solar Home System for $4.6 ± 294 INR.	The cost for a SOPRA installation is 1 million Euro, equal to 71 million INR.
Involvement of the local people	The owner of the solar charging station is trained to rent the solar lamps.	The local people are involved from the beginning. Influential people are used to inform the local people.	It is not clear how the local people are involved, but they are made aware of the Solar Home System and	It is not clear how the local people are involved.

		Also people are educated about maintaining the system.	the possibility to share energy.	
Smart technologies	No	No	No, but when the swarms are connected to each other, smart technologies could help to make the energy exchange more efficient.	Yes, the advanced regulated system is a smart application, which regulates the pricing, storage and selling of energy.

The projects are chosen because they all have something unique which is explained below as an addition to Table 2-3.

1. **Lighting a billion lives**

Lighting a billion lives is a unique project, because of the financing program: even the poorest have access to electric lights. The solar charging stations are financed by funds and subsidies and the local people only pay a small amount of money for the lights. The operator of the solar charging station is trained. With the loan financing model local people become an solar charging operator and can earn money. They pay a monthly fee to operate the solar charging station.

2. **Greenpeace Dharnai Live!**

Dharnai live is a unique project because the local people are involved from the beginning of the project. The most important person of the village is approached to spread the information and convince the local people to participate in the project. The Decentralized Renewable Energy System (DRES) or also known as a decentralized micro grid is maintained by trained and educated local people themselves.
After the decentralized micro solar grid is established the local people pay for every kWh and package (Ram et al., 2012). An example is given in Table 2-4.

Table 2-4 Overview cost energy package of Dharnai Live! ("Solar energy microgrid powers India village in Bihar Greenpeace Blogs," 2014)

	Package 1 one LED light of 6W, mobile charging point of 12W, Solar Street Light	Package 2 Three LED light of 6W, mobile charging point of 12W, Solar Street Light
Total consumption of electricity	18 W	30 W
Total monthly unit consumed	8 units	13 units
Rate per unit	9.50 INR	11 INR
Monthly tariff	75 INR	140 INR
Security deposit	300 INR	500 INR
Wiring costs	300 INR	500 INR

The local people pay a security deposit, wiring costs, a monthly tariff and a rate per unit. This makes them independent of the national electricity grid and political decisions. The local people are content with the DRES, but the government decided to electrify the village and the DRES is now unused because the extended national grid delivers cheaper energy ("Electricity Access and Renewables Integration | The Energy Collective," 2014).

3. Swarm electrification

The swarm electrification concept is different from the other mentioned projects because it is distributed. It is applied in Bangladesh, but the concept also has potential for rural India because of the distributed layout.
The system consist of a Direct Current (DC) Solar Home Systems (SHS), currently consisting of 20 to 85 Wp solar panels, a battery, and a charge controller (S Groh et al., 2014; Sebastian Groh et al., 2014). The difference between a normal SHS and swarm electrification is that swarm electrification connects groups of Solar Home Systems with each other and with other groups as shown in Figure 2-3.

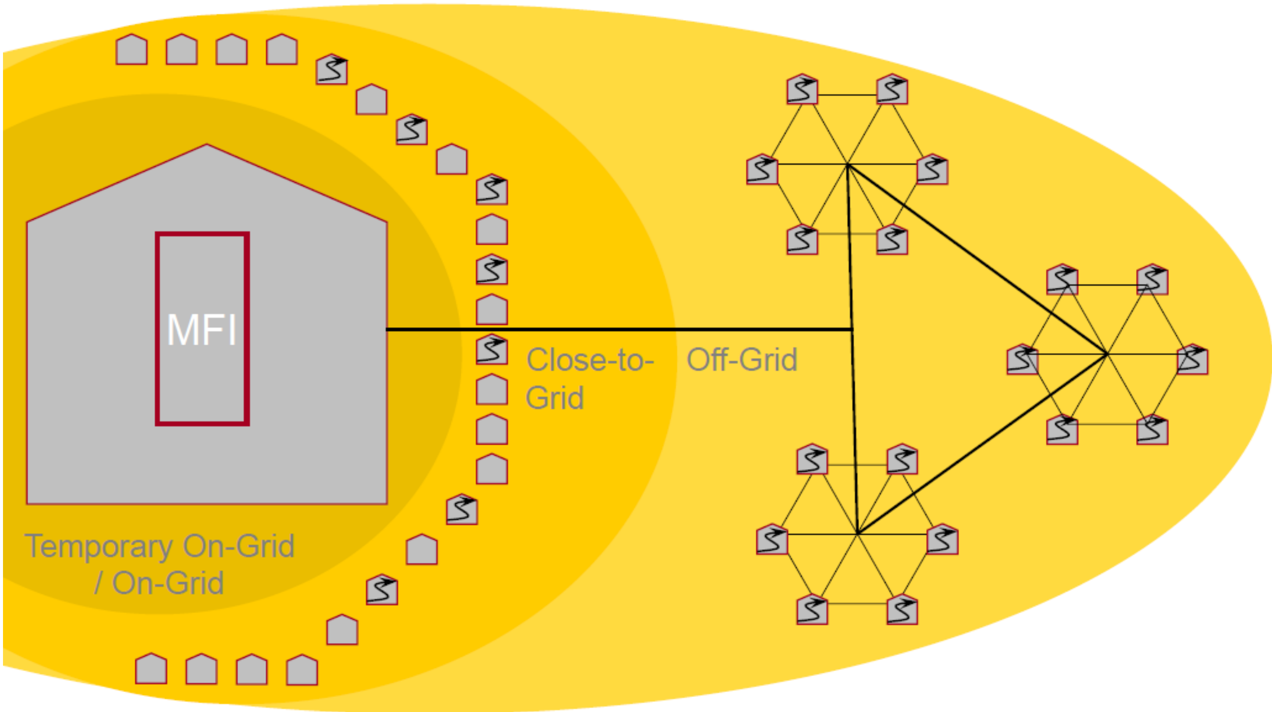

Figure 2-3 Swarm electrification. Each group of Solar Home Systems is a swarm and a micro grid. These swarm are connected to other swarm to exchange energy. It is also possible to connect to other grids in the area (Berlin et al., 2013)

The swarms (groups of SHS) can be connected with other swarms, but also with a national or regional grid. The Solar Home Systems in a swarm are also connected with each other so they can exchange energy. Unfortunately, the energy exchange is not yet applied.
The Solar Home System are bought by the local people through micro financing. However, a selected number of [people can pay for this system, the poorest are still left in electricity poverty. (S Groh et al., 2014) state that it is possible to create a win-win situation for both people with a SHS and for people who cannot afford a SHS by sharing the power and introduce dynamic pricing.

4. SOPRA

Alfen group from TBI holding has developed SOPRA; Sustainable Off-grid Power Station for Rural Applications. The system consists of a number of transformers, a battery pack and an advanced regulating system for the batteries (Kaas, 2012; “SOPRA - Alfen,” n.d.).
SOPRA can implement not only solar power, but also wind, water and other renewable energy sources. The advanced regulating system for batteries stores energy in the battery so it is not

lost. The advanced regulating system is a unique aspect of this project, because it makes it smart and allows the generated energy to be used in a very efficient way.

The reference projects have potential, as literature also states, because of the distributed or decentralized layout. With the four success factors the reference projects have more chance of success according to (Heist, 2011; Mertens, 2011). A combination of technical solutions and social-economic aspects should lead to a successful solution to electrify rural India.

2.2 Field trip findings

The goal of the field trip is to get a broader understanding of the local context and to find out how the local people use the Rural Spark Energy Kit.
The first paragraph explains the Rural Spark solution with respect to the technical specifications, social-economic aspects and the smart technologies which of which literature shows they are important.
The second paragraph uses findings from the field trip to give a broader understanding of the local life and how local people use the Energy Kit. This is done keeping in mind three important aspects which resulted from the field trip: pricing, maintenance and information exchange.

2.2.1 Rural Spark solution

This paragraph describes the technical aspects of the Rural Spark solution and the social-economic aspects of the Rural Spark network.

The Rural Spark solution is an Energy Kit which consists of a PV panel, a Spark Station with 20 USB 5 volt outlets to charge LED lamps or mobile phones. The Energy Kit comes in two sizes: the Basic size has a PV panel of 40 Wp and the Plus size has a PV panel of 80 Wp. The LED lamps are from manufacturer Greenlight Planet, model Sun King Solo, have a 1 Ah battery and can provide 130 lumens per Watt (“Sun King™ Solo – Greenlight Planet,” n.d.). The LED lamps need four hours of charging time, which results in 5 Wh per lamp. An illustration of the Rural Spark Energy kit can be found in Figure 1-1.

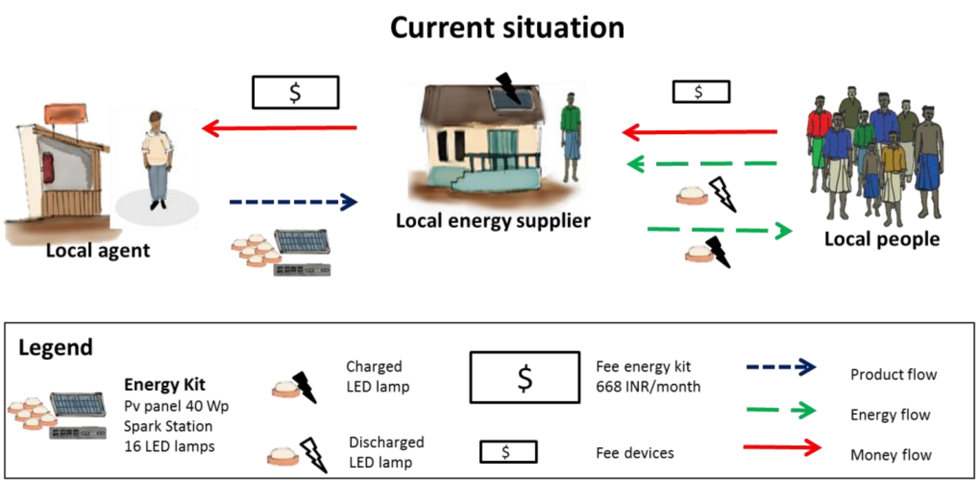

Figure 2-4 illustration of the current situation (illustrations from Rural Spark)

Rural Spark works with local agents in rural areas to make the local people aware of the Energy Kit. In the current situation there are two areas where Rural Spark is active: the village Guraru and the Bankey Bazar area. To explain the role of the stakeholders and the relationship between stakeholders the village Guraru is used.
The local agent has a store in the village Guraru with Energy Kits and LED lamps. He rents these out to local people in the area. These people become a local energy supplier and pay a monthly fee of 668 INR to the local agent. The local agent also receives a small margin on the Energy Kit, which makes it profitable to be a local agent. Figure 2-4 shows an illustration of the Rural Spark network, with the local agent on the left, renting out the Energy Kit to the local energy supplier. The local energy supplier rent out charged LED lamps to the local people. The local people pay the local energy supplier, the local energy supplier pay the local agent. Table 2-5 gives an overview of the specifications for the current situations.

Table 2-5 overview of Rural Spark Energy Kit specifications

Aspects	Rural Spark
Lay-out	Distributed
Scale	20 lamps per Energy Kit, small village
Capacity	40 Wp or 80 Wp
Storage capacity	Not available
Wired	Not wired
Lamps	20 LED lamps 5 Wh for full charge of 4 hours
How does it work	Local people with an Energy Kit become a local energy supplier. They charge the LED lamps and rent these out to people in the village without an energy kit.
Benefits for local people	The local people have access to payable electricity. The local energy suppliers earn a little money with the Energy Kit.
Financing	The local energy suppliers pays 668 INR for the 40 Wp Energy Kit and 1184 INR for the 80 Wp Energy Kit per month to the local agent. The local agent earns a little money renting out Energy Kits, by the margin of the fee. The products are produced by funds.
Involvement of the local people	The local agent makes the local people aware of the Energy Kit and the benefits. It is also his task to check for defects and repair these.
Smart technologies	No

Table 2-5 shows that the Energy Kit has no storage capacity, only the lights which can be charged. Adding a storage device is a first improvement. The Energy Kit doesn't have any smart technologies.
With the addition of a storage device energy exchange becomes possible. Smart technologies can be used to make this energy exchange more efficient.

Rural Spark has carefully considered the financial aspects. The products are made by funds, which is actually a negative aspect, but taken into account that the local people can earn money with it, makes the product interesting. This phenomenon is called “smart subsidies” and is described by (Martinot et al., 2002). Also the local agent can make money with the product. The network of local agents, energy suppliers and final users only works when everyone fulfils their task. These tasks are shown in Table 2-6.

Table 2-6 Overview of stakeholders and their tasks

Stakeholder	Tasks	Comments
Rural Spark	Develop products	The service platform contains a service with

	Provide the service Platform. Sell products to local agents.	information about the local energy suppliers and whether they have fulfilled they payments.
Local agents	Rent out Rural Spark products out to local people. Collect payments of the local energy suppliers. Manage contracts and information regarding the local energy suppliers. Fix broken products.	The local agent has a small warehouse with spare parts of the Energy Kit.
Local energy suppliers	Generate electricity using Energy Kit Charge LED lamps. Rent out LED lamps. Walk to the local agent to fulfill payment.	The local energy suppliers are the local people who rent the Energy Kits.
Local people	Pay for the LED lamp (daily or per four weeks).	The local people are the local people without a energy kit and they rent the LED lamps.

The social aspects regarding information exchange are executed by the local agent who has the most knowledge and also maintains the Energy Kit as shown in Table 2-6.
Rural Spark is unique compared with the references projects in Table 2-3 because of their design approach. The solution is not only bottom-up but also technical and social-economic aspects are taken into account.

2.2.2 Findings from the field trip

Paragraph 2.2.1 described the Rural Spark solution in theory. The field trip provides a broader view of the current situation regarding the Energy Kit. The most important aspects are pricing, maintenance and information exchange. The interviews and observations can be found in appendix III.

Pricing
Rural Spark's local energy suppliers live in the block Guraru and the Bankey Bazar area nearby Bodhgaya. The people earn their living from working on the their land or managing a store. Some people work at the brick factory or provide services such as making clothes. The Rural Spark Energy Kit is an extra source of income, because they earn money renting out the charged LED solar lamps. Their profit, after paying the fee of around 1000 INR for the solar Energy Kit, is about 600 INR. They ask 75 to 90 INR for one lamp each month. Some people ask 2 INR per day for each lamp, which result in a lower income. The income of the Rural Spark Energy Kit is about 10% of their monthly income, which is about 6000 INR per household. This corresponds to the findings in literature (Ram et al., 2012).

According to the four success factors described in paragraph 2.1.2, economic benefit is important. This means there should be some economic benefits for the stakeholders.
This is confirmed by the question:

"Even if he doesn't have enough energy for himself, he would sell the energy to make profit of it because that's the only possibility?"
"Yes, that's true." (interview local energy supplier 1, 6th of November 2014)

The local energy suppliers rather have extra profit than electric lights.

The local energy supplier in Bankey Bazar mentioned, according to the translator, that *if she rises the price to 3 rupees per lamp a day, instead of 2 rupees, people won't rent the lamps anymore, because it is equal to kerosene.* The price of the lights must compete against kerosene and other alternative fuels. The price cannot be too expensive because poor local people cannot afford it according to the local energy suppliers in Bankey Bazar.
However, while increasing the price could lead to less customers it could also result in a higher profit according to Figure 2-5.

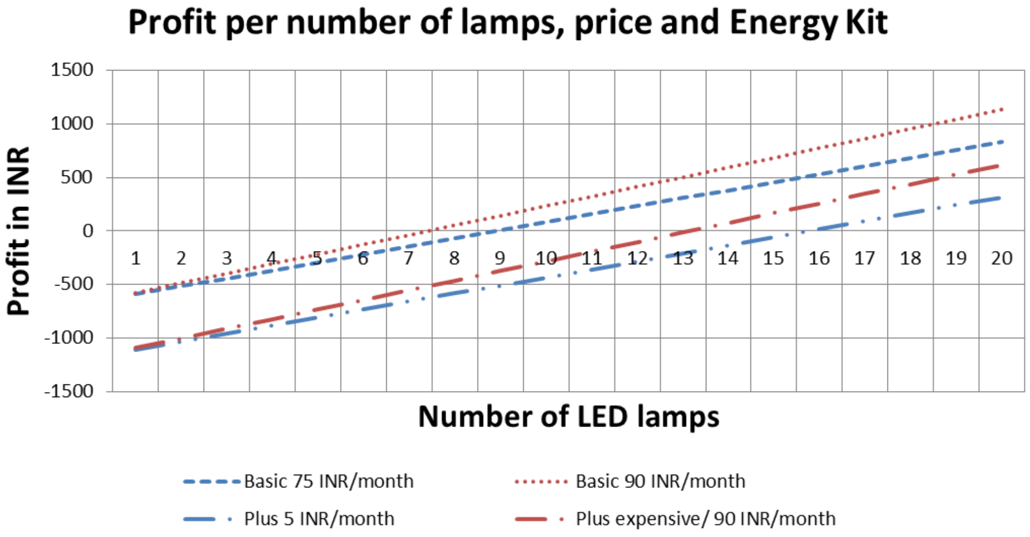

Figure 2-5 Profit of the local energy suppliers through the Energy Kit in relation to the lamps and price. When less lamps are rented out due to low generation the profit is lower However, when the price is increased the profit becomes higher, even with the less lamps rented out. The graph also shows that more than 10 lamps must be rented out to gain profit for the Basic Energy Kit and 14 lamps for the Plus Energy Kit.

Increasing the price has benefits for the local energy supplier because a higher profit is obtained even if less lamps are rented out. Generally, the local energy supplier is happy with the Energy Kit and there are no issues.

"*Only when its cloudy and all lamps are connected, they won't be charged all. The generation is not enough". (interview local energy supplier 1, 6th of November 2014).*

To little lamps result in unsatisfied local people because there are not enough lamps to lend. This also influences the income of the local energy supplier.

The findings show the following aspects:

1. The local energy suppliers want to make profit.
2. Price of the LED lamps should compete with other fuels, such as kerosene, which results in a price lower than 3 INR per day.
3. The generation is not continuous, therefore the price should adapt to the generation to create a more stable income and a more reliable system.

Information about maintenance
According to the four success factors described in Table 2-1, information, education and maintenance are important. This is confirmed by observations during the field trip.
The information about maintenance is important, because this will result in a more reliable and sustainable system.

During the field trip in Bankey Bazar, the local energy supplier noticed that a lamp was not charging well and thought the lamp was broken. It turned out the lamp was not broken but the cable was. It is not clear whether this is due to imprudence or bad quality of products. In both cases, the local energy suppliers and local people should know how to deal and maintain the products. In addition, the local agent should know about the defects, but he is busy with his own shop. It takes a long time for the local agent to visit the local energy suppliers and to repair broken products, because of the distance and the lack of decent roads and transportation. Figure 2-6 shows the village Guraru and the distances as well the smaller villages nearby.

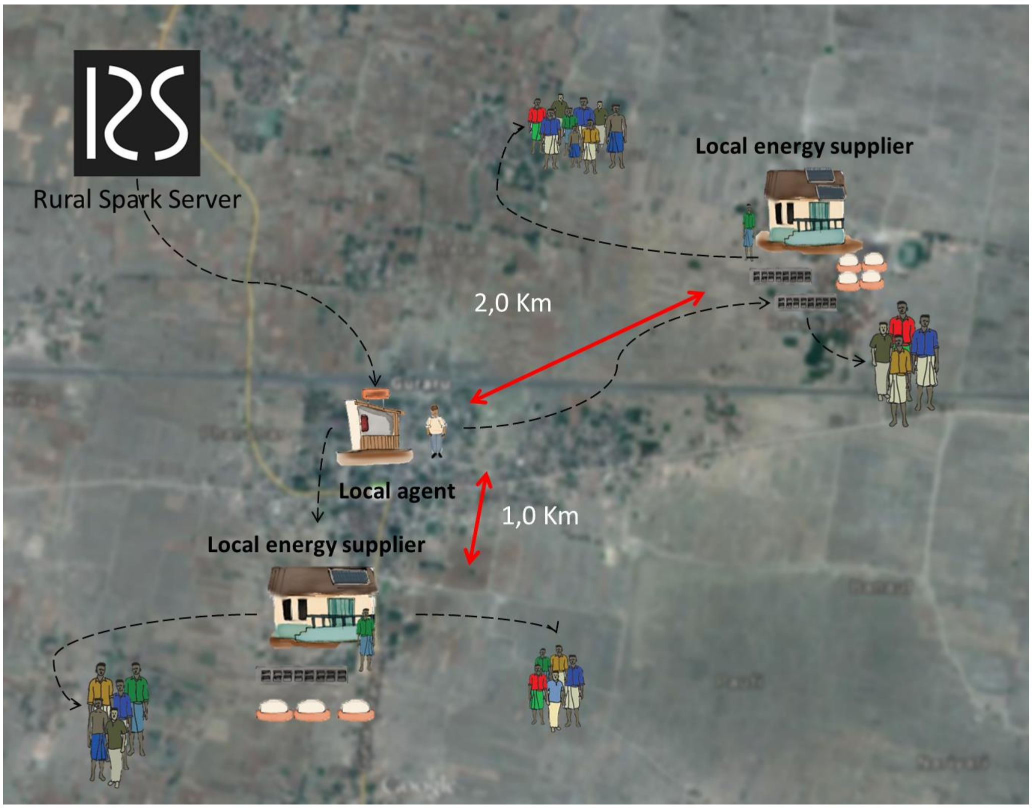

Figure 2-6 The village Guraru and villages around it. The local agent is situated in the village Guraru..Local energy suppliers life in the small villages nearby. The local people rent lamps from the local energy suppliers.

It takes time to cover the distance between the small villages because there are no proper roads.
Currently, the local energy suppliers wait until they have to fulfill the payment and meet the local agent to ask about the issues with the Energy Kit. This results in four weeks with a defect, which could be solved if the local energy supplier is more educated.

The field trip shows that:

1. The local energy supplier does not have the knowledge to detect or repair small defects.
2. The local agent does not have enough time to visit the local energy supplier frequently to detect defects and to do repairs.
3. The lack of maintenance knowledge results in lower income for the local agent en local energy suppliers and unsatisfied customers.

Information and knowledge exchange

During the field trip on the 7th of November in Bankey Bazar, Rural Sparks business partner Basix, a livelihood promotion institution, translated for us. A conversation Basix had with a local energy supplier was about increasing the price to earn more money. The local energy suppliers, in this case a seamstress, said that when they would increase the price the people wouldn't rent lamps anymore. Basix tried to explain that sometimes products become more expensive, just like they blouses she made.
From the information described above it can be concluded that the local energy suppliers need more information about how to do business.

Another point that was discussed that day was the general knowledge regarding the dangers of kerosene and the benefits of the electric lights. The local energy suppliers could use this knowledge to convince their customers to rent lamps, despite the price being higher than kerosene.

The field trip shows that the local energy suppliers need more information about:

1. How to do business: increase the price when necessary.
2. More general information regarding the benefits of electric light, in order to better inform the local people.

Notable statements

The pricing, maintenance and knowledge are the most recurring subjects, however the following quotes are also worthwhile mentioning

First, the local energy suppliers are content with the Energy Kit, but they would like to use other devices:
"A fan would be useful on the hot days and if it runs on the Energy Kit." (interview local energy supplier 1: 6th of November 2014).

There is also a demand for more lights:

"*There is a demand for 20 more lights. I want another Energy Kit." (interview local energy supplier 3: 6th of November 2014).*

During the conversation with the local agent in Guraru, it became clear that the local energy suppliers experience inconveniences with the payment method. First, the payment should be monthly and not every four weeks. Secondly, it takes a lot of actions for the local agent to fulfill the payment. He has to send a couple of messages to Rural Spark and receive an activation code for the Energy Kit.

The additional findings summarized:

1. The Energy Kit should also provide a connection for other devices such as a fan.
2. There is a higher demand for lights than the generation supplies.
3. The payment method should be easier and on a monthly base.

More observations and statements can be found in appendix II: Field trip.

2.3 Limitations and opportunities

This paragraph shows an overview of the findings from literature and the field trip regarding the current situation of the Rural Spark Energy Kit. The overview is based on four key factors which result from literature and the field trip.
Matching supply and demand is one of the key factors, because this is required to efficiently use solar power (Koen Kok et al., 2008). The local energy suppliers also mentioned that on cloudy days the lamps wont fully charge.
The second key factor is the price, which become clear from the field trip. The local energy suppliers want to make a profit, but also want to consider the budget of the local people.
Maintenance is also an important aspect because the local agent lacks time and the local energy suppliers lack knowledge to maintain the system.
The last factor is information exchange between local energy supplier and local agent, but also information exchange with the local people. Table 2-7 shows the limitation and opportunities for each key factor.

Table 2-7 The limitations and opportunities for the current situation for every key factor

Factor	Limitations	Opportunities
Matching supply and demand	1. During monsoon the supply and demand do not match. 2. There is a higher demand for lights. 3. Other electric devices cannot be used with an Energy Kit	1. Store energy when supply is high and use it when demand is high but generation is low. 2. Use the generated electricity more efficient to charge extra lights without an extra Energy Kit or PV panel. 3. The Energy Kit should provide a connections for other electric devices than lights.
Pricing	1. The income/profit of the local energy suppliers is not continuous, but weather depended. 2. The price per lights per day has a limitation of 3 INR, because of the price of kerosene and other alternative fuels.	1. Variable prices can be used to make income more continuous.
Maintenance	1. Local energy suppliers lack knowledge to maintain the Energy Kit adequate. 2. Local agents lacks time to properly check and repair the Energy Kits. 3. The energy kit is vulnerable because of bad maintenance.	1. Maintenance schedule for the local energy supplier and local agent will provide information about how and when to maintain the energy kit. 2. More information exchange between the local energy supplier and local agent results in quicker repairs and a more reliable system.
Information exchange	1. Local energy suppliers lack knowledge about doing business with the Energy Kit. 2. Payment method required	1. Information and education about how to use the Energy Kit, variable pricing and general knowledge about benefits of solar power to make the Energy Kit more

	much actions and information exchange between operators.	sustainable. 2. The payment method should be easier and faster.

The analysis shows that there is room for improvement. The technical challenge is to match supply and demand and to use the generated electricity as efficient as possible. An opportunity is the use of battery storage. This will also increase the continuity of local energy suppliers' income and the reliability of the Energy Kit. The pricing is limited by the competition of other lighting fuels such as kerosene, as well the limit of what the local people can afford. The lack of knowledge about maintaining the Energy Kit results in inefficient use of the product. A maintenance schedule could provide a solution, as well better information exchange between the local agent and local energy supplier.

2.4 Scenarios

Table 2-7 shows that the current situation needs some improvement in order to provide and match the current demand in rural India. From literature and the field trip it is concluded there is need to match supply and demand, better information exchange between the operators regarding price and maintenance. .
Literature showed that smart technologies can help with efficient use of storage. Therefore the added value of smart applications for each scenario is researched.

The first scenario is with a central storage. The reason this scenario is chosen is because reference projects such as SOPRA showed a large battery storage seems to work in practice. With this large storage the seasonal differences can be covered. The question is whether this is also applicable in rural India.

The second scenario is more focused on a distributed network where all the local people have a small energy source. This source can be a PV panel like the local energy supplier have, or a battery pack or other chargeable devices. The goal of this scenario is to create a distributed network were all local people have access to an energy source. This is in line with literature which proposes a more distributed energy network such as Greenpeace, Lighting a Billion lives and Swarm electrification (Greenpeace, 2014a; S Groh et al., 2014; "Lighting a Billion Lives - About us," n.d.).

The elaboration of the scenarios can be found in chapter 3.

3 Results

This chapter describes the results of the three scenarios. Table 3-1 gives an overview of the three scenarios. The first paragraph gives the parameters and values found in literature and the field trip for the current situations. The second paragraph describes scenario one, followed by scenarios two in the third paragraph. For scenario one and two, an overview of the key factors defined in paragraph 2.3 is given. Further are discussed: the limitations and opportunities, the applicable smart technologies and the comparison with the current situation.

Table 3-1 overview of scenarios and their specification

Aspects	Current situation	Scenario 1	Scenario 2
Lay-out	Decentral	Decentral	Distributed
Scale	Guraru village ± 150 households	Guraru village ± 150 households	Guraru village ± 150 households
Capacity	40 Wp	40 Wp	40 Wp
Storage capacity	Not available, only chargeable lamps	Large battery for seasonal storage	Small battery for day and night storage, and for surpluses
Wired	No	Yes	No, exchange takes place by walking
Lamps	16 to 20 per energy kit (old model of Rural Spark Energy Kit)	16 per energy kit	16 per energy kit
How does it work	The local agent provide the Energy Kit with the lamps to the local energy supplier. The local energy supplier rent out the lamps to local people.	Each local energy supplier has a large battery storage. There are connected to other local energy suppliers and share surpluses to use the energy as efficient as possible.	Each local energy supplier has lights and small battery package which can be charged. The battery packages can be used when the generation is too to charge all 16 lamps, or to rent out the battery packages to local people.
More information	Paragraph 2.2.1 and paragraph 3.1	Paragraph 3.2	Paragraph 3.3

Table 3-1 gives a short overview of the difference between the current situation, scenario one and two. In the current situation there is no storage available, only the chargeable lights, while the other two scenarios have storage. Scenario 1 has a large storage whit the goal to cover the seasonal demand, Scenario 2 has small storage devices which are exchange between local energy suppliers and local people instead of exchange through wires. The elaboration of each scenario is also found in Table 3-1.

3.1 Current situation

The current situation consists of local agents who buy the Energy Kit from Rural Spark and rent these out to local people in the villages. The local people with an Energy Kit become a local energy supplier and charge LED lamps to rent out to local people. More information about the current situation is described in Paragraph 2.2.1.
The current situation is the starting point for the other two scenarios. Table 3-2 gives an overview of the current situation specifications based on the finding from paragraph 2.2.1.

Table 3-2 Overview of specifications for the current situation

Category	Parameter	Value	Source
Basic demand	Lights	1.25 Watt, 4 hours charging time, 20 Wh per light 16 lights per energy kit. 2 per household	Field trip
Additional demand	Mobile phone	2 Watts, about 3 hours charging time	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
	Fan	15 Watt, 9 hours operation time	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
	Television	100 Watt, 2 hours operation time	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
Total additional demand	Mobile phone+ fan+ television	341 Wh	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
Storage	Battery capacity (Small)	20 Wh	("RURAL SPARK PRODUCT BROCHURE," 2014)
Price	Energy Kit Basic (40 Wp)	668 INR	(Rural Spark, 2014)
	Energy Kit Plus (80 Wp)	1,184 INR	Rural Spark, 2014)
	Lights per day	2 INR	Field trip
	Lights per month	80 – 90 INR	Field trip
Income	Total income per month	± 6000 – 7000 INR	Field trip (Ram et al., 2012)
Income	Income from energy kit per month	100 – 600 INR	Field trip

More information about the current situation can be found in paragraph 2.2.1 and Appendix II: Field trip.

3.2 Scenario 1: Central storage

Scenario one emphasizes on solving the seasonal mismatch through a large battery for each local energy supplier and a wired connection between each local energy supplier. When the generation is lower than the demand, the local energy suppliers withdraw energy from the storage. Figure 3-1 gives an illustration of the scenario with the stakeholders, the money, energy and product flow. With the product flow meant is the transfer of products such as the Energy Kit and lamps which are rented out.

The key factors defined in paragraph 2.3 are used to given an overview of the characteristics of scenario one. These characteristics are based on literature findings, the field trip and/or calculations.
From this overview the limitations and opportunities emerge. The opportunities are utilized by smart grid technologies.
At the end scenario one is compared with the current situation.

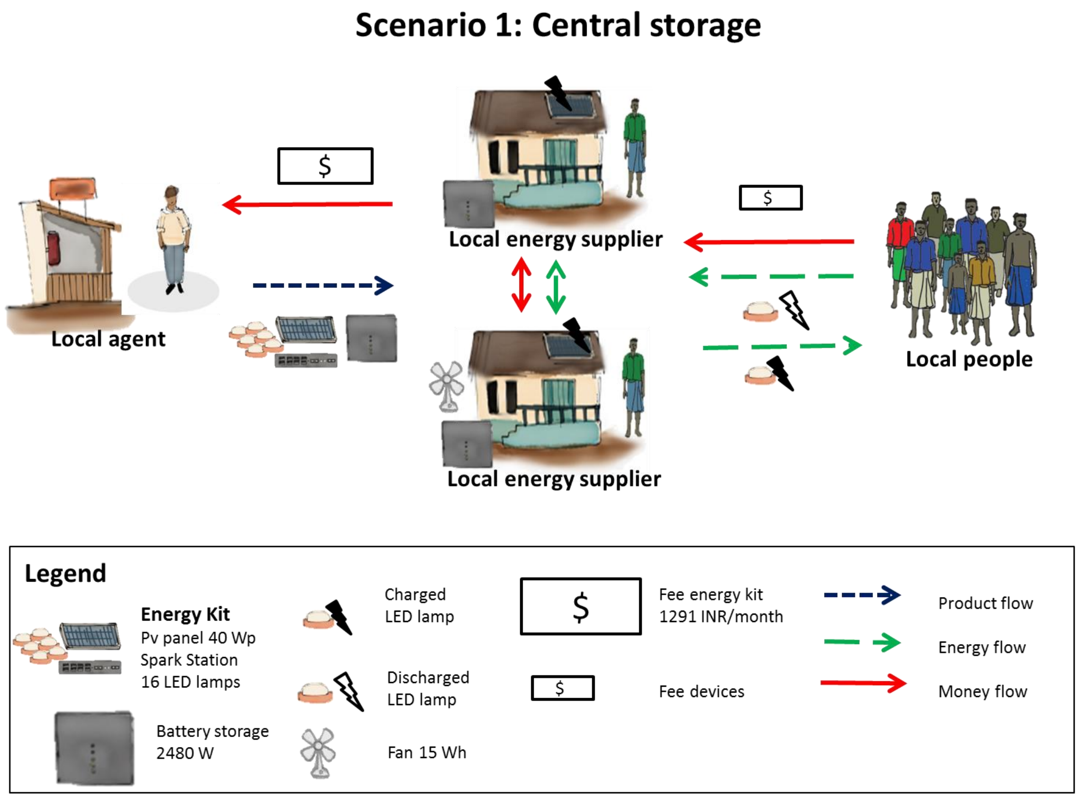

Figure 3-2 Illustration of scenario one with central storage. The local energy suppliers are equipped with a large battery. With this battery they can charge always 16 lamps and sometimes use a fan. The local energy suppliers exchange energy with each other when there is a shortage. The local people can rent lamps from the local energy supplier (illustrations from Rural Spark)

The local energy suppliers are equipped with the new Energy Kit, which can also connects 12 volt devices such as a fan. This fan can be used when the battery is already full and enough generation is available. The local energy suppliers exchange electricity when there are shortages or surpluses. The generated energy will be used as efficient as possible.

3.2.1 Specifications scenario 1

This part shows the specifications of scenario one. The specifications are from the literature, field trip or calculations. All calculations can be found in Appendix II: Calculations. Table 3-3 shows the specifications which are required to show the feasibility.

Table 3-3 Specifications scenario 1:central storage

Aspect	Value	Explanation
Voltage	12 Volt	5 volt can be used for maximum 100 meters. However this is a USB wire, 30 meter is the maximum. 12 volt can be used for a distance of 100 meter. 12 volt is used for many batteries and electric devices such as a fan and

		television. 24 Volt can be used for maximum 500 meters. This voltage is harder to reach, because the PV panel generates 12-24 volt. More PV panels are required to assure this voltage. 60 volt is the best option regarding losses over a distance, but the current solar panel doesn't provide 60 volt, more PV are required or a transformer to bring up the voltage, and bring the voltage down again once it reaches the end user. 12 volt is the most suitable option for the current demand . 60 volt is useful for a higher demand when three or more PV panels are used per local energy supplier.
Distance	Max 100 meter	The distance between the Spark Station and central battery can be 100 meter, when 12 volt is used. A large distance is possible when voltage losses higher than 14% are acceptable. More than 500 meter can be reached if a higher voltage is used. This distance is too short to create a network of local energy supplier who exchange energy through wires.
Battery choice	Lead acid	Lead acid is a suitable choice for the central storage because the size and weigh does not really matter. Using Lithium results in small batteries, but this is not a necessity. A advantage of lead acid is that it is cheap and widely available in India. The price is important, because the local people want to make profit, which is not possible with the lithium batteries of this size. The lead acid battery need maintenance every 3 to 6 months, but on the other hand does it have a high overcharging tolerance. This requires extra actions from the local energy suppliers.
Battery Capacity	2480 Wh	The battery capacity for the minimal demand is 2480 Wh in an ideal situation and without losses. With the voltage losses (12 volt, cable of 1 meter calculated with the wet of Pouillet) power losses and self-discharging losses, which is 4,5% losses. This battery capacity is calculated with 31 days to cover. This is the longest period without the minimum demand. Calculations regarding the battery and losses can be found in appendix III calculations paragraph 2.1 and 2.4. Side note: The battery can be smaller if the local people accept less quality. Maybe when the price becomes lower they will accept this.
Price Energy Kit	1291 INR per month	The price includes the Energy Kit, a lithium battery of 2480 Wh, 16 LED lamps and cables. The battery price is based on the cost per kWh per cycle. This is including production, transportation and replacement costs. The price calculations can be found in Appendix III: calculations paragraph 2.3. The Energy Kit price is based on the production price with extra margin on production cost and 3rd party tools according to Rural Sparks business plan (Rural Spark, 2014).
Battery payback time	±5 years	The lithium battery has higher investment costs, but a lower price per cycle, the payback time is unrealistic for application in rural India. Over 100 years payback time is not realistic and interesting especially when comparing this number with the payback time for lead acid batteries which is about 16 years. Large batteries are not economically feasible to use in rural India.

Profit	±150 INR per month	With the central storage the fee of the Energy Kit rises, but the profit decrease to 150 INR when 90 INR/lamp/month is asked.

Technically it is possible to use a central storage with a lead acid battery when high losses are accepted (distribution losses). The cable length is decisive for the distance between battery and end user. The distance should be more than 500 meter because the local people are prepared to walk 500 meter, but not more. At 500 meter the distribution losses are higher than 50%, which makes the system less efficient. A wired connection is efficient when the voltage is around 24 or 60 volt. This can be reached with more PV panels.
This is one improvement the Energy Kit could undergo, as well the application of smart technologies to regulate the energy generation, storage and usage.

3.2.2 Limitations and opportunities

The central storage has some limitations and opportunities. One of the most clear limitation is the lack of profit.

Table 3-4 Overview of limitations and opportunities for scenario 1: central storage

Factor	Limitations	Opportunities
Matching supply and demand	- To cover the seasonal mismatch, a large battery is required. - A wired connection is only useful when 100 meter or more is covered. This distance results in high losses with the proposed 12 volt.	- With the right management tool the battery can charged and used at the right moments. - Higher voltage will reduce the losses over the distance, which result in larges distances.
Pricing	- There is no profit when a central battery is used. - Prices higher than 90 INR per lamp are required to make a small profit.	- Using the generated energy as efficient as possible to charge extra lamps or other rentable devices, the profit as well the value of the Energy Kit can rise.
Maintenance	- The local energy suppliers and agent need extra knowledge regarding the battery to maintain it adequate.	- Maintenance schedule for the local energy supplier and local agent will provide information about how and when to maintain the Energy Kit and battery. - More information exchange between the local energy supplier and local agent results in quicker repairs and a more reliable system.
Information exchange	- Local energy suppliers lack knowledge about doing business with the Energy Kit. - Payment method required much actions and information exchange between operators.	- Information and education about how to use the Energy Kit, variable pricing and general knowledge about benefits of solar power to make the Energy Kit more sustainable. - The payment method should be easier and faster.

Table 3-4 shows that only the information exchange aspects are unchanged compared with the current situation. For matching supply and demand a solution is found, but the battery must be really big. The battery is a technical solution, but results in less to no profit. More management is required to make profit or higher prices. The battery requires extra maintenance and knowledge.

3.2.3 Smart technologies

Sinha describes smart technologies which can be used to create a smart grid. These technologies can be used to exploit the opportunities. There are nine smart technologies:

1. Smart Meters
2. Meter Data Management
3. Field area networks
4. Integrated communications systems
5. IT and back office computing
6. Data Security
7. Electricity Storage devices
8. Demand Response
9. Distributed generation

Table 3-5 gives an overview of smart technologies applied in the scenario with central storage. The issues are determined from the limitations and opportunities in Table 3-4.

Table 3-5 Overview of smart technologies applied in the first scenario

Aspect	Smart technology
- To cover the seasonal mismatch, a large battery is required. - With the right management tool the battery can charged and used at the right moments.	Electric storage device A smart meter measures how much is generated, used and stored.
- There is no profit when a central battery is used. - Using the generated energy as efficient as possible to charge extra lamps or other rentable devices, the profit as well the value of the Energy Kit can rise.	A smart meter gives information about how much energy is available. With meter data management the price can be determined.
- The battery requires extra attention to prevent overcharging. - The local energy suppliers and agent need extra knowledge regarding the battery to maintain it adequate. - Maintenance schedule for the local energy supplier and local agent will provide information about how and when to maintain the Energy Kit and battery.	Smart meter data can be used to detect if the battery is fully charged. Integrated communication system communicate with the local energy supplier and the local agent about maintenance actions.
- Information and education about how to use the Energy Kit, variable pricing and general knowledge about benefits of solar power to make the Energy Kit more sustainable. - The payment method should be easier and faster.	The integrated communication system gives information about the price, maintenance and general knowledge regarding the Energy Kit.

With the proposed smart technologies the opportunities and the limitations of the central storage can be covered. A smart meter, integrated communication systems and storage are required to match supply and demand.
It is technically possible to make the central storage however, social-economic it is not recommended to implement a central storage with the current and additional demand.
A smaller storage could be useful to cover the additional demand or the day and night mismatch.
For this reason the first scenario, with central storage, will not be developed any further.

3.2.4 Comparison with the current situation

The scenario with central storage should be an improvement of the current situation as described in chapter 2. Comparing Table 2-7, the current situation, and Table 3-4, scenario with central storage, results in the following main differences.

Matching supply and demand
In the current situation the main limitation is the mismatch between supply and demand, and the demand for more lights and other electric devices. The central storage is a solution to match supply and demand, especially when a smart meter is applied to regulate when and how to use the stored energy. The battery stores energy, but also loses it through the wires and self-discharge rate of the battery. These losses are higher when the distance covered by the cables increase, but in the end this is more efficient than without the battery. The central storage is an technical improvement compared with the current situation.

Pricing
Compared with the current situation the central storage impairs the profit of the local energy suppliers. The battery and the cables are too expensive for the current demand.

Maintenance
The battery requires extra attention in order to prevent overcharging. Maintaining the Energy Kit becomes more complex and extra information is required. With the smart meter and integrated communication system the right information about maintenance can be given at the right time.

Information exchange
The lack of information stays the same as well the payment method. The integrated communication system could play a role in improving the information exchange and the payment method.

Summary
The central storage is technical possible, but due to the high cost and low to none profit, it is economic not feasible. Smart technologies could play an important role in information exchange.
The battery could be used as a daily storage instead of a seasonal storage. This way the local people charge during the day the LED lamps and the battery when possible, and use this in the evening for the television for example. The battery can be smaller and create a daily benefit.

3.3 Scenario 2: small storage devices

Scenario two is based on a distributed layout, instead of decentralized layout. In this scenario the local energy supplier does not only lend out LED lamps, but also battery packages and other devices which can store electricity. This way the generated energy is used more efficient and exchanged with the local people.
The battery package can be rented for a higher tariff than the lamps, because it can charge more lamps and can even be used to provide other devices with electricity. Figure 3-3 llustrates the second scenario.

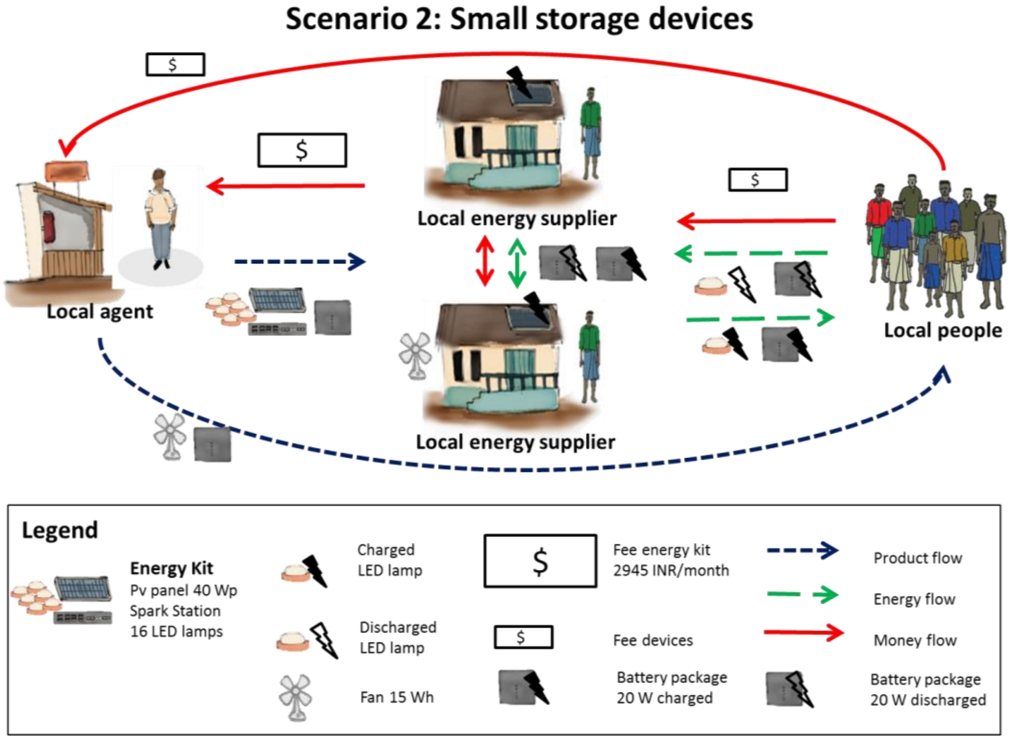

Figure 3-3 illustration of the second scenario with small storage devices. The local agent rent out the energy kit and extra devices to the local energy supplier such as LED lamps and battery packages. The local people can also rent battery packages, lights and fans from the local agent. The batteries can be exchanged with other local people or used by themselves to charge lights or mobile phones (illustrations from Rural Spark)

This paragraph gives the specifications of scenario 2 emerged from literature, the field trip and calculations. With these specifications the limitation and opportunities are improved by means of smart technologies. The last part compares the current situation with scenario two.

3.3.1 Specifications scenario 2

Table 3-6 shows an overview of the technical and social-economic aspects for the second scenario: small storage devices.

Table 3-6 Overview of specifications of scenario two: Small storage devices

Aspect	Value	Explanation
Voltage	5 Volt and 12 volt	5 volt can be used for maximum 100 meters. However this is a USB wire, 30 meter is the maximum. This is ideal for the small storage devices such as the LED lamps and battery packs. 12 volt can be used for a distance of 100 meter. 12 volt is used

		for many batteries and electric devices such as a fan and television. This is ideal for the additional demand such as the fan and television. There are many other household equipment running on 12 volt. 24 volt and higher is useful to transport electricity over large distances, but requires also more PV-panels to assure the voltage. 5 and 12 volt are the most suitable for this scenario because of the small storage devices an additional demand.
Distance	Max 500 meter	The distance between the local energy supplier and other local peoples is not determined by cable losses, because they are not applied. The distance is determined on how far the local people are willing to walk to obtain electricity. According to Rural Sparks' pilot with battery packages, this is 500 meters (Rural Spark, 2015a). Literature also mentions a walking distance of 500 meter to 1 kilometer to get water and other fuels (Rao, Gokhale, & Kanade, 2008; Undp et al., 2004).
Battery choice	Lithium battery	The self-discharging time of a lithium battery, for example LiFePO4, is 3% each month, in perfect conditions, while a lead acid battery has 5%. Also the energy density is higher, respectively 30-50 for lead acid and 90-120 for lithium batteries, which result in smaller batteries. The higher cycle life of 1000-2000 against 200-300 of lead acid, results in longer battery life, if overcharging can be prevented. With a battery management system this can be achieved (Muneer, 2014). The lithium battery can be discharged fully, while the lead acid can only be discharge to 50%. This result in larger batteries. The lithium battery is mainly used in chargeable and portable devices which is an extra argumentation to apply lithium batteries (Palit, 2014). The specifications of the batteries can be found in Appendix III: Calculations paragraph 3.2. Notable is that the lithium battery is not widely available in India and therefor the price could be higher.
Battery capacity	2 x 20 Wh battery packages per Energy Kit	The battery has two goals of which the first one is storing surpluses to cover the day and night mismatch. The second goal is to uses the battery packages to charge or run other devices such as lamps and the fan. Calculations can be found in appendix III: paragraph 3.1 which show that 2 battery packs of 20 Wh is useful to match the minimum demand of 16 lamps. The battery provide 5 volt, and in serial connection the voltage can add up according to the law of Krichhoff.
Price Energy Kit	1112 INR per month	The price consist of the Energy Kit (270 INR), 2 lithium battery of 20 Wh (2 x 84,85 INR) and 16 LED lamps (16 x 26 INR). The Energy Kit consist is based on the production price with extra margin on production cost of 30%. Values can be found in appendix III: paragraph 3.3.
Battery payback time	1 year	The fee of the battery pack is based on the investment cost divided by 12 months which is 84,85. The payback time is 1 year.
Profit	0 and 2000+	With the small battery package the income can vary between 0 and 2000 INR This depends on how many battery package or

INR per month	lights are rented out. An example is given in table Table 3-7.

Table 3-6 shows the specifications for scenario two with small storage devices. Table 3-7 shows an comparison with the current situation to illustrate that it is economic feasible to use the small storage devices.

Table 3-7 Comparison with the current situation and scenario 2. The months July to December are the winters season and less generation is available. This result in lower income. Using all the available energy to charge lights, result in higher income. Instead of lights also battery packages can be charged or directly used for other devices.

Month	Average number of lamps charge per day in the current situation	Monthly profit in INR for the current situation	Average number of lamps per day for scenario 2	Monthly profit in INR for scenario 2
January	16	612	24	600
February	16	612	46	1788
March	16	612	49	1950
April	16	612	51	2058
May	16	612	45	1734
June	16	612	30	924
July	11	197	11	-232
August	15	527	15	88
September	13	386	13	-72
October	16	612	16	168
November	16	612	24	600
December	8	-30	8	-155
Annually profit in INR		5976		9129

Table 3-7 shows that annually the local energy supplier earn more when he uses al the energy, even if he has to pay extra for renting the extra lamps.
The energy could also be stored in battery package to rent out, or use later to overcome the shortage in the cloudy months.

3.3.2 Limitations and opportunities

Scenario two, with small storage devices has some limitations and opportunities. Table 3-8 shows the limitations and opportunities for each key factor.

Table 3-8 Limitations and opportunities per key factor scenario two: small storage devices

Aspect	Limitations	Opportunities
Matching supply and demand	- The small battery package cannot match the seasonal mismatch, only the mismatch for a couple of days. - The demand for more lights can be achieved, but the additional demand is harder to achieve.	- With smart technologies the generated energy can be used more efficient.
Pricing	- The fee for the Energy Kit rises with extra lights or	- Variable prices depending on the weather/generation results in higher

	battery packages. - The fee for renting lights should be higher to obtain the same level of profit for the local energy suppliers as the current situation.	profit. - Variable battery use, only when there is enough energy available, will result in higher and continuous profit.
Maintenance	- The lithium battery requires extra maintenance regarding preventing overcharging. - The local energy suppliers and agent need extra knowledge regarding the battery to maintain it adequate.	- With an maintenance schedule and instruction the local energy supplier should be able to maintain the Energy Kit by himself. - An battery indicator shows how full or empty the battery or storage devices is. This will prevent overcharging.
Information exchange	- Local energy suppliers lack knowledge about doing business with the Energy Kit, especially regarding battery use. - Payment method required much actions and information exchange between operators.	- Information and education about how to use the Energy Kit, batteries, other devices, variable pricing and general knowledge about benefits of solar power to make the Energy Kit more sustainable. - The payment method should be easier and faster.

Table 3-8 shows the limitations and opportunities for the small storage devices. Notable is the fact that prices rise, but could result in higher profit compare to the situation without a battery. This requires extra information regarding maintaining the battery, but also how to use it as efficient as possible. Renting the batteries from the local agent during months generation is high enough to charge and rent out the battery, will result in a more stable profit. The local energy supplier should get the right information when the rent the batteries and when not. With all the technical improvements and the extra income for the local energy suppliers, the social aspect such as information exchange and a less time consuming payment method is not improved.
The next paragraph describes the extra value of smart technologies for each key factor: matching supply and demand, pricing, maintenance and information exchange.

3.3.3 Smart technologies

This paragraph gives more information about to use of smart technologies for each key factor shown in table Table 3-8.

1. Matching supply and demand

With the small storages such as battery packages and LED lamps, more energy can be used compared to the situation without the extra storage. The problem is that it is not clear when it is more convenient to charge battery packages, lamps or when not to. In order to this, generation data is required which can be obtained with a smart meter. This is one of the smart technologies described by (Sinha et al., 2011).
The smart meter obtains information from the end users: in this scenario the local energy supplier. This data is provided, with some added information to the utility, who is in this

scenario also the local energy supplier. Figure 3-4 gives an overview of the actions the smart meters has to take for the right information.

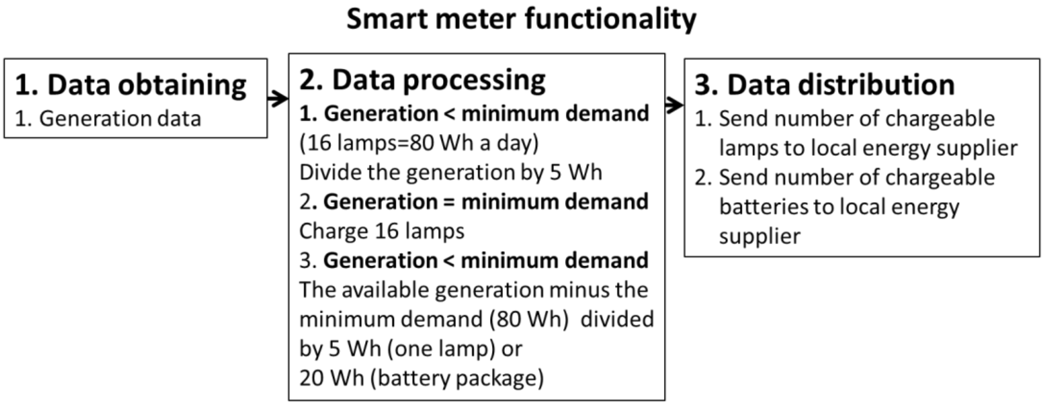

Figure 3-4 Smart meter functionality. First step is to from generation data the PV panel. This data is processed in order to get useful information such as the number of lamps and battery packages that can be charged. The data is send to the local energy supplier.

Figure 3-4 shows three steps to get the right information from the smart meter. The first step is obtaining the generation data. This data is processed in useful information such as the number of lamps and batteries that can be charged.
The last part is distributing the data to the local energy suppliers so they know what to do. This is a sort of demand response, where the use follows the generation, instead of generating more to achieve the demand.
With this data the energy supplier can also define prices. This is explained in the next section.

2. Pricing

To define the price for the rentable lamps and battery packages, the smart meter undertakes the same actions as when the supply and demand is matched, only another data process takes place.

Table 3-9 Data processing to define the price for lamps and battery packages

Situation	Action
Generation< minimum demand	Multiply the normal costs of the lamp (2 INR) with 16 and divide it with the available chargeable lamps.
Generation = minimum demand	The price is minimum 2 INR, or any price which is communicated with the local people.
Generation > minimum demand	Divide the number of lamps that can be charged with the price of the lamps multiplied with the amount of lamps. Battery package are also calculated the same way. The extra generation beside the minimum demand, divide by 5 INR. Or any minimum price the local energy suppliers agreed on

The actions result in a price for the lamps and or batteries. This is based on the findings from literature and the field trip, such as the finding that the minimum price for lamps per month is 80 INR and the daily price is 2 INR.

Table 3-10 Overview of profit with different storage strategies. Charging only 16 lamps results in the lowest income. Charging 16 lamps and 2 battery packages result in a monthly increase of 180 INR. Charging 32 lamps an two battery result in even higher profit as well for charging only lamps. The lamps are rented out for 80 INR per month, the battery packages 90 INR. The fee the local energy supplier has to pay is 26 INR for each lamp and 85 INR for each extra battery package besides the two include with the energy kit.

Month	Number of chargeable lamps per day	16 lamps	16 lamps and 2 batteries	32 lamps and 2 batteries	Unlimited lamps
January	24	168	348	777	600
February	46	168	348	1212	1788
March	49	168	348	1212	1950
April	51	168	348	1212	2058
May	45	168	348	1212	1734
June	30	168	348	1093	924
July	11	-232	-52	-52	-232
August	15	88	268	268	88
September	13	-72	108	108	-72
October	16	168	348	348	168
November	24	168	348	778	600
December	8	-472	-292	-292	-155
Annually profit in INR		651	2811	7871	9129

Table 3-10 shows that using the storage devices increases the profit for the local energy suppliers. The highest financial benefit is achieved when all energy is used for lamps. It is, however questionable if this is realistic because renting out 51 lamps is a large number. The energy can be stored in lamps or battery packages. The advantage of the battery packages is that it can be used for other purposes than lighting: for example for charging a mobile phone or using a fan. The battery can also be used for own purposes or to create a more stable income in months when the generation is low and cannot reach the minimum demand of 16 lamps.
All these options should be communicated with the local energy suppliers. The information exchange is explained in a later section.

3. Maintenance

To maintain the Energy Kit, the local energy suppliers should know how to detect and repair the Energy Kit. The smart meter can automate the detection of defects when the right information is obtain. For example it could detect when the voltage of a PV panel is low, which could mean something is wrong with the PV panel. The PV panel must be checked for dust, position and damages. Also the cable and connections with PV panel must be in checked. Table 3-11 show an example of maintenance actions per component.

Table 3-11 Example of maintenance actions

Component	Action	Frequency	Comments
PV panel	Cleaning	Monthly	The panel generates at its best when the panel

	Checking position		is clean from dust. The optimal angle position differs from season.
Cables	Checking of damages	Monthly	Every monthly the local energy suppliers has to do the payment at the local agents shop. This is the moment to mention defects or ask a new cable.
Spark Station	Keep dust free	Daily	
LED lamps and other devices	Check if charging and working properly	Daily	Checking if the devices work properly ensures the income and comfort.
Battery	Prevent overcharging	Daily	The smart battery management system indicated if the battery is full or not.

To give all these information, the smart meter must be able to obtain data about voltage for example.

4. Information exchange

To make the data distribution possible, integrated communication systems and a field are network are required. (Güngör et al., 2011) analyses the most used communication technologies and standards. More information can be found in Appendix III: Calculations paragraph 3.4. The wireless technologies such as ZigBee, wireless mash and cellular network communication are the most interesting for rural applications.
ZigBee is interesting, because it is cheap and easy to implement. It has the required specifications, such as load control and reduction, which would be used if the network become more advantaged.
The most interesting is probably the cellular network communication which uses GSM, GPRS, 3G and Wimax. The big advantage is that the cellular network already exists, therefore no extra costs are required to build the network. The high coverage range between 1 to 10 kilometer is suitable for rural areas.
The most promising technology for communication is cellular network communication, in combination with GSM technology which has lower costs, better coverage and lower maintenance costs. (Güngör et al., 2011) also states that this is the best candidate as a smart grid communication technology for demand response and advantage metering infrastructures.

The communication network is used to send information:

1. To the local energy supplier about the energy consumption, generation and storage.
2. To the local agent about defects .
3. To the local energy supplier with general information regarding solar use.
4. Telepayment, when the money is digital and no cash is required.

Unfortunately, with all the smart technologies, an easier payment method for the local energy supplier is not possible as long they receive payments in cash. They still have to go to the local agent to fulfill the payment. However the local agent now has the ability to activate the Spark Station from distance. When the payment is received, the local agent only has to send a message to the Rural Spark server and it can remotely activate the Spark Station, if it has a GSM connection.
Another solution, for the future could be using some prepaid card which the local energy supplier buys to activate the Energy Kit for multiples months.

The applied smart technologies are smart meters, integrated communications systems and a field area network with GSM technology.

3.3.4 Comparison with the current situation

This paragraph compares the current situation as described in paragraph 2.2.1, with scenario two where small storage devices create a more distributed energy network. The comparison is made with all the key factors.

Matching supply and demand
Compared with the current situation, the season mismatch is still there. However, the small storage devices are able to provide a higher demand because the energy is used more efficient. The Spark Station gets an upgrade with a 12 volt connection and therefore other electric devices can be used. With the small battery packages connected in serial, it is also possible for local people to use a fan or other 12 volt devices.

Pricing
Due to the battery package, the monthly fee for the energy kit becomes higher. However, it is possible to store energy and sell it, which could increase the profit of the local energy supplier by ten times. With a smart meter the best price is calculated and communicated with the local energy supplier. When the local energy supplier does not follow the instructions, the profit is lower than in the current situation, because he also pays for the battery package but doesn't use it properly.

Maintenance
The battery package needs extra attention because overcharging is not tolerated. This can be solved with a battery management system, but also checking the status of the battery regularly. The smart meter obtains data regarding the status of the PV panel to detect defects and gives information to the local energy supplier how to repair it.

Information exchange
The information exchange from the smart meter to the local energy suppliers is achieved by GSM technology. The information the local energy supplier receives is the price and number of lamps he can charge, maintenance advice, instructions and general information about solar power and doing business.
The communication network can be used to activate the Energy Kit from distance. This could simply the payment method when no cash money is required.

4 Conclusion and recommendations

The goal of this research is to improve the Rural Spark Energy kit in technical and social-economic aspects, in order to provide the current basic and additional electricity demand of the local people in rural India.

This chapter presents the research conclusions (paragraph 4.1) and gives recommendations for further research (paragraph **Error! Reference source not found.**).

4.1 Conclusion

In this paragraph the research question is answered followed by the research sub-questions.

The main research question of this report is:

How can the technical and social-economic aspects of the Rural Spark Energy Kit be improved, in order to better provide the current and additional electricity demand in rural India?

The Rural Spark Energy Kit can be improved by applying smart storage devices and smart technologies. Applying small storage devices the energy network of local energy suppliers becomes more flexible. The smart technologies regulate when and how much lamps, batteries and other devices can be charged or used. This results in a higher profit for the local energy suppliers. With the battery packages it is also possible for the local people to charge their own lights and to use other devices such as the fan when the battery package are coupled in series. The battery packs and the upgrade of the Energy Kit with a 12 Volt outlet responds to the additional demand of fan and television use.
The integrated communication system with GSM connection also gives information about maintaining the Energy Kit and other information such as the price, how much lamps can be charged and general information.
Summarized, smart technologies in combination with small storage devices makes the Rural Spark Energy Kit more flexible and efficient and improve technical and social-economic aspects.

The research sub-questions are:

1. *Which technical improvements are required to match the current basic electricity demand and to which extend can the additional electricity demand be covered?*

The small storage devices is a suitable improvement for rural India to cover the basic demand and to cover the demand in the summer months, it is also possible to cover the additional demand partly, however the large storage in the first scenario covers the seasonal mismatch better.
The battery package are 20 Wh lithium batteries, which is enough to charge four LED lamps. Batteries can also be used in series to use 12 volt devices such as a fan. With connected batteries a fan can be used for two hours..
The battery packages and extra lamps, result in more possibilities for the local people. They can rent a battery package to charge their own mobile phone or battery, or to use a fan. This way the local people have a temporary energy source which makes the network more distributed than the current situation.

Another suitable solution is the addition of a of 12 volt outlet for the local energy supplier. They can use the fan directly when the generation is high enough, or store it and us it on a moment when the generation is too low to cover the minimum demand of 16 LED lamps.

1. *How should the current social-economic approach be changed in order to cover the current basic and the additional demand?*

The pricing is one of the four key factors that emerged from literature and the field trip. The local energy suppliers would like to make profit which is in the current situation already possible, but with the extra LED lamps, and battery packages they can earn almost two times more. The fee for the energy kit increases from 668 to 1112 INR, but the price for renting the LED lamps stays the same. The price and profit is a positive point for local energy suppliers.

In both scenarios maintenance of the battery is used. In the first scenario the lead acid battery needs maintenance every 3-6 months, as well the cables between the batteries. The second scenario requires daily maintenance for the lithium battery, because overcharging is not tolerated. With a battery management system this can be prevented.

Scenario two also requires a lot of information in order to provide the minimum demand, as well for the additional demand. The information, maintenance and payment method is not improved in these scenarios.

2. *What is the added value of smart technologies for the Rural Spark Energy Kit in rural India?*

The added value of smart technologies lies in utilizing the opportunities of each scenario. To use the battery packages and extra lamps in order to gain more profit, information is required about the generation. The smart meter obtains generation data and processes this in useful information for the local energy suppliers. Useful information is: the number of lamps and battery packages they can charge and the price for each device.
With the integrated communication system with GSM technology, the Energy Kit can send and receive information. The local energy suppliers receive messages on their mobile phone regarding the price and number of lamps they have to charge..
The smart meter is also able to detect failures by measuring the voltage of the PV panel. Maintenance instructions and general information is send to the local energy supplier in order to increase their knowledge.
The smart technologies have many benefits for the scenario two, but could also be applied for scenario one.

4.2 Recommendations

During the research a number of problems were encountered and some interesting perspectives were found. Table 4-1 gives an overview of the research questions and the answers. For each answer a recommendation is given, which isexplained below the table.

Table 4-1 Overview of research question and result with recommendations.

Research question	Result	Recommendations
Technical improvements	Storage of 20 Wh and extra lamps result in covering the basic demand and the additional demand of a fan in the summer.	Research for the optimal size for the batteries, or determination of a combination of large storage and small storage devices.

	More functionalities due the 12 volt outlet for the local energy suppliers.	
	Energy is better used.	
	Local people have the possibility to charge their own light and use other devices with the battery package: temporary energy source.	
Social-economic	Higher fee, but higher profit when the small storage devices are used at the right moment.	
Smart technologies	The addition of a smart meter results in information about the right price, amount of devices to charge and maintenance instructions.	The smart technologies are not tested in the field and it is still unsure if they would be a success.
	With the integrated communication system the obtained information from the smart meter can be send to the local energy suppliers mobile phone. Also general information can be send to enrich their knowledge.	The costs of the smart technologies are not taken into account. A good business plan must be developed to gain more knowledge about the revenue flows.

1. Optimal battery size

The decentralized scenario showed that it is technically not efficient enough to apply wired connections between local energy supplier in rural India due to the high distribution losses. A wired solution is not suitable, however the battery could be used to cover the daily demand like the small storage devices do. Keeping this in mind, research on the optimal battery size, or a combination of large and small storage devices might be use full. This could result in a different type of network, with large and small local energy suppliers.
More research is required to find the optimal size for the batteries, or a combination of large and small storage devices.

2. Implementation of smart technology in the field

This research shows some examples of smart technologies which can be applied, such as the smart meter and integrated communications devices However it is not yet clear how this is can be applied in the Energy Kit. More research is required about how all the smart technologies can be implemented in the Energy Kit.
Another point of attention is how these technologies will work in practice. The theory might be promising, but the local people are the decisive factor for success. The new Energy Kit, with a smart meter, integrated communication with GSM technology should be realized and tested by the local energy suppliers to prove the success.

3. Business plan

The cost of the smart technologies are not taken into account in this research, because the technologies need some adjustments before being usable in the Energy Kit and in rural India. The price for these technologies is unsure and therefor a good business plan must be developed to gain more knowledge about the costs and revenue flows.
The success of the new Energy Kit depends on the investments the local energy suppliers have to do and profit they will make. A good business plan, including an overview of prices, is therefore a necessity.

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Appendix I: Literature study

1 Introduction

Millions of people in rural India live with no or insufficient electricity supply. The Indian government failed to supply everyone with electricity before 2012(Palit & Chaurey, 2013; Govinda Upadhyay, 2012). The top-down approach has been proven unsuccessful and another approach is required to electrify rural India.

Literature shows that solar powered micro grid have potential for rural electrification . This research focuses on the technical and social-economic possibilities for rural India, in combination with smart technologies.

First the current electrification situation in India is discussed to find out what the problems are and why it is so hard to extend the current electricity grid to rural areas.
The second paragraph goes more into detail about the rural electrification situation in India. The focus lies on their wishes regarding electricity and the social-economic aspects such as how they live, how much they have to spend and pay for electricity.
The third paragraph goes more into detail what the future of rural electrification in India.
Reference project regarding rural electrification are discussed in the fourth paragraph. More insights about what is technical possible are discussed, as well the social-economic aspects.
The last paragraph describes the smart technologies which are applied in the reference projects.

The last chapter is the conclusion of important aspects found for a solar energy network in rural India with the focus technical, social-economic aspects and smart technologies.

2 Rural electrification in India with solar energy

2.1 Electrification situation in India

This paragraph described the current electrification situation in India.
Electrification starts with the generation of electricity. According to the International Energy Agency India generates most of their energy though coal which is shown in Figure 2-1.

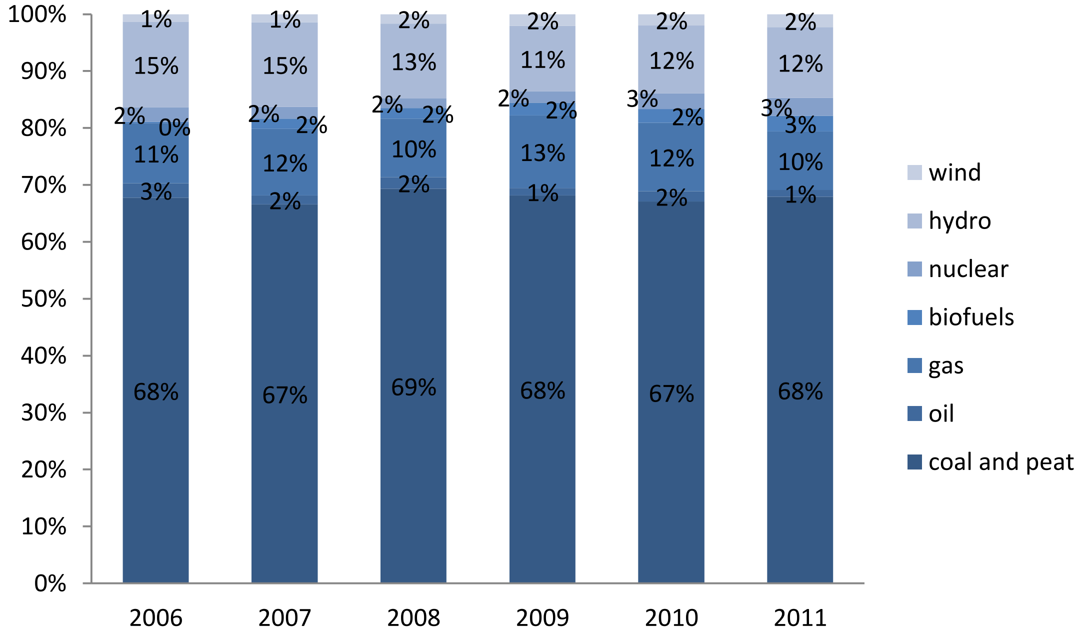

Figure 2-1 Electricity generation by fuel in India from 2006-2011 (“IEA - Report,” 2011)

The use of renewables is around 15% and is slowly growing. The question arise whether this generation is enough for all the people. Compared to other countries India generates less per capita kWh electricity than develop countries. This is shown in Table 2-1.

Table 2-1 Population size, electricity production and electricity consumption per capita for the United States, Netherlands and India.(“Electricity consumption per capita - Country Comparison,” 20112)(“The World Factbook,” n.d.)

Country	Population in million	Land area in km²	Electricity production in billions kWh	Electricity consumption per capita in kWh
United States	313.9	9,826,675	3,953	11,919.8
Netherlands	16.7	41,543	105.7	6,724.19
India	1,236.3	3,287,263	835.3	498.39

Table 2-1 shows that compared to the Netherlands only about eight times more electricity is generated in India, while there live almost 80 times more people in India. The people in India have to use less electricity while they have more people available. Table 2-2 shows that India has 304 million people without access to electricity.

Table 2-2 Overview of Asian countries and their electrification rate national, urban and rural in 2012.(IEA, 2014)

Region	Population without electricity in millions	National electrification rate %	Urban electrification rate %	Rural electrification rate %
China	3	100	100	100
India	304	75	94	67
Southeast Asia	140	77	92	65
Rest of developing Asia	175	61	82	52

A big part of un-electrified people are located in rural areas. There is a mismatch between the location of supply and demand. This is not the only mismatch in supply and demand because India generates for too little electricity with deficits of 8% shown in energy requirement and 5% at the peak demand shown in Table 2-3.

Table 2-3 Deficits in energy requirement and peak demand in December 2012 (CEA, 2012)

Region	Energy requirement (MU)	Deficit %	Peak demand (MW)	Deficit %
Northern	23,523	-7.3	37,861	-8.2
Western	28,276	-4.1	39,476	-5.6
Southern	23,865	-17.5	35,132	-17.4
Eastern	8,177	-5.0	14,302	-5.3
North Eastern	995	-5.0	1,948	-4.6
Average	215,7682	-7.98	25,7438	-4.94

The Southern areas of India has to deal with more deficits than the North. Again the mismatch of supply and demand is showed. Table 2-4 shows an overview of the current electrification situation India. There are many problems with the traditional grid in India for example the huge gap in supply and demand, but also the transmission and distribution losses.

Table 2-4 Overview of the current electrification situation in India

Current situation	Source
300 to 400 million people in India are without access to electricity	(G Upadhyay et al., 2012) (Mertens, 2011) (Millinger et al., 2012) (Govinda Upadhyay, 2012)
Indian government want to electrify all the villages and hamlets	(Banerjee, 2006) (Acharjee, 2013) (Cust, Singh, & Neuhoff, 2007) (Sinha et al., 2011)
Main problems with the national grid in India are: 1. Huge gap in supply and demand 2. Very high transmission and distribution losses 3. Predominantly manual operation of the grid	(Harish & Kumar, 2014) (Banerjee, 2006) (Rihan, Ahmad, & Beg, 2011) (Acharjee, 2013)

4. Poor utilization of enormous renewable energy potential 5. Low metering efficiency and minimum consumer participation 6. Lack of utilization of advancements in information technology in the power.	
Rural areas falling behind in economic development due to lack of electricity.	(Oda & Tsujita, 2011) (Chaurey et al., 2004)
Rural education is falling behind	(Oda & Tsujita, 2011) (Chaurey et al., 2004) (Palit & Chaurey, 2013)
Electrification plays important roles in poverty reduction	(Oda & Tsujita, 2011) (Chaurey et al., 2004) (Shailaja Rego, Naresh Kumar, 2013)

Table 2-4 summarized, there are challenges in rural India to improve the access to electricity, but also to stimulate the economy and education level. A reliable electricity grid might reduce the poverty but is only reliable when the current electricity grid problems in India are not present.

Conclusion

India generates too little energy for all their people which cause black outs. These blacks out are due to the lack of generation, but also the higher transmission and distribution losses, along with energy theft and poor utilization. The black outs are experienced mostly in the urban areas, while 30% of the rural doesn't have access to electricity. More than 300 million people in Indian live without access to electricity.

2.2 Electrification situation in rural India

Paragraph 2.1 ended with the defects of the traditional Indian electricity grid. To electrify rural areas, first more should be known about the problems and wishes in rural India. This paragraph describes first the current electrification in rural India.

According to Mertens (2011) energy is used for food, cooking, lighting, electric devices and transportation as shown in Table 2-5.

*Table 2-5 Energy demand in 2005 and 2030 [MJ*pp*day]*(Mertens, 2011)

	Energy demand for	Energy demand in 2005 [MJ*pp*day]	Energy demand predicted in 2030 [MJ*pp*day]
Food	Food	8.5	8.5
	Food indirect	3.1	3.1
	Non-food indirect	4.6	15.5
Cooking	Firewood & chips	12.2	12.6
	LPG	0.2	0.7
	LPG indirect	0.1	0.5
Lighting	Kerosene	1.0	0.5
	Kerosene indirect	0.7	0.4

Electric devices	Electricity	0.9	2.6
	Electricity indirect	3.8	8.5
Transportation	Petrol & diesel	0.2	0.7
	Petrol & diesel indirect	0.1	0.5
Total		**36**	**54**

Concluding from Table 2-5 the energy use will grow in the future, the kerosene might decrease while the electricity use increase. Non-food indirect and firewood & chips use the most energy. With the help of electricity the used energy becomes cleaner and cheaper. Electricity can also be used for transportation and lighting, but cooking and lighting are of main importance according to Mertens.

In Table 2-6 electrical usage is shown in a rural village. The time is an indication and depends on the hours electricity is available.

Table 2-6 Electrical usage and devices in a rural village(Govinda Upadhyay, 2012)

Equipment	Power (W)	Timing (Hr)
Blub	10	3-4 Hours during the evening
TV	50	1-2 Hours during the evening
Mobile charger	5	Once in 3 days for 2-3 hours
Fan	25	2-3 hours during the day time in summer

Table 2-6 shows that the light bulb is the most used electrical appliance, followed by the fan. Rural inhabitants want light during dark hours and cool their house to create a more comfortable home. The temperatures can be very high and therefor a fan is also a health issue. The TV and mobile charger are to create a more comfortable life, but also to gain access to information. That lighting is the most important matches Mertens' statement that cooking and lighting are the most important.

Undp, Bank, (2004) shows in his research about the impact of energy on women's live in rural India that women from houses with electricity spend less time collecting fuel fetching water, and cooking. With the extra time they have, more time is spend on leisure activities such as reading and watching TV. The research also says that reading and watching TV are significant factors in raising awareness, broadening horizons, and educating rural women and thus should be seen as status-enhancing activities. The research also concludes that electricity mainly used for lighting, but also for entertainment and for space cooling with fans (Undp et al., 2004)

Table 2-7 shows the electricity demand for Palari, a rural village with electricity to show how rural people use electricty. The electricity use is dived in domestic purposes, industrial, agriculture, medical center and school.

Table 2-7 Estimated electricity demand for Palari village(Sen & Bhattacharyya, 2014)

S. No.	Load	No. in use	Power (Watts)	Summer (April–Oct.)		Winter (Nov.–March)	
				Hrs/ day	Watt-hrs/ day	Hrs/ day	Watt-hrs/ day
	Domestic purposes						
1	Low-energy lights (CFL)	1	20	6	120	7	140
2	Low-energy lights (CFL)	1	20	6	120	7	140
3	Low-energy lights (CFL)	1	11	5	55	6	66
4	Radio	1	10	3	30	4	40
5	Ceiling fan	1	30	15	450	0	0
6	Table fan	1	15	9	135	0	0
	Total				**910**		**386**
A	**No. of houses**	**304**			**276640**		**117344**
	Industrial/commercial/community purposes						
1	Shops	10	500	8	40000	7	35000
2	Community centre	1	1000	8	8000	6	6000
3	Small manufacturing units	5	3000	12	180000	10	150000
4	Street lights (CFL)	5	30	10	1500	12	1800
B	**Total**				**229500**		**192800**
	Agriculture & irrigation purposes						
1	Water pump	8	745	5	29824	3	17894
2	Irrigation pump	4	1490	6	35789	4	23859
3	Well	1	745	4	2982	2	1491
C	**Total**				**68595**		**43244**
	Medical centre						
1	Low-energy lights (CFL)	4	20	4	320	6	480
2	Ceiling fan	4	30	6	720	0	0
3	Refrigerator	1	600	20	12000	16	9600
D	**Total**				**13040**		**10080**
	School						
1	Compact fluorescent lights	5	20	2	200	4	400
2	Ceiling fan	2	30	6	360	0	0
3	Computer (desktop)	1	300	2	600	2	600
4	Television	1	100	2	200	2	200
E	**Total**				**1360**		**1200**

Note We have assumed energy efficient appliances such as fans and lights

The number one in use is the domestic appliances such as light, radio and fans, but also the community center, well, refrigerator, computer and television. Other electric appliances are for agriculture and irrigation purposes, which is an important aspect for their health. Concluding from Table 2-7 the domestic appliances are used the most, followed by appliances for water and food.
All together there are different levels of electricity use shown in Table 2-8.

Table 2-8 overview of electric devices use and peak demand for different incomes (Ram et al., 2012)

	Absolute minimum	Low income household	Medium income rural household	Urban household
Lighting	✓	✓	✓	✓
Cell phone	✓	✓	✓	✓
Fan/cooler		✓	✓	✓
Radio/TV		✓	✓	✓

Water pump			✓	✓
Other				✓
Peak demand per household	30 Wp	150 Wp	500 Wp	1 kWp
Annual energy demand per household	65 kWh	500 kWh	1,000 kWh	1,200 kWh

Where the minimum demand is 30 Wp, the higher incomes in rural areas can use 150 or 500 Wp. In comparison with the other sources, the villagers in rural India want at least be able to use light, cell phone, fan and a TV. Therefor the low income should be the standard followed by the medium income. The demand of the urban household is something for the next step when a reliable system is implemented.

Mertens (2011) makes a distinction between food, cooking, lighting, electrical devices and transportation. Other sources discuss mainly the same parts but also other activities for example owning a small shop ("Lighting rural India: Out of the gloom | The Economist," n.d.). In addition pumping water from groundwater resources to drink and irrigate land to provide food and take care of their health, is also mentioned.
However kerosene and bio fuel are mainly used for cooking which produce dangerous fumes. This also goes for light where kerosene and oil are commonly used (Agoramoorthy & Hsu, 2009)(Palit, 2014)(Undp et al., 2004). 43% of rural household's still use kerosene, 85% of rural India still using firewood, crop residue or cow dung as its primary source of fuel for cooking. After sunset there are no to less activities in rural areas because the kerosene and oil lamps give insufficient light (Undp et al., 2004). Other negative effects of no light are for example, theft, insect bites, poor lighting for cooking and lack of social interaction after sunset ("Lighting rural India: Out of the gloom | The Economist," n.d.)(Chaurey et al., 2004).
In Table 2-9 an overview is given for the issues in rural India regarding the lack of electricity.

Table 2-9 Topic overview of issues in rural India

Topic	Explanation	Sources
Health	1. Unhealthy smoke of kerosene and bio fuels when cooking and use light 2. Search for fuels is heavy work	(Agoramoorthy & Hsu, 2009) (Palit, 2014) (Undp et al., 2004)
Safety and comfort	1. Lack of social interaction after sunset: unsafe and time for relaxing of study. 2. Theft and danger 3. Falling behind in economic development due to lack of electricity. 4. Education is falling behind 5. Electrification plays important roles in poverty reduction	(Chaurey et al., 2004) ("Lighting rural India: Out of the gloom | The Economist," n.d.) (Oda & Tsujita, 2011) (Chaurey et al., 2004) (Palit & Chaurey, 2013) (Shailaja Rego, Naresh Kumar, 2013)

The dangerous fumes of using kerosene and bio fuels for cooking and lighting are bad for the health of rural inhabitants. Therefor improving the cooking and lighting fuel is a big step forward for their health. Also the safety and comfort can be improved with the help of electricity and make their lives more balanced (Undp et al., 2004).

This paragraph summarized the local people want lighting, followed mobile phone charging, fan and television. This result in a peak demand of 150 Wp. With electricity health, safety and comfort issues can be improved. Also the development in rural areas regarding economics and education can be improved with electricity.

2.3 Future rural electrification

Paragraph 2.1and **Error! Reference source not found.** shows many reasons to electrify ural India. However, expanding the traditional grid is not a solution because of economic and technical reasons explained earlier. This paragraph looks for a possible solution to electrify rural India and some prove that it is actually possible and successful.

Searching for rural electrification, many projects and research are found which are shown in Table 2-10.

Table 2-10 Overview of researches about rural electrification

Research title	Source	Publication
Renewable Energy-Based Mini-Grid for Rural Electrification: Case Study of an Indian Village	(Sen & Bhattacharyya, 2014)	Journal article
Mini-Grids for Rural Electrification of Developing Countries	(Palit, 2014)	Book
DC Micro-Grid with Distributed Generation for Rural Electrification	(Sarker et al., 2012)	Journal article
Evaluation of Indian rural solar electrification: A case study in Chhattisgarh	(Millinger et al., 2012)	Journal article
Rural electrification in India and feasibility of Photovoltaic Solar Home Systems	(Kamalapur & Udaykumar, 2011)	Journal article
The determinants of rural electrification: The case of Bihar, India	(Oda & Tsujita, 2011)	Journal article
Comparison of options for distributed generation in India	(Banerjee, 2006)	Journal article
Electricity access for geographically disadvantaged rural communities—technology and policy insights	(Chaurey et al., 2004)	Journal article Suggestion of distributed generation
Progress of the luz solar program for rural electrification	(Diniz et al., 2002)	Journal article Uses PV-panels

It is notable that all researches propose a solution in with decentralized and distributed generations. The used designation is micro or mini grids. Different definitions of micro grids can be found in Table 2-11.

Table 2-11 Definition micro grid

Definition micro grid	Source
In isolated micro grid a connection with the main grid is not existing requiring the micro grid to be self-sustaining. In this type of micro grid it acts as a small power system with its all component (generation, transmission, and distribution). The main driver for isolated micro grid is the availability of local energy resources.	(Beshr, 2013)
The sources can operate in parallel to the grid or can operate in island.	(Piagi & Lasseter, 2006)
Micro grids are electricity distribution systems containing loads and distributed energy resources (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or	(Sebastian Groh et al., 2014)

while islanded.	
Micro-generation technologies include micro-wind turbines, photovoltaic (PV) systems, micro combined heat and power (micro-CHP), fuel cells and other green technologies.	(Oe et al., 2013)
The Smart Micro Grid is characterized by the presence of DERs (e.g. photovoltaic panels, micro turbines, fuel cells) and passive loads (e.g. building without DERs).	(Marchi, Ponci, & Monti, 2013)

According to literature in Table 2-11 a micro grid is a grid that is not necessarily connected to a main grid and takes care of the generation, transmission and distribution by itself. The generation is mainly done with local and renewable energy resources.
Islanding and rural electrification are mainly based on the same principle as micro grid: an independent grid with local energy suppliers.

Sometimes there are some misunderstandings between decentralized and distributed. **Error! eference source not found.** shows the difference between centralized, decentralized and distributed to make the difference clear.

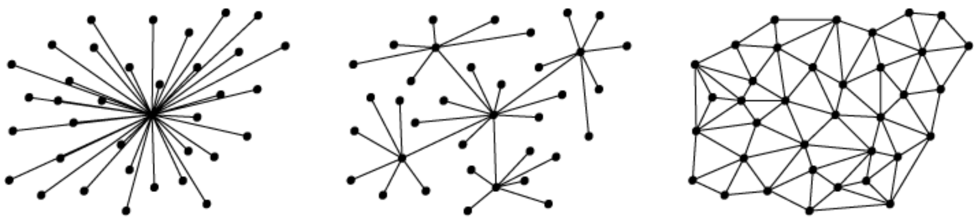

Figure 2-2 Difference between centralized, decentralized and distributed (wikipedia user 1983, 2007)

Centralized is how the traditional grid is organized; a central generation source and distribution to the final users. Decentralized has smaller generation sources and distributes the energy to users nearby. A distributed organization is where generation source are connected to other generation sources. Another advantage of distributed generation is the ability to function when one source malfunctions. If one generation source has problems, the connection with other generation sources makes it possible to back up. In this research with distributed generation is meant:

4. Generation source close the user (solar power)
5. The generation is mainly done with renewable sources: Distributed Energy Resources(DER)
6. Generation sources are connected to other source and can operate when one failing

From literature it become clear that a micro grid with a distributed structure has high potential for success. First because the micro grid can operate independently of traditional grid, but also together with the traditional grid. Secondly, the distributed part makes is possible to become fully autonomous because failing generation source are covered by other sources in the network. The question arise if this is truly a successful concept.
According to (Heist, 2011; Mertens, 2011) not only the technique must be successful, but also the social-economic aspects which are shown in Table 2-12.

Table 2-12 Success and failure factors for rural electrification in India according to Mertens and Heist

Success and failure factors
- Temporary subsidy

+	The price and service should correspondence with possible economic benefits for the users.
+	Involvement of the final users (local energy suppliers)
+	Education and information is needed to succeed. Also a maintenance scheme the local energy suppliers maintain is required.

A very important aspect is the temporary subsidy which should not be present. When the local energy suppliers can afford the system by themselves, it will be more likely succeed then when the subsidy is over. This correspondence with the second success factor: possible economic benefits. If the local energy suppliers can earn money with the product, they are more likely to invest in such a system. However, it is a very difficult task to convince the local people of the potential of a system according to (Heist, 2011). The best way is demonstrate the system and let them experience what is able to. This comes together with information about the system, but also education about how to maintain it.

This paragraph shows that the future of rural electrification can be found in decentralized or distributed energy networks, also known as micro grids. These micro grids are able to become autonomous and operate without the national electricity grid. Not only the technology must be suitable for rural India, also the social-economic aspects such as subsidies, price, involvement and information supply is important.

2.4 Reference projects

This paragraph describes five reference solar micro grid projects. Each project is decentralized or distributed and uses solar energy as power sources.
For each project the technical features are described such as the layout, distribution and storage. The economic aspects such as the price and financing of the system are described, as well how the people are involved to make it a success. The four success factors described in Table 2-12 are used as parameters for the social-economic aspects.

2.4.1 Lighting a billion lives

This project provides rural areas with light though solar panels. **Error! Reference source not ound.** shows a solar charging station of LaBL. Each station consist of 5 solar panels of 50 W and is connected to the junction box which has 10 ports to charge solar lamps. A battery of 24 volt and 100Ah is also available because of the stochastic behavior of solar generation, which means that energy is not generated all the time Each lamp provides an illumination of 200-500 lumens which is equal to a 40 W incandescent bulb. The solar LED will burn for 4 to 6 hours and reaches 8 hours when the dimming mode is used. This project has a decentralized layout where the charging stations are the central points.

Figure 2-3 Solar charging station of Lighting a Billion Lives (LaBL) ("Lighting a Billion Lives - Technology options," 2015)

Lighting a billion lives has two financing programs. The first one is fee for service model, where the solar charging station is financed by funds and grants. The local people only have to pay a small amount to get a light for one day. This way lighting is available for even the poorest.

The second financing program is a loan finance model, where operators start their own solar charging station. This is financed by financial institution and subsidies from partner organizations and even the government.

Compared with Greenpeace, lighting a billion lives does not involve the local people strongly, but give information about how to use the products. Also the financing models are mostly the same. However, lighting a billion lives gives local people the opportunity to become a local generator by operating a solar charging station.

With this simple system 50 households in rural areas have access to sufficient and clean light, for the same price as kerosene. Each villages has one or more solar charging station, depending on the electricity demand and size of the village. In **Error! Reference source not ound.** success and failure of Lighting a Billion Lives are evaluated.

Table 2-13 Evaluation of success and failures of LaBL

	Success and failure factors	Applied in LaBL	Comments
-	Temporary subsidy	Yes	The finance is support through grants for a large extent
+	The price and service should correspondence with possible economic benefits for the users.	Yes	Even the poorest areas can afford the daily rent. The price is also comparable to kerosene.
+	Involvement of the final users	Yes	The people who rent out the lamps are chosen by the villagers. Mostly someone important or with much respect.

+	Education and information is needed to succeed. Also a maintenance scheme the local energy suppliers maintain is required.	?	Somehow information is provide, but it is not clear whether the local energy suppliers are educated or not and have maintenance scheme.

From Table 2-14 is becomes clear that LaBL is a successful project when it comes to lighting rural areas. However, the subsidy is a dangerous factor for the affordability of the system. When the subsidy is not continued, the prices for daily rent rises to cover the building cost of the solar charge station. This makes LaBL depending on financial source form outside. Not only the subsidy is a weakness, but also the fact that only one person or household know how to work with the equipment. When this party is no longer, the knowledge about how to maintain the solar charging station will also disappear.
LaBL might lighten billions of lives, but the question arise whether this system will hold in on the long term.

2.4.2 Greenpeace Dharnai Live!

In the village Dharnai Greenpeace implemented a Decentralized Renewable Energy System (DRES) or also known as a decentralized micro grid(Greenpeace, 2014a). This grid has a capacity of 100 kW provided by solar panels and a battery back-up ("Solar energy microgrid powers India village in Bihar Greenpeace Blogs," 2014). .The local people can buy 3 types of packages with increasing peak demand. An overview of the packages are shown in Table 2-14.

Table 2-14 Overview of packages in Dharnai live (Greenpeace, 2014b)

	Package I	Package II	Package III
LED light of 6 [W]	1	3	1
Mobile charging point 12 [W]	1	1	1
Solar Street light	1	1	1
Total consumption of electricity [W]	18	30	18
Total monthly unit consumed [unit]	8	13	19
Rate per unit [₹]	9.50	11	13
Monthly tariff [₹]	75	140	15
Security deposit	300	500	1000
Wiring cost [₹]	300	500	Actual costs

Table 2-14 shows three packages available in Dharnai. The third package is a commercial package. Package one provides only one light, a mobile charger and a street light which is a the minimum demand in a rural village. Package two is most used because of the extra lights.

Greenpeace focused on educating the local people to manage the system by themselves (Greenpeace, 2014a). The most influential person of the villages helps to convince the local people about the added value of the Decentralized Renewable Energy System. After the decentralized micro solar grid is established the local people pay for every kwh (Ram et al., 2012). This makes them independent of the national electricity grid and political decisions. Greenpeace use subsidies and funds to finance the DRES.

However, the local people were content with the DRES, the government decided to electrify the village and the DRES is now unused because the extended national grid delivers cheaper energy (“Electricity Access and Renewables Integration | The Energy Collective,” 2014). In Table 2-15 the evaluation of success and failure factor of Dharnai can be found.

Table 2-15 Evaluation of success and failures of Dharnai

Success and failure factors		Applied in Dharnai	Comments
-	Temporary subsidy	Yes	The Greenpeace project is only temporary financed. After this period the system should run on its own.
+	The price and service should correspondence with possible economic benefits for the users.	Yes	The users of the solar system have to pay to use electricity, which is ₹75 comparable with 1% of their monthly income. (Ram et al., 2012).
+	Involvement of the final users	Yes	Villagers are approach to help build up the system.
+	Education and information is needed to succeed. Also a maintenance scheme the local energy suppliers maintain is required.	Yes/no	Villagers are educated to maintain the system. It is not clear whether there is a maintenance scheme or not. For a long term success this is also required.

Greenpeace did a good job on electrifying Dharnai with a decentralized system. They put lot of effort in making the villagers aware of the system and the possibilities. The villagers were involved from the beginning and influential people from the village are of main importance. Unfortunately, the Indian government decided to electrify the village through expanding the national grid(“Electricity Access and Renewables Integration | The Energy Collective,” 2014). The villagers believed that solar energy is not the real electricity.
From this project can be learned that the involvement of the villagers is required and important to succeed, but more important is to create awareness of the new created situation. This micro grid was the end station according to Greenpeace, but actually the village was not that far away from being electrified. The involvement of the government should be taken into account and respected. The micro grid should not work alone, but coexist with the national grid and even work together(“Electricity Access and Renewables Integration | The Energy Collective,” 2014).

2.4.3 Swarm electrification

The swarm electrification concept is applied in Bangladesh. The system consist of a direct Current (DC) Solar Home Systems (SHS), currently consisting of 20 to 85Wp solar panel, battery, and charge controller (S Groh et al., 2014; Sebastian Groh et al., 2014). The difference between a normal SHS and swarm electrification is that swarm electrification connects groups of house with each other and with other groups as Figure 2-3 shows.

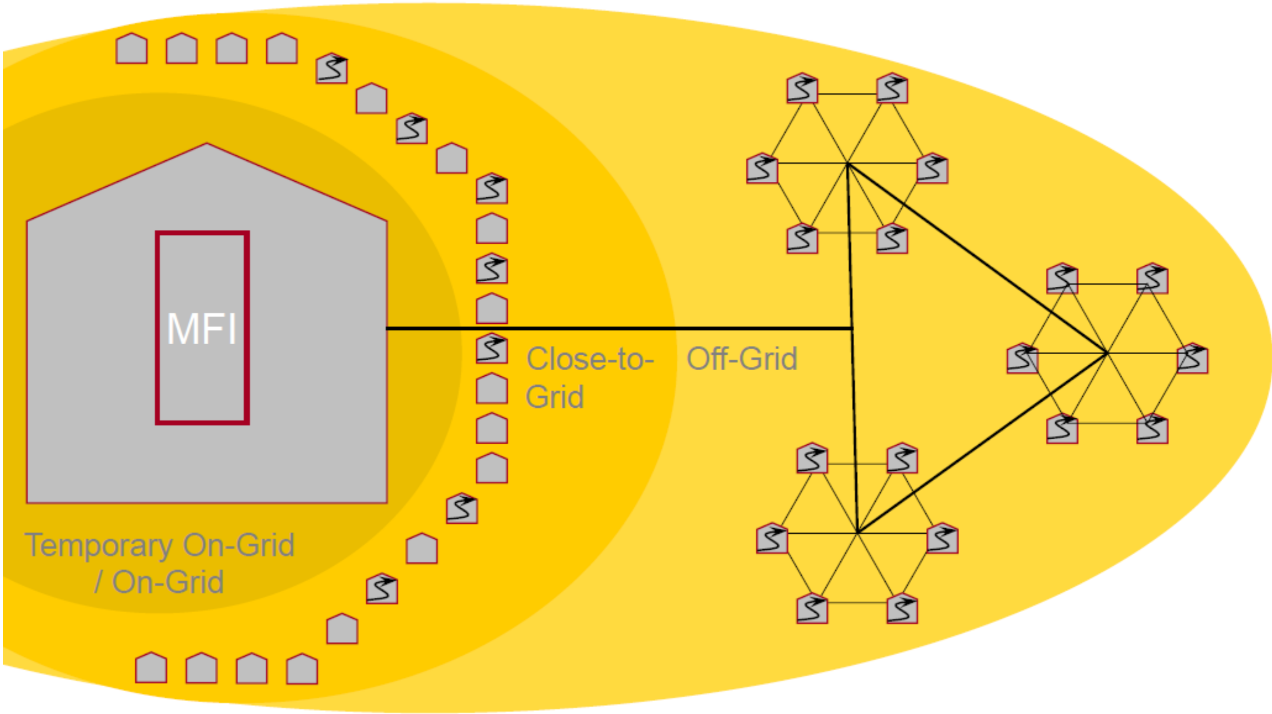

Figure 2-4 Swarm electrification (Berlin et al., 2013)

The swarms (groups of SHS) can be connected with other swarms, but also with a national or regional grid. The SHS in a swarm are also connected with each other so they can exchange the energy. Unfortunately, the energy exchange is not yet applied in Bangladesh. This project shows a distributed layout within a swarm, with the option to connect to local electricity grids.

The swarms (groups of SHS) can be connected with other swarms, but also with a national or regional grid. The buildings in a swarm are also connected with each other so they can exchange the energy. Unfortunately, the energy exchange is not yet applied in Bangladesh. In table

The Solar Home System are bought by the local people through micro financing. However, many people can pay for this system, the poorest are still left in electricity poverty. (S Groh et al., 2014) state that it is possible to create a win-win situation for both people with a SHS and for people who cannot afford a SHS by sharing the power and introduce dynamic pricing.

Success and failure factors		Applied in swarm electrification	Comments
-	Temporary subsidy	no	There is no subsidy. The people buy their own solar home system.
+	The price and service should correspondence with possible economic benefits for the users.	Yes/no	Not everyone can but a SHS, so it is expensive. There are also all lot of benefits.
+	Involvement of the final users	No	This is not clearly pointed out, but it seems villagers are not involved.

+	Education and information is needed to succeed. Also a maintenance scheme the local energy suppliers maintain is required.	No	Villagers are not educated and informed, but this is not clearly mention.

Swarm electrification is a combination of distributed and decentralized generation. It has the ability to eventually connect to other villages or even the national grid. A big advantage of this system is that the people become owner of a solar home system, or already are. The payback time is only three year. However, it is not clear what price is used but is seems to work. The villagers are not informed about the system, but still uses it.

2.4.4 Rural spark

Rural Spark is a company who tries to electric rural areas with smart energy solutions. The Energy Kit consist of a 40 Wp PV panel and a Spark Station. The Spark Station is a convertor with 16 5 volt outlets, and two 12 volt outlets. The 5 volt outlets are used to charge solar LED lamps and are rented out to local people. This why everyone has access to electricity.

To make this all possible Rural Spark produce the product with the help of funds. The Energy Kits are sold to local agents who have a store in the rural areas. The local agents make the local people aware of the Energy Kit and the possibilities. Once the local people want to rent a Energy Kit, they become a local energy supplier and can earn money with generating electricity. This is shown in Figure 2-5..
The rent of the Energy Kit with 40 Wp PV panel is 668 INR, with 80 WP PV panel 1184 INR per month. When 75 INR per lamp per month is asked, the local energy suppliers earn around 500 INR per month with the Energy Kit.
The four success factors are analyzed in Table 2-16.

Table 2-16 Success and failure factor of Rural Spark

Success and failure factors		Applied in swarm electrification	Comments
-	Temporary subsidy	Yes	Rural Spark get funds to produce the Energy Kits.
+	The price and service should correspondence with possible economic benefits for the users.	Yes	Local energy suppliers earn money with the Energy Kit. Local people can rent lights for an acceptable price.
+	Involvement of the final users	Yes	The local agent informs the local people about the Energy Kit.
+	Education and information is needed to succeed. Also a maintenance scheme the local energy suppliers maintain is required.	Yes	Rural Spark tries to educate the local people through the local agents.

Table 2-16 shows that Rural Spark invested in involvement mwith the people through a local agent. However, in theory this is a positive point, the question arise if this will work in practice. The temporary subsidy are only to make the products, once there are in use, the local agent and people maintain the product. The Energy Kit will still exist, even if the funding is gone. The funding are required to produce more Energy Kit and for development.

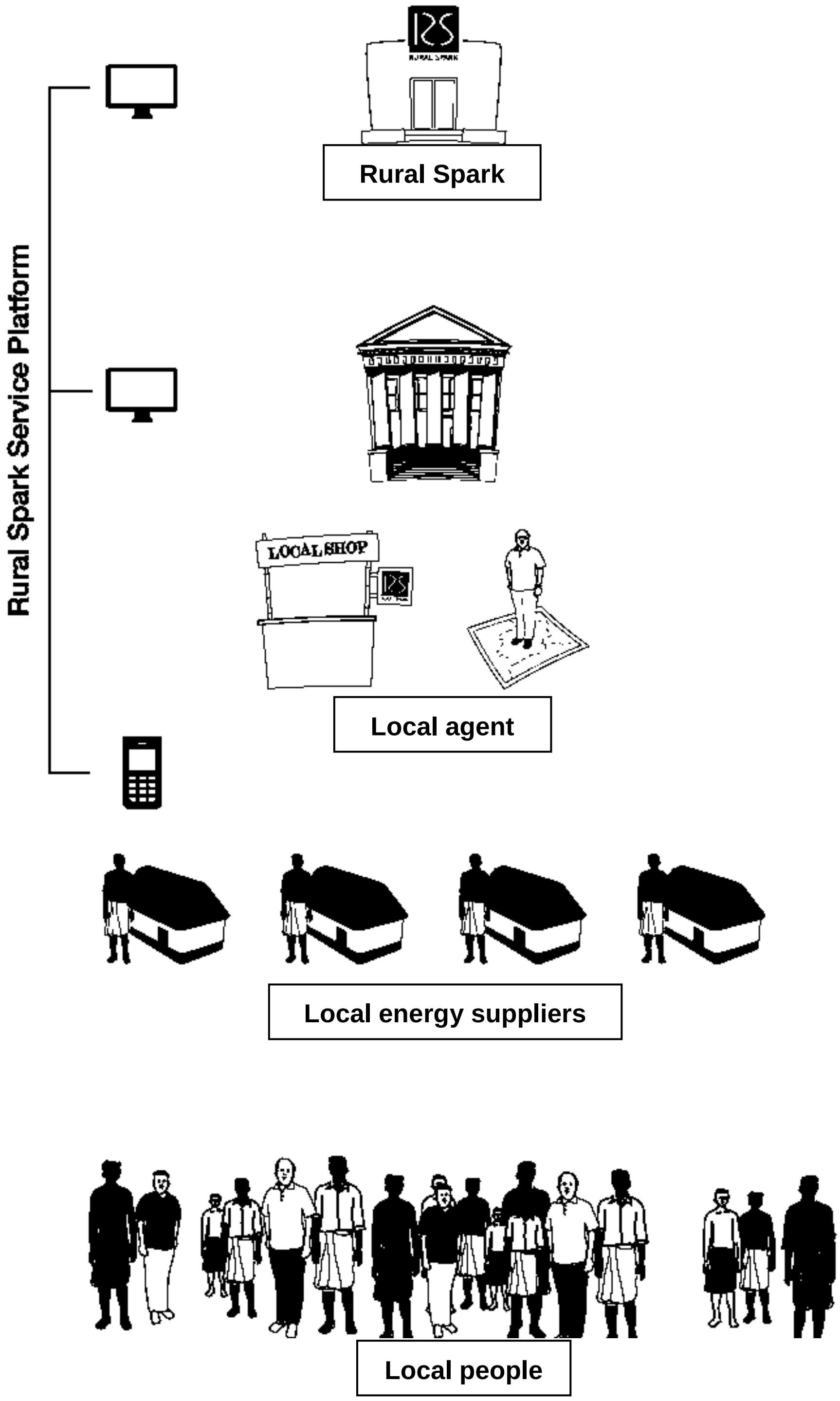

Figure 2-5 Illustration of the Rural Spark network (Illustrations from Rural Spark)

Figure 2-5 shows the service platform of Rural Spark and the hierarchy. The local people are the one who make the Energy Kit network possible. Without local people who can pay for the LED lamps the network of local energy supplier wouldn't work. It is important to make the price payable for the local people as suggest in point two of the success and failure factors.

2.4.5 Sopra

Alfen group from TBI holding has developed SOPRA; Sustainable Off-grid Power Station for Rural Applications. The system consists of a number of transformers, a battery pack and an advanced regulating system for the batteries(Kaas, 2012; “SOPRA - Alfen,” n.d.). **Error! eference source not found.** shows a schematic overview of the SOPRA system with in the middle the advance regulating system for batteries.

Figure 2-6Schematic overview of SOPRA(“SOPRA - Alfen,” n.d.)

SOPRA can implement not only solar power, but also wind, water and other renewable sources. The advanced regulating system for batteries stores that energy in the battery, rather than being lost. The users can pay for their energy in different ways.

The financing of this project is achieved by donations and funds for research this application. However, SOPRA is applied in the Netherlands, the solution is developed for rural areas. A case village in Burundi with 8000 inhabitants, shows that the business case is feasible taking the case flow into account (Kema, 2012). The whole system is financed through funds and financing programs.

Alfen group from TBI holding has developed SOPRA; Sustainable Off-grid Power Station for Rural Applications. The system consists of a number of transformers, a battery pack and an advanced regulating system for the batteries(Alfen –TBI)(“SOPRA - Alfen,” n.d.)(Kaas, 2012). **Error! Reference source not found.** shows a schematic overview of the SOPRA system with n the middle the advance regulating system for batteries.

Table 2-17 shows whether SOPRA has the potential to succeed in rural India or not.

Table 2-17 Success and failure of SOPRA

Success and failure factors	Applied on SOPRA?	Comments
1. Temporary subsidy	?	It is not clear if the SOPRA project is subsided or not.
2. The price and service should correspondence with possible economic benefits for the users.	?	Costs are not specified.
3. More involvement of	?	SOPRA is placed in different

	the final users (inhabitants of the villages)		climates and countries. It is not clear whether the villagers are involved or not.
4.	Education and information is needed to succeed. Also a maintenance scheme the users can maintain is needed.	?	It is not clear how the villagers are informed about SOPRA.

Table 2-17 shows that it unknown how SOPRA is applied in practice especially, when it comes to the villagers and their involvement.

2.4.6 Conclusion of the reference projects

The project of Greenpeace, Lighting a billion lives, Rural Spark and SOPRA are decentralized. Swarm electrification is more a combination of decentralized and distributed. The reference projects all make use of funding in a certain way. Greenpeace, Rural Spark and SOPRA use funding to make the products, while Swarm electrification and Lighting a Billions lives use the funding as a lone which is paid by the local people.
Greenpeace, Rural Spark and Swarm electrification focus on involving the people to maintain the product by themselves. Lighting a Billion life and SOPRA are not clear about how they do this. The involvement of the local people is important for the system to succeed as well as the maintenance information.
Not only the local people much be involved, also the government should be involved and encourage to cooperate.

2.5 Smart technologies

Searching for intelligent energy trade results in terminology like power matching, energy balancing, energy matching, supply-demand matching and demand site management. All these terminology are linked to matching the supply and demand at the right moment in order to provide continuous power to the user. This can also be translated to two of the smart grid objective described by (Sinha et al., 2011). The first one is "*the ability to incorporate consumer equipment and behavior in grid design and operation"*. This can be interpreted that the network should be able to react on the consumers behavior. For example, when the consumer want to use more lights, the network is able to provide more power in order to reach the demand. When this behavior occurs very often this is something to consider in the energy trade strategy.
A second smart grid objective is *"The grid provides quality power consistent with consumer and industry needs"*. This is interpreted as matching supply and demand at all times. The smart grid objective described by Sinha are shown in Table 2-18.

Table 2-18 Smart grid objectives(Sinha et al., 2011)

Smart grid objectives	
1.	Self-healing

2.	Ability to incorporate consumer equipment and behavior in grid design and operation.
3.	Tolerant of attack
4.	The grid provides quality power consistent with consumer and industry needs.
5.	The grid accommodates a variety of resources
6.	Fully enables and is supported by competitive electricity markets.

Not all smart objective are necessary in rural India, but to reach these objective, Sinha introduces smart grid technologies as described in **Error! Reference source not found.**.

Table 2-19 Smart grid technologies according to Sinha (2011)(Sinha et al., 2011)

Smart grid technologies	Description	Source
10. Smart Meters	*"The smart meter is an advanced energy meter that obtains information from the end users' load devices and measures the energy consumption of the consumers and then provides added information to the utility company and/or system operator for better monitoring and billing"*	(Zheng et al., 2013).
11. Meter Data Management	Implementation of a multi-location instance that would allow individual utility to take advantage of the system by allowing view a subset of the collected data from all of the locations after integration with Advance Metering Infrastructure system.	(Sinha et al., 2011)
12. Field area networks	Network for data transmission between user. Main important functionality is communication and connection between different users.	(Baig et al., 2013)
13. Integrated communications systems	Standards, protocols, network, and computer systems that help to be "the brains" of the smart grid.	(Ellis, 2012)
14. IT and back office computing	Information technology	
15. Data Security	Protection and reliability of the data	(Ellis, 2012)
16. Electricity Storage devices	For example batteries.	
17. Demand Response	"Demand Following Generation". This can be realized by intentional modification in electricity consumption pattern by reducing or rescheduling	(Bhattarai et al., 2013)

	instantaneous electricity demand, called demand response (DR)	
18. Distributed generation	An electric power generation within distribution networks or on the customer side of the network.	(Ackermann et al., 2001)

Error! Reference source not found. mainly shows technologies to match and trade energy. he smart meters are required to measure the energy demand, which is communicated with the meter data management trough field area networks. An IT and back office computing does the data management and decides what the energy price will be. Integrated communication systems exchange the right information about price, supply and demand with the users.
The most important smart grid objective for rural India is the integrated communication system and set up a Field area network to communicate between the operators. Table 2-20 gives an overview of the standard integrated communication system according to (Güngör et al., 2011).

Table 2-20 Integrated communication systems and an explanation according to (Güngör et al., 2011)

Integrated communication system	Advantages	Disadvantage
ZigBee	Good option for metering and energy management ideal for smart grid implementations Simple, mobile, robust, low bandwidth requirement, low cost of deployment. Load control and reduction Demand response Real-time pricing Real-time system monitoring Advanced metering support Easy network implementation Operation within an unlicensed spectrum	low processing capabilities, small memory size, small delay requirements and being subject to interference with other appliance. Interference detection schemes, interference avoidance schemes and energy-efficient routing protocols, should be implemented. Coverage range: 30-50 m
Wireless mash	cost effective solution dynamic self-organization, self-healing, self-configuration, high scalability services. Good coverage in urban and suburban areas multihop routing. signal repeaters and adding more repeaters to the network can extend the coverage and capacity of the network. Advanced metering infrastructures home energy management	Network capacity, fading and interference Node cost, Third party company is required to manage the network, encryption techniques are applied to the data for security purposes loop problems causing additional overheads in the communications channel that would result in a reduction of the available bandwidth.
Cellular network communication	Cellular networks already	Some power grid mission-

	exist. No extra cost for building the communications infrastructure data gathering at smaller intervals, a huge amount of data will be generated and the cellular networks will provide sufficient bandwidth for such applications. secure the data transmissions with strong security controls. coverage has reached almost 100%. Support AMI, Demand Response, Home Area Network (HAN) applications. Anonymity, authentication, signaling protection and user data protection security services are the security strengths of GSM technology [37]. Lower cost, better coverage, lower maintenance costs, and fast installation 1-10 Km coverage range	critical applications need continuous availability of communications.
Power line communication	-	Use exciting power lines
Digital subscriber lines	-	Use exciting of the voice telephone network

The power line communication and digital subscriber lines, are not useful in rural India because they lack existing power lines and voice telephone network. Most interesting are the technologies which are cheap or work on an existing system to prevent establishment costs. ZigBee is interesting because of the low cost and cellular communication networks because it already exist.

Another important aspect is the matching supply and demand which can be reached with the smart meter. In literature the terms are power matching or energy matching. Literature describes energy matching and power matching algorithms are mostly agent based according to Table 2-21.

'*An agent is a software or hardware component with autonomy that provides an interoperable interface to an arbitrary system working for some clients in pursuit of its defined goals. Agents have the capability to react to changes in its environment, be driven by a set of tendencies, and be able to interact with other agents. A Multi-Agent System (MAS), therefore, is a community of such autonomous, intelligent and goal-oriented agents who cooperate and coordinate their decisions making to reach a global goal*.' (Asare-Bediako, Kling, & Ribeiro, 2013)

Table 2-21 Selection of research with an agent based technologies for matching and/or trade energy supply and demand, and reason why to use agent based technology

Research which use agents to match and trade energy	Reasons for using agents to trade and match energy
(Ampatzis, Nguyen, & Kling, 2013)	Agents have three characteristics: reactivity, pro-activeness and social ability . Thus, intelligent agents understand their environment, take decisions towards achieving their goals and can communicate with other agents.
(Sonnenschein, Lünsdorf, Bremer, & Tröschel, 2014)	Due to the large amount of units, decentralized control, autonomous agents and the concept of self-organizing systems will become key elements in order to intelligently use the inherent flexibilities of distributed controllable generators, power storage systems and controllable power consumers.
(Asare-Bediako et al., 2013)	The results show that using distributed agents' intelligence, residential appliances can be operated to respond to external signals while maintaining the user's preferences of comfort level and needs.
(K. Kok et al., 2005)	Different authors identified Multi agent Systems (MAS) as a suitable design paradigm for Distributed Energy Management which propose the use of electronic equilibrium markets as the core coordination mechanism.
(Koen Kok et al., 2008)	Multi-agent systems, especially those based on electronic markets have been identified as key technologies to balance multiple stakes in a multi actor environment.
(Geelen et al., 2013)	Different types of agents can coordinate the matching of supply and demand of electricity in the network.
(Maruf, Hurtado Munoz, Nguyen, Lopes Ferreira, & Kling, 2013)	To achieve a local supply-demand matching in smart grids, multi-agent systems (MAS) can represent a network where the agents can exemplify different loads and generators.

Table 2-21 only shows a selection of researches, but it makes clear that agent based is a possible solution to realize intelligent energy trade. The main reasons for choosing agent based technology is because the agents can make their own decision in a certain environment, which for this research is rural India. They have reactivity, pro-activeness and social ability. The agents can match supply and demand, but are also able for price matching. Some of the studies above discus combination of agent based and another technology. These technologies and a short description or application can be found in Table 2-22.

Table 2-22 Combination of agent based technology and other

Energy matching techniques	Description / application	Source
Game Theory	Coalitional game theory can be applied in arbitrating	(Ampatzis et al.,

	possible conflicting interests occurring between operating agents. These conflicts can be the result of the interaction between the energy market and network services, or between device agents participating in an auction.	2013) (Mojica-Nava, Quijano, & Pavas, 2013)
	EGT (Evolutionary Game Theory) improves traditional game theory negotiation approaches, since it considers past interactions (learning) and future implications not have to be manual, but can be automatic through two-way digital communication.	(Swearingen, 2011)
Artificial Neural Network (ANN)	Artificial Neural Network (ANN) is an artificial intelligence technique which can mimic the human brain and is able to map any non-linear function. It has the ability to learn and simplify from examples to produce significant solutions to problems,	(Maruf et al., 2013)
	Recently Artificial Neural Network (ANN) has been used to forecast the energy load, daily curve and so on. One significant characteristic of neural network is to perform nonlinear modeling between input and output data	(Khalid & Langhe, 2010)
Fuzzy systems	fuzzy logic systems, that are a proven methodology for dealing with imprecision and uncertainty. Currently, there are many soft-computing applications in power system operation; some examples particularly focused on voltage using fuzzy logic and/or multi-agent systems.	(Leon & Taylor, 2013)

Table 2-22 shows that game theory is focused on making the right decision. Together with agents this technology can negotiate about the price and amount of energy to be used or sold. With Evolutionary Game Theory (EGT) it is also possible to predict and learn things. The learning factor is also possible with artificial neural network were energy load, curve and weather can be forecasted. In combination with the learning ability this a very strong technology for intelligent energy trade.
Fuzzy systems are separate in type 1 and 2. Fuzzy type 1 which don't know uncertainties and only use their degrees of truth. Type 2 has the ability to deal with more uncertainties (Leon & Taylor, 2013).These technologies won't be further discussed.

The definition for intelligent energy trade in this research is:
The ability to match supply and demand automatically though an agent based approach with smart technologies.

Concluding from this paragraph, smart grid technologies are useful to apply in rural India to create a smart energy network. The most important aspect is the communication between energy suppliers and matching supply and demand. ZigBee and cellular communication networks are interesting apply in rural India because of the cheap implementation cost. With an agent based structure the smart network can be managed and power matching can be reached.

3 Conclusion

India generates too little energy for all their people which cause black outs. These blacks out are due to the lack of generation, but also the higher transmission and distribution losses, along with energy theft and poor utilization. The black outs are experienced mostly in the urban areas, while 30% of the rural doesn't even have access to electricity. More than 300 million people in Indian live without access to electricity.

The local people want lighting, followed mobile phone charging, fan and television. This result in a peak demand of 150 Wp. With electricity health, safety and comfort issues can be improved. Also the development in rural areas regarding economics and education can be improved with electricity.

the future of rural electrification can be found in decentralized or distributed energy networks, also known as micro grids. These micro grids are able to become autonomous and operate without the national electricity grid. Not only the technology must be suitable for rural India, also the social-economic aspects such as subsidies, price, involvement and information supply is important.

Reference projects show that decentral and distributed layout are applied.The project of Greenpeace, Lighting a billion lives, Rural Spark and SOPRA are decentralized. Swarm electrification is more a combination of decentralized and distributed. The reference projects all make use of funding in a certain way. Greenpeace, Rural Spark and SOPRA use funding to make the products, while Swarm electrification and Lighting a Billions lives use the funding as a lone which is paid by the local people.
Greenpeace, Rural Spark and Swarm electrification focus on involving the people to maintain the product by themselves. Lighting a Billion life and SOPRA are not clear about how they do this. The involvement of the local people is important for the system to succeed as well as the maintenance information. Not only the local people much be involved, also the government should be involved and encourage to cooperate.

SOPRA and Swarm electrification are both smart grid or tend to be a smart grid. Smart grid technologies are useful to apply in rural India to create a smart energy network. The most important aspect is the communication between energy suppliers and matching supply and demand.
ZigBee and cellular communication networks are interesting apply in rural India because of the cheap implementation cost. With an agent based structure the smart network can be managed and power matching can be reached.

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Appendix II: Field trip

1 Introduction

Millions of people in rural India live with no or insufficient electricity supply. The Indian government failed to supply everyone with electricity before 2012 (Undp et al., 2004). The top-down approach has been proven unsuccessful and another approach is required to electrify rural India. The bottom-up approach is encouraged. Rural Spark is a company who develops technical solutions to provide electricity for rural areas with a bottom-up approach.

Rural Spark solution

The Rural Spark solution is an Energy Kit which consist of a PV panel with a Spark Station which can charge 20 LED lamps or mobile phones. Rural Spark make the Energy Kit and sells them to local agents in rural areas. The local agent make the local people aware of the product and how they can use it. When the local people want to rent an Energy Kit, they become a local energy supplier. With renting out the charged lamps to local people they earn a little money, and create access to electricity for everyone(“RURAL SPARK PRODUCT BROCHURE,” 2014).

However, the Energy Kit provides electricity, the local people want more lights and want to use even other devices. To find out what other devices they wish to use, and in which way the Rural Spark Energy Kit can contributes to improve their lives a field trip to rural India is conducted.

This report of the field trip starts with the methodology about how and why the interview is conducted. Followed by the results of the interviews and observations. The conclusion gives an overview of the most interesting aspects regarding electricity use and the Energy Kit.

2 Starting points

This chapter describes the starting points of the field trip. First the objective of the field trip is given, followed by the research question, and method.

2.1 Objective and research question

The field trip is conducted to get an broader understanding of the context and understand the local people values and habits. This will help to get new insight regarding the electricity us in rural India, and the use of the Rural Spark Energy Kit.
At the end of this report the main question can be answered.
What are the daily activities of the Rural Spark Local Energy Suppliers and what are their wishes regarding electricity use and the Rural Spark Energy Kit?

2.2 Method

To answered the research question, two methods are applied: observations and semi-structured interview.

Observations are captured by photo camera. For example how they live and cook and what devices they use.

The semi structured interview is prepared with a topic guide about different daily activities found in literature such as cooking, studying and work. The topic guide is shown in Table 2-1.

Table 2-1 Topic guide semi-structured interview rural India

Topic	**Question**
Introduction about myself	I'm Christina and a student who tries to find out how the people live here and how they use electricity. I got interested in this project because I believe everyone should have the luxury to use electronic devices.
Introduction about the rural inhabitants	What are you doing in you daily life? How do you it? Why this way? What takes up the most time? With how many do you live in your house? What do they do?
Cooking	What are you cooking? How do cook? Why this way? When do you cook? Why at this time? What would make it easier for you to cook?
Study /Education	What do you study/teach? How do you study/teach? Where do you study/teach? When do you study/teach? What would make it easier to study/ teach? What do you need to study/teach? What do you want to do after you are done with your study? Why?
Work	What work do you do? When? How? What would make it easier to do you work? What do you need to do you work? Where do you do you work? How long? When do you start and end? Why?
Activities	How much time do you have after you're done with your

	work or study? What do you do with the time? What would make it easier to use the time in a good way?

he topic guide is used to gives structure to the interviews which are conducted as a conversation.

2.2.1 Location

The interviews are held in area Bankey Bazar and the block Guraru which consist of one large village and several small villages as shown in Figure 2-1 and Figure 2-2.

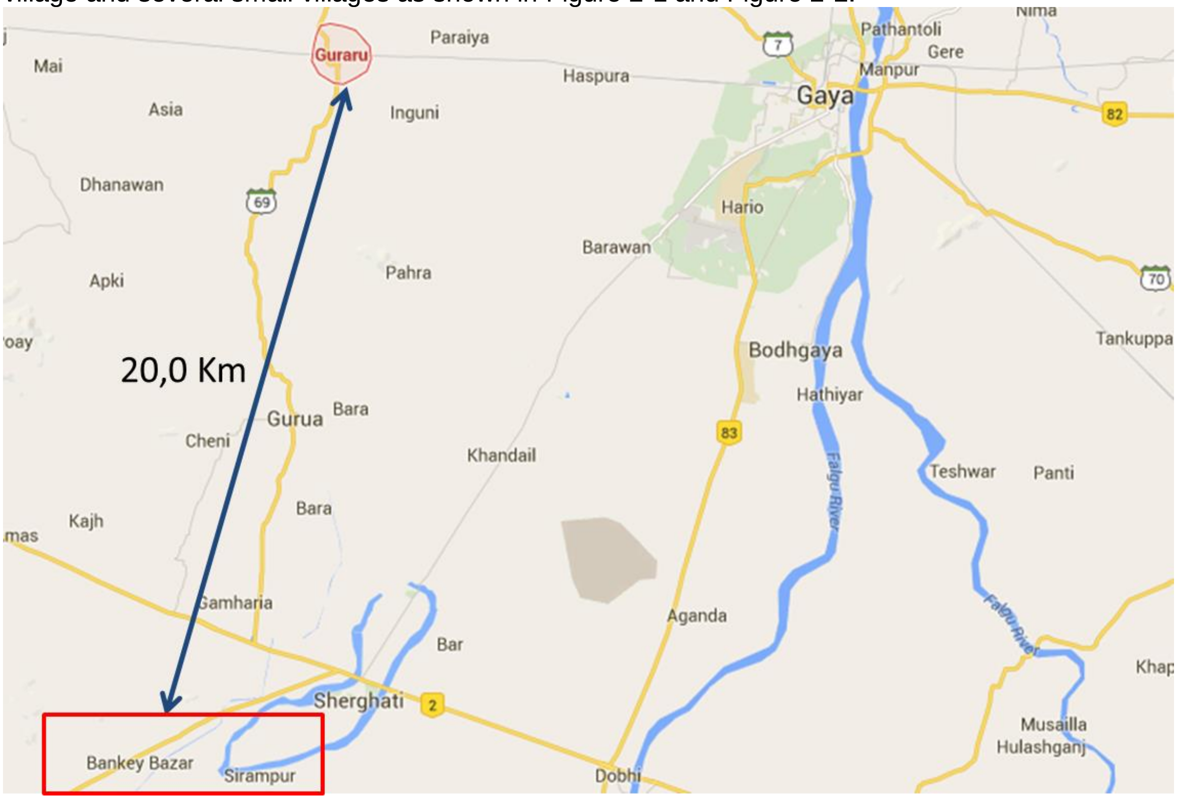

Figure 2-1 Bankey Bazar area and Guraru block

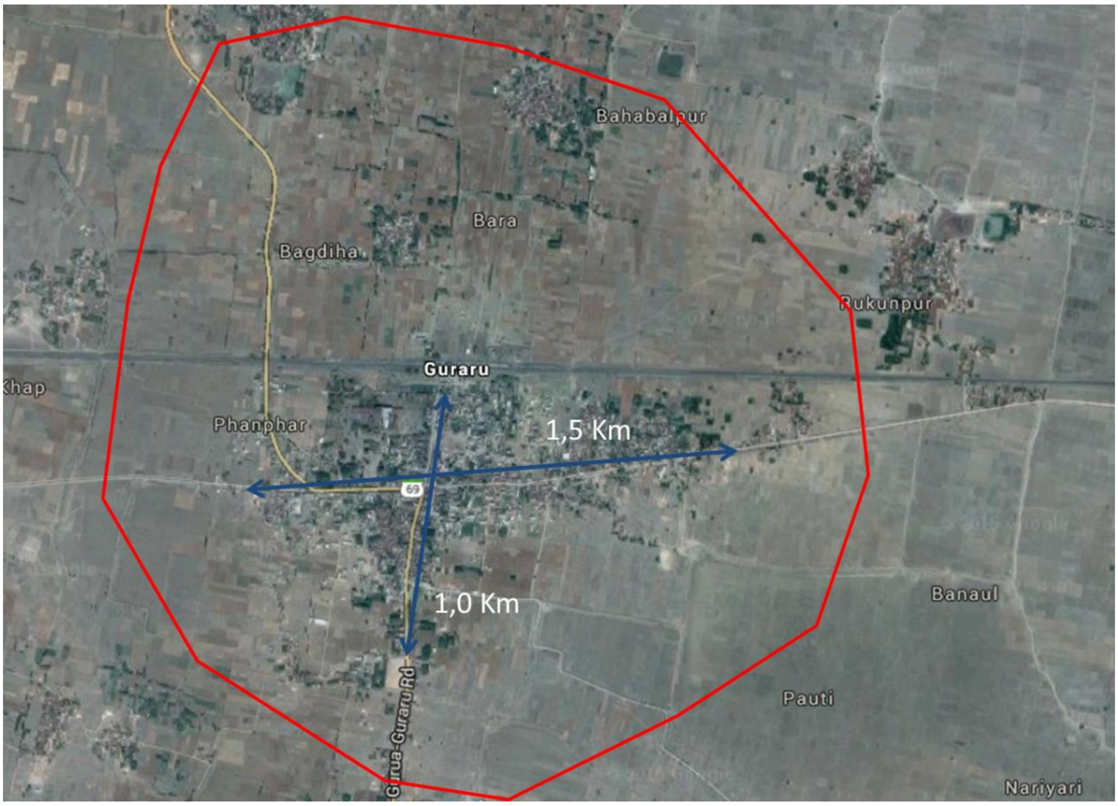

Figure 2-2 Guraru block and the dimensions of the big village

These block are chosen because the Rural Spark local energy suppliers operate in this area.

2.2.2 Time

The interviews on 6th of November, the interviews took place in the block Guraru which has a population of 2685 with 424 families and is located 50 km from Bodhgaya ("Guraru Village Population - Guraru - Gaya, Bihar," n.d.). The block is attainable by train and car.
Four local energy suppliers are visited, but only three are interviewed about their daily life and how they use the Spark Station. The interviews are held with a translator because the local energy suppliers don't understand English.

The second day on, 7th of November took place in Bankey Bazar area. This area consist of 91 villages with a population of 100345 with 15048 houses Bankey Bazar is located 44 km from Bodhgaya in Bihar and is only reachable by car ("Bankey Bazar Block | Bankey Bazar Block map," n.d.).
Two local energy suppliers are visited in the block Guraru and one is interviewed. Again a translator is used to ask the question to the local energy suppliers. Interviews and other conversations with the local energy suppliers are recorded but also notes were made.

2.2.3 Participants

The people who are interviewed are local energy suppliers of Rural Spark. The local agent of Rural Spark made an arranged these meetings.
Table 2-2 shows the features of the local energy suppliers.

Table 2-2 Characteristics of local energy suppliers per village

	Local energy supplier	Routers	Lamps	Price in rupee	Per day/month	Village
1	Gopal	1	17	80	Month	Bankey Bazar
2	Neighbor	1	20	80	Month	Bankey Bazar
3	Brick man	2	40	90	Month	Bankey Bazar
4	Small shop owner	1	20	90	Month	Bankey Bazar
5	Small shop owner 2	2	30	2	Day	Guraru
6	Seamstress	1	20	2	Day	Guraru

The first four local energy suppliers are visited on the first day which is the 6th of November 2014, last two on the 7th of November.

2.2.4 Role

During the field trip my goal was to get a broader understanding of the rural people lives and their electricity use and wishes. This field trip was visited as a researcher, but also as an newcomer; this was my first visit to rural India and in didn't know what to expect.
An employee of Rural Spark, Willem, joined me on this trip. He also never visited rural India or India before and therefore we made a good team gaining information.
Kunal, the local agent of Rural Spark took us to the local energy suppliers. He was our translator for the first day, but also used this time to do his job: detecting malfunctions of the energy kit and solve them.

The second day Basix, a new business partner of Rural Spark, took us to the field before an important meeting. The goal was to get more feeling with the local energy suppliers and the challenge for both companies. This was a good opportunity to gain more information, but interviewing people was harder because we were with many people. Not only me and Willem joined this trip, but also Bart and Harmen from Rural Spark and about nine people from Basix. The people from Basix aslo translated for us.

3 Results

In this chapter the some pictures of the observations are showed and an elaboration of the interviews.

3.1 Observations

During the field trip the goal was to get more feeling with the rural Indian life; The pictures below show an impression.

Figure 3-1 Electricity poles with broken wires. The wires are stolen and to sell the coper.

Figure 3-2 Left: Elementary school children. Right: Middle school children. They go to school from 10:00-14:00


Figure 3-3 Left: The road at the beginning of Bankey Bazar. Right: The street in the village with open sewer in Bankey Bazar


Figure 3-4 Left: Street in Guraru. Right: Road to one of the small villages in Guraru


Figure 3-5` Left: Pucca house (solid), made of bricks and cement Right: Semi-pucca house, made of bricks and wood

Figure 3-6 Left: water pump inside the house. Right: Water pump outside the house

Figure 3-7 Cooking device on the left and on the right dried cow dung as cooking fuel

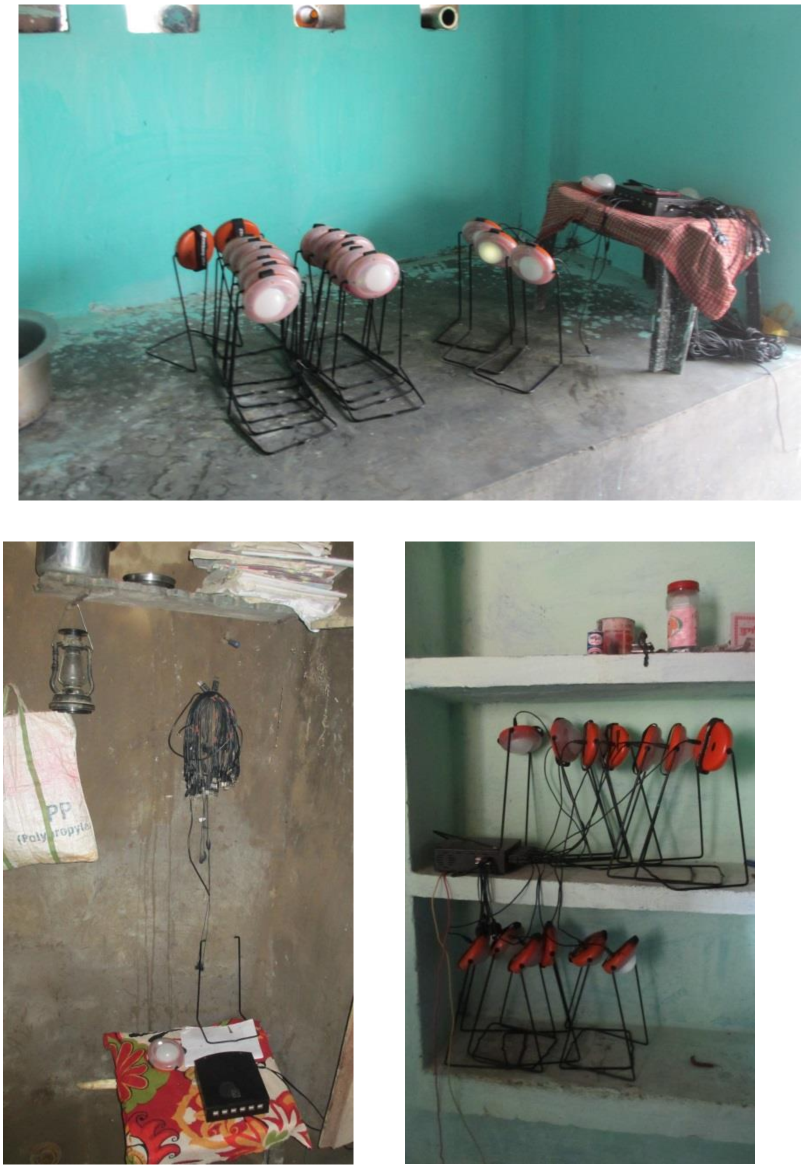

Figure 3-8 arrangements of lamps and Spark Station

Figure 3-9 arrangement of solar panels on the roof

Figure 3-10 Impression of a big rural village where solid buildings and temporary buildings can be found

The pictures shows a small piece of the Indian rural life. It is notable that the people have a lot of facilities such as schools and shops. However, the present of basic hygienic is lacking. There is no sanitation and an open sewer is very common as shown in Figure 3-3. Water is obtained by the ground water pump, but there is no running water or water pipes.
There is a room which can be defined as a kitchen because of the cooking device.
The buildings are mostly build of bricks and a corrugated sheet roof. Something the roof is of hard material such as cement, and something of reed.
The Rural Spark energy kit provides light to the building, which is necessary because the villages doesn't have a connection to the electricity grid. Some villages are connected to the electricity grid, but power is not available for 24 hours a day.

3.2 Interviews

In this part the interviews are describe in more detail. First a short profile of the local energy supplier is given. Followed by a transcription of the interview. Before each question or answer a letter is given of the person who ask or answer the question.

Local energy supplier 1

Table 3-1 profile local energy supplier 1

Profile local energy supplier 1	
Job	Shop owner
Village	Guraru
Amount of energy kits	1
Amount of lamps	17
Price	80 INR per four weeks

C = Christina
W= Willem – Employee Rural Spark
K = Kunal – Rural Spark local agent

W For how long does he has the solar panel?
K Four months now.
W Is the energy kit what he expected to be, regarding the lamp?
K Yes, the business goes well and the lamps work well. He has 17 lamps.
The village is electrified in August but they only have 10 hours supply a day.
W does the rural spark energy kit gives more light?
K Only when its cloudy and all lamps are connected, they won't be charged all. The generation is not enough.
C with time start does his day start? And what are his daily activities?
K He wakes up at 5 am, and has a small general shop very near his house where he sell potatoes, biscuits, grain and rice. He also has some agriculture.
C which time is he done with the shop? When does he makes dinner and how long does it take?
K It takes 2, 3 hours for evening dinner. They make dinner on cow dungs as fuel. 6:30 they start with dinner.
C when does it get darks and does he use the lights? And for how long?
K 5:30 – 5:45 switch on the light.
C in the shop? In the house?
K one in the shop and one in the home.
C For how long they use the lights? Till they go to bed?
K switch on at 5:45 PM till morning 4:00 AM.
W why so long?
K because it all dark and they find it nice to have some light.
C Does he has a fan in the shop or in the house?
K No , he does not have a fan only the lights?
C Does he want a fan? Does he thinks it useful?
K yes it will be useful on the hot days and if it runs on the energy kit.
Kunal talks to the neighbor and explains that a village nearby, called Mitapur, has 150 inhabitants and is not electrified. This might be a good opportunity for Rural Spark.
W How does the electrification harms his business of renting out lights?
K This is not something to discus with the local energy suppliers.
C how many people live in this house?
K Six People
C If he has more panels, does he want to make a profit of it want to use it by themselves?
K Of course the want to make profit of it, because they earn only a small amount with the shop and agriculture. every one want to make a profit to earn money.
W even if he doesn't have enough for himself, he would sell the energy to make profit of it because that the only possibility?
K yes, that's true.
W how many people are local energy suppliers in this village?
K only two. He and his neighbor.
We thank the local energy supplier for his time and visit his neighbor who is also a local energy supplier. Table 3-2 *shows the schedule of local energy supplier 1.*

Table 3-2 Schedule local energy supplier 1

Time	Activity	Energy needed
5:00 – 5:30	Wake up	No energy needed
6:00	Go the land, cultivate it	Maybe, for water pump and transportation of the goods
7:00	General shop	Light in the evening
17:30 :17:45 – 4:30	Turn on the lights and sell	Yes, lights (they like to have light, because it totally dark)
18:30 - 19:30/20:30	Cooking	Energy – cow dung

Local energy suppliers 2

Table 3-3 Profile local energy supplier 2

Profile local energy supplier 2	
Job	Shop owner
Village	Guraru
Amount of energy kits	1
Amount of lamps	20
Price	80 INR per four weeks

W is see the neighbor has two solar panels?
K The second local energy supplier has two panels, but one is an older one and not connected to Rural Spark Energy kit. He use it for his own light and the lights of the energy kit are rented out. He also has an television which does not function and an AC fan connected to the grid.
C does he also has a shop ore shop? How does he earn money?
K He has a small amount of land for agriculture and a small shop. He sells kerosene which he get from the government and sells rice and wheat to the people below poverty level. He sell the products to people with a red or white card.
C When does he to his land to cultivate it?
K In the morning around 5 AM.
C How long is he at his land?
K he has a small amount of land so only for an half hour. He has one cow where he takes out the milk. He doesn't sell the milk. The shop opens at 8:00 to 14:00 and in summer 7:00 to 13:00.
W How much times does it cost to be a local energy supplier?
K in the morning he charges the lamps at 9 AM. At 16:30 he takes out the lamps and he gives it to the people in the villages. He does not note down to who he rents out the lamps, because he can remember.
W how much of their income is from being a local energy supplier?
K 600 rupees of 20 lamps. He charges 80 rupees , 30 rupees to Rural Spark.
W is this a big part of his income?
K It is small part of his income. They can increase their income with more panels.
W Do you think there is demand for more lights?
K yes, everyone needs lamps, because it is all darkness.
We thank the local energy suppliers for his time and take some pictures.

Kunal asks the first local energy supplier if he would go to the next village, Mitapur, to sell the lamps or energy kits. He becomes a sort of distributer. Kunal asks this, because the current

distributer in Guraru doesn't sell well anymore or takes initiative. Asking the current local energy supplier to expand the network might work better according to Kunal.
Willem notice that the solar panel of the second local energy supplier is dirty. It needs to be cleaned and he wonders if there is an instruction how to clean it properly without damaging the panel. Kunal says that there is an instruction. Table 3-4 is the daily schedule of local energy suppliers 2.

Table 3-4 Schedule local energy supplier 2

Time	Activity	Energy
5:00	Wake up	No energy
5:30 - 6:00	Land – Milking cow	Only energy for transport and water
8:00- 14:00, winter 7:00 – 13:00 summer	Shop opens	
9:00 – 16:30	Charge the lamps	Energy for the lamps
16:30	Rent our lamps/ brings to villagers	Energy for the lamps
18:00 – 20:00	Cooking	Energy for cooking (cow dung) Light when it gets dark

Local energy supplier 3

Table 3-5 Profile local energy supplier 3

Profile local energy supplier 3	
Job	Employee at brick factory
Village	Guraru
Amount of energy kits	2
Amount of lamps	40
Price	90 INR per four weeks

W From how far do his customers come?
K All the people who rent the lamps live in small huts in the area where the brick are made.
W all the lights are always rented out?
K yes
W How long is he a local energy supplier?
K It's been two months he is a local energy supplier.
W is he satisfied with the business?
K yes, he is satisfied.
W are there wishes for in the future?
C For example a fan, television, radio or other devices to make his live easier.
K there is demand for 20 more lights. He gone take a second energy kit. They don't have any other wishes.
C How does he makes the brick? Does he brings everything to the oven by truck?
K yes he takes it with by the truck.
K he also has a second panel at his home. We can go there. He says that the village people are complaining because not all lamps are charged well.
W the panel is in a good position? So something is wrong the router.
K the router is already replaced.
C How many rupee per lamp per month.

K 90 rupee per lamp in a month.

Table 3-6 shows the schedule of local energy supplier 3

Table 3-6 Schedule of local energy supplier 3

Time	Activity	Energy
5:00	Wake up	No energy
6:00	Working at the brick factory Charging lamps	Energy needed for the oven and transport (truck) Energy needed to charge lamps
16:30	Rent out lamps	Energy for the lamps
17:00 – 20:00	Cooking	Energy for cooking (cow dung) Light when it gets dark

Local energy supplier 4

Table 3-7 Profile local energy supplier 4

Profile local energy supplier 4	
Job	Shop owner
Village	Guraru
Amount of energy kits	1
Amount of lamps	20
Price	90 INR per four weeks

C how much lamps does he have and how much does he asks for the lamps?
K he has 20 lamps and ask also 90 rupee for each lamp a month
C when does he opens the shop? And what are his other daily activities?
K he opens the shop at 10:00. He also owns a small piece of land where he goes to in the morning. Around 16:30 he makes dinner. This takes 2 to 3 hours and he uses the cow dung to cook.
C when does he rent out the lamps?
K between 10:00 and 18:00 he charges the lamps and rent them out.
This interview was very short because we had to go back to the hotel.

The next day we visited Bankey Bazar together with Basix. Because we were with many people and everyone wanted to ask the local energy suppliers questions, the part below describes as detailed possible the conversation between Basix, Rural Spark employees and the local energy suppliers. Table 3-8 is the schedule of local energy supplier 4.

Table 3-8 Schedule of local energy supplier 4

Time	Activity	Energy
5:00	Wake up	No energy
6:00	Working on the land	Energy for water irrigation and transport of the goods
10:00 – 18:00	Open shop, rent out lamps	Energy to charge the lamps
17:00 – 20:00	Cooking	Energy for cooking (cow dung) Light when it gets dark

Local energy supplier 5

Table 3-9 Profile local energy supplier 5

Profile local energy supplier 5	
Job	Shop owner
Village	Bankey Bazar
Amount of energy kits	2
Amount of lamps	30
Price	2 INR per day

Basix:
This was an remote village. Only 2 years ago they build a road to the village. Since independence there was never light here. Two years ago there were connected with power. There a two transformers installed, only one is working so half of the village get power. Irrigation is a big problem here, because there is no power for an electric pumps. We are planning to provide on experimental basis solar water pumps. They pay 100 rupee per day to pump water, we will ask 60 rupee for the solar water pumps.
The 30 Rural Spark lights are rented out every day for 2 rupee per lamp a day.
Bart: where is the energy kit?
Basix: it is at her shop. We are going there now.

We went to the local energy suppliers shop and saw the 30 lamps with two energy kits.

At the shop the local energy supplier took the change to ask about the bad charging lamp. Bart from Rural Spark changed some cables and noticed it was the cable and not the lamp. The local energy supplier also complained about the unclear notification if the lamp is fully charged or not. Bart explained this is indicated through slow and fast blinking of the lamp.

Local energy suppliers 6

Table 3-10 Profile local energy supplier 6

Profile local energy supplier 6	
Job	Seamster
Village	Bankey Bazar
Amount of energy kits	1
Amount of lamps	20
Price	2 INR per day

Basix:
This local energy suppliers started in December 2013 and has 20 lamps. She also rents them out for 2 rupee per lamp a day. She keeps one lamps for herself.
She says that a neighbor has difficulties paying for the lamps. If she rises the price to 3 rupees people won't rent the lamps anymore, because it is equal to kerosene.
Basix tries to convince the local energy suppliers that it dangerous to use kerosene lamps because of the probability of fire and the inhalation of the smoke. This is dangerous for their health. LED lamps give more light for the same price and no danger for their health.

To convince the local energy supplier about raising the price of the lamps, he ask for the price of the blouse she makes and sells. They cost 60 rupee per blouse, while a year ago she asked 40 rupee. So it is possible to increase the price of the lamps. If she won't do it, Basix takes all the lamps. They need to learn how to do business and make more profit of the energy kit.

Conversation with the distributor in Guraru

Distributor in Guraru	
Job	Sell energy kits. Manage payments and (new) contracts. Detect malfunctions and communicate this to the local agent for repairs.
Village	Guraru

Kunal explains that the distributor did a good job in the beginning and sold many energy kits. He visited the villages to talk with the household and hung posters in his shop to gain awareness of the energy kit. But the energy kits are not selling very well anymore and he is trying to figure out why. The distributor is really busy with his own business selling pre-paid mobile phone cards and charging electric devices. He is not visiting the villages anymore an therefor no new customers are joining. Detecting failures only happens when the customers come to the shop to do their payments. The customers also complain that the payment takes a lot of action with the mobile phone, but also that it is not convenient that the payments are every four weeks and not once a month. This are technical aspects Rural Spark is working on. Kunal suggest the idea of promoting the energy kit at the shop more and do some demonstrations.
Willem notices that there is no energy kit displayed in the shop and asks where the energy kits are. It takes a while before the energy kit shows up from a storage nearby.

4 Conclusion

This chapter answers the research question of this report:
What are the daily activities of the Rural Spark Local Energy Suppliers and what are their wishes regarding electricity use and the Rural Spark Energy Kit?

The local energy suppliers live in small houses made of brick, corrugated sheets and other local materials. They don't have running water, gas or electricity. To get water they use a ground water pump.
The local energy suppliers start their day early in the morning around 5 o'clock. They go to their land and depending on the size they spend half hour to two hours on the land. After their work on the land they open the shop. When the shop is open, they start to collect the lamps from the local people and charge the lamps. The lamps are charged from 9 in the morning till 5 in the noon. Around this time diner preparations start because it takes around 3 hours to prepare it on the cow dung. Water is pumped from the ground water pump nearby the houses. The local energy supplier mentioned that they use the lamps at home , but also one extra at the shop.

A household earns about 6000 INR per month. A household consist of about 6 people.
With the Rural Spark Energy Kit the local people can earn about 600 INR extra per month. They ask 80 to 90 INR per lamp per month and have to pay 1000 INR fee to the local agent. The local energy suppliers from Gurauru asked 80 to 90 INR per lamp per month. The local energy suppliers in Bankey Bazar ask 2 INR per lamp per day. When rising the price to 3 INR, the local people rather buy a liter kerosene, because they can use it for other purposes. The price of the lamps is limited by the alternative lighting fuels.
Another issue regarding the payment, is the method. It takes a lot of time to walk to the local agent to fulfill the payment. Also it is not sufficient that the payment is every four weeks instead of a month. The local agent also mention the many actions he has to take before a payment is done.

The local energy suppliers are content with the energy kit, but when it is cloudy, not all lamps charge fully. When asking if they have whishes regarding the energy kit, they say they want more lights. Also a fan would be appreciated if it runs on the energy kit.
It is notable that the local energy suppliers have no to less knowledge about maintaining the energy kit. They notice something is not working well, but do not know how to repair it. The local agent does not have enough time to check all the malfunctions regular, which result in less efficient use of the energy kit.

All the together the price is a very important aspect, followed by the maintenance and the information exchange regarding this subjects. The payment method is to time consuming and the demand does not match the supply when it is cloudy.

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Appendix III: Calculations

1 Parameters / current situation

The parameters emerged from literature and field trip and is used as starting point for scenario 1 and scenario 2.
Table 1-1 shows the parameters and the values with the source.

Table 1-1 Parameters and values for the case study found in literature and field trip

Category	Parameter	Value	Source
Basic demand	Lights	1.25 Watt, 4 hours charging time, 20 Wh per light 16 lights per energy kit. 2 per household	Field trip
Additional demand	Mobile phone	2 Watts, about 3 hours charging time	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
	Fan	15 Watt, 9 hours operation time	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
	Television	100 Watt, 2 hours operation time	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
Total additional demand	Mobile phone+ fan+ television	341 Wh	(Sen & Bhattacharyya, 2014; Govinda Upadhyay, 2012)
Storage	Battery capacity (Small)	20 Wh	("RURAL SPARK PRODUCT BROCHURE," 2014)
Price	Energy Kit Basic (40 Wp)	668 INR	(Rural Spark, 2014)
	Energy Kit Plus (80 Wp)	1,184 INR	Rural Spark, 2014)
	Lights per day	2 INR	Field trip
	Lights per month	80 – 90 INR	Field trip
Income	Per month	± 6000 – 7000 INR	Field trip (Ram et al., 2012)
Income	Per month from energy kit	100 – 600 INR	Field trip
House hold	Number of people	± 6	Field trip (Government of India, 2013).
Operators	Rural Spark	1	(Rural Spark, 2014)
	Local Agent	At least one in every area	(Rural Spark, 2014)
	Local energy suppliers	1 to many per village	(Rural Spark, 2014)
	Local people	1 to1000 per village	(Rural Spark, 2014)
Success factors	Involvement		(Heist, 2011; Mertens, 2011)
	No subsidies		(Heist, 2011; Mertens, 2011)
	Information and education		(Heist, 2011; Mertens, 2011)

2 Scenario 1 central storage

This chapter described the calculations for the first scenario regarding the battery capacity, type, general losses an pricing.

2.1 Battery capacity

To calculate the battery capacity, the periods with surpluses and shortage must be known. A surplus of energy means more generation than the 16 LED lamps, which result in 80 Wh a day. Everything below the 80 Wh is a shortage.

Weather data from Bihar, obtained from ISHRAE India, is used to determine the critical periods during the year. First the theoretical generation of the PV during the year is determined through the area of the PV panel and the captured daily energy.
Secondly, the demand for 16 LED lights, fan and television is shown. The green line shows the demand for 16 LED lamps, blue shows the demand for 16 LED lamps added with 9 hours fan of 15 watt. The red line is the addition of 2 hours television of 100 watt.
The difference between the generation line of 40 Wp or 80 Wp is the shortage or surplus.

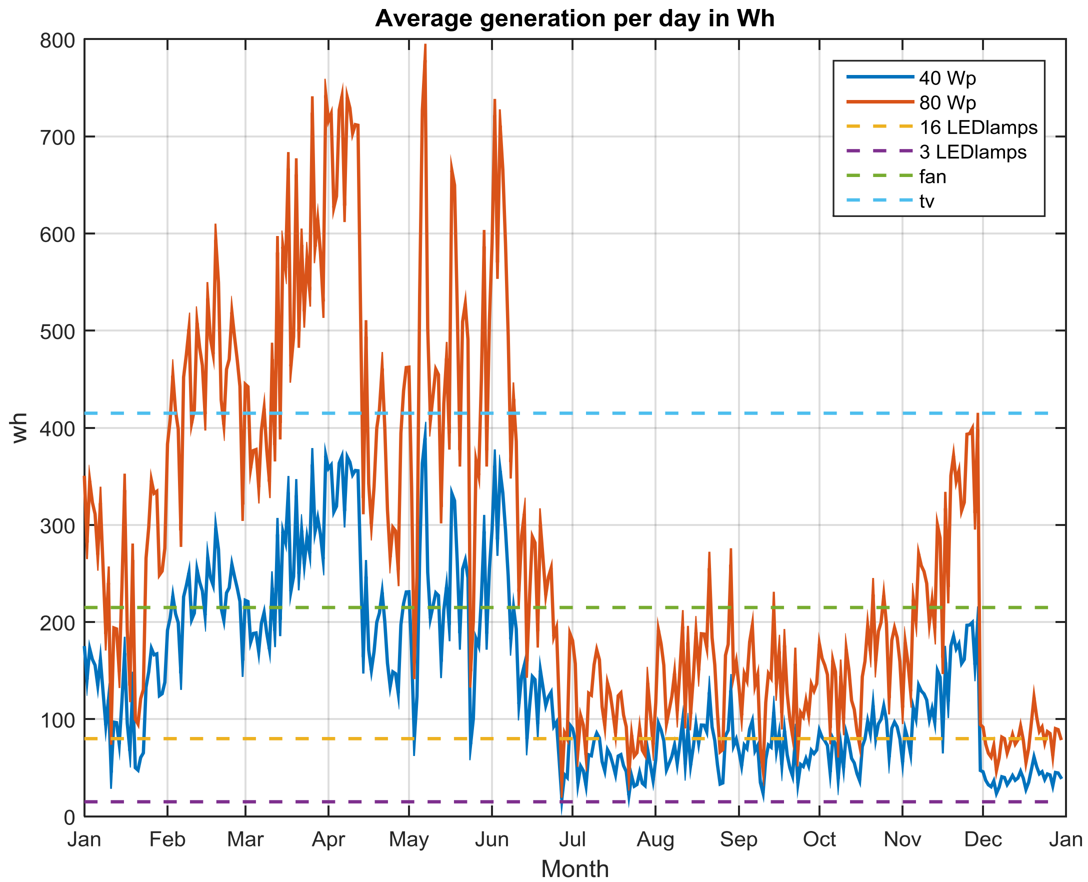

Figure 2-1 Average generation per day, for 40 Wp blue line and 80 Wp PV pane red line. The yellow line shows the minimum demand of 16 LED lamps, the purple line 3 LED lamps, the green line for 9 hours fan of 15 watt with addition of the 16 LED lamps and the blue dotted line for 2 hours television of 100 watt with addition of the 16 LED lamps.

Figure 2-1 shows that one PV panel is not sufficient enough for the minimum demand. Two PV panels is almost enough, with some days a shortage. The second half of the year the generation is much lower and result in a shortage for a long period.

The battery capacity depends on the number of days it has to cover. This information can be obtained from the data weather and the days without the minimum demand.

Table 2-1 Overview of days without minimum demand and charging times

Aspect	Value	Unit
Capacity PV panel	40	Wp
Maximum consecutive days shortage (less than 16 lamps which is 80 Wh)	31	Days
Total days shortage (less than 16 lamps which is 80 Wh)	136	Days
Battery capacity to cover 31 days	2480	Wh
Average charging time	30	Days
Maximum charging time	120	Days

There are 31 days consecutively without minimum demand. All days without minimum together is 136 days. For the first scenario the battery must cover the seasonal mismatch of31 days.
To cover these 31 days the battery should be at least 80 wh x 31 days = 2480 Wh.
The charging time is calculated by the integral of each day and look up that days where the generation is higher than 2480 Wh. This result in Table 2-2.

Table 2-2 day of the year when the battery is fully charged and the associated charging time

Days when battery is fully charged	Charging time in days
41	41
57	16
75	18
87	12
97	10
110	13
130	20
149	19
162	13
207	45
327	120
352	25
Average charging time	30
Maximum charging time	120

The battery for the decentralized scenario is 2480 Wh with an average charging time of 30 days. Figure 2-2 shows the shortage and surpluses for the basic demand.

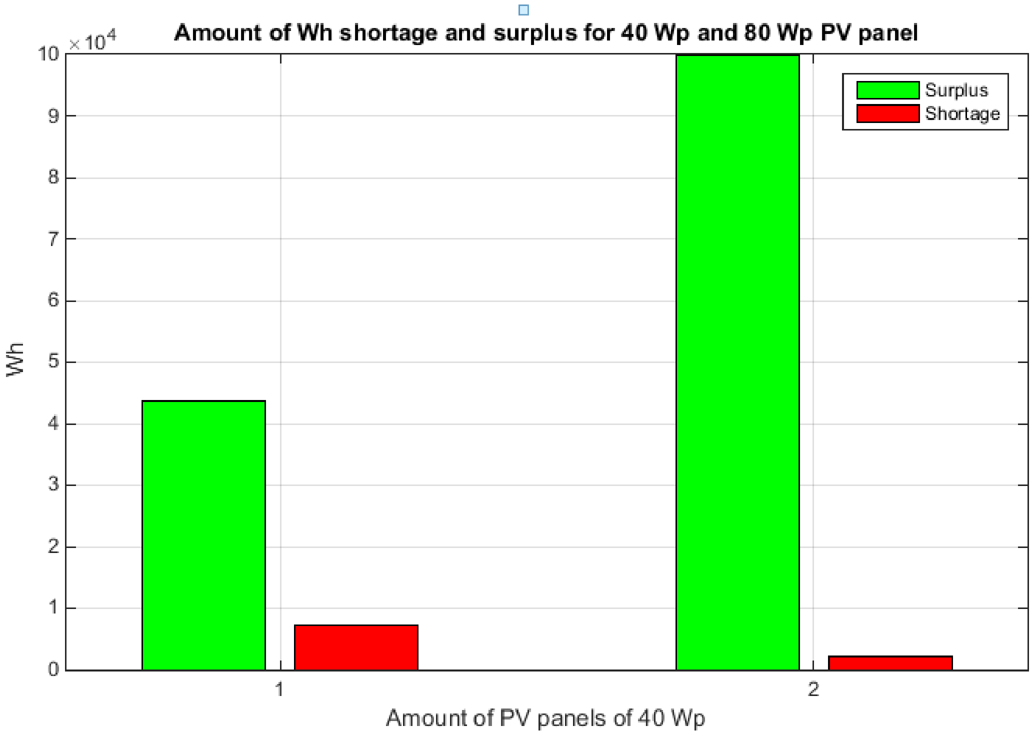

Figure 2-2 Shortage and surpluses for the basic demand

There is enough electricity supply available to overcome the shortage.
Figure 2-3 shows the shortage for additional demand.

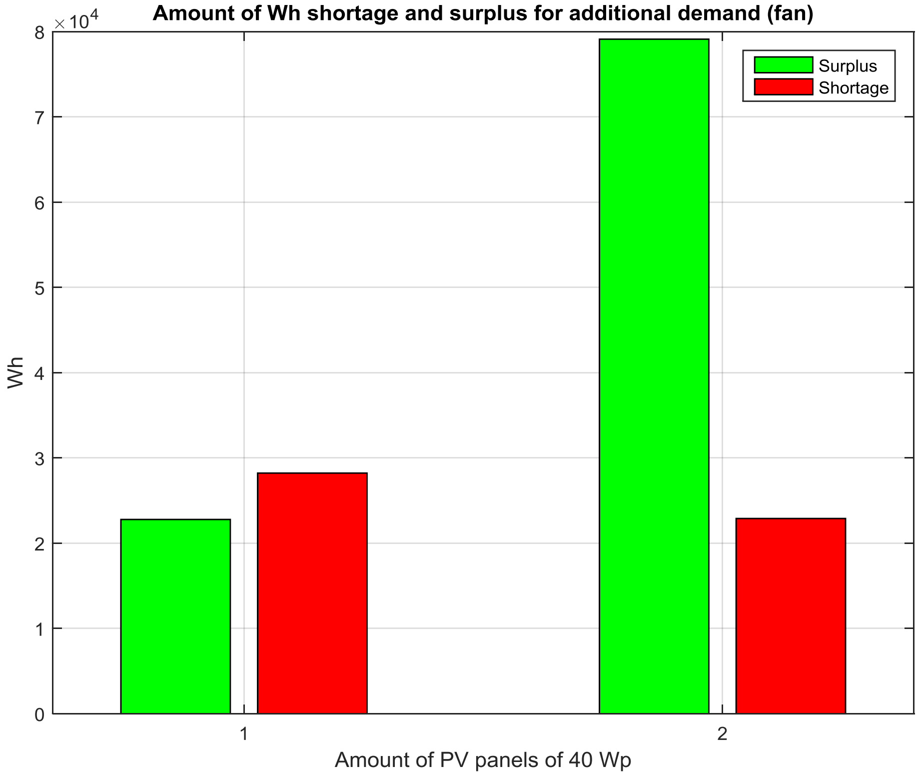

Figure 2-3 Amount of Wh shortage and surplus for the additional demand with the fan for one and two pv panels (basic and plus energy kit). The basic energy kit has more shortage than surpluses, so the fan cannot be used at all the of the year.

There is a shortage of energy when the additional demand is applied, however this calculation assumes that the fan is used the whole year. In the summer periods the fan is used more than in the winter period. Therefor it can be said that this is an average. Two PV panels generate far more than required for the additional demand. The energy can be stored or used for other applications.

2.2 Battery choice

The most frequently used battery is a lead acid battery and nowadays also the lithium battery for solar storage applications(Andersson & Collin, 2009).
Error! Reference source not found. shows the characteristics of the lead acid battery and a ithium battery, the LiFePo4 as example.

Table 2-3 Characteristics of Lead Acid and LiFePo4 batteries (Muneer, 2014)

Aspect	Lead Acid	LiFePo4
Specific energy density (Wh/Kg)	30-50	90-120
Cycle life	200-300	1000-2000
Fast charge	8-16 h	1 h or less
Overcharge tolerance	High	Cannot tolerate
Self-discharge from start	5% per month	2-3% per month
Maintenance requirement	3-6 months	Not required
Battery cost per Kwh in INR	10908	50911
Cost per Kwh per cycle in INR	56	31

The battery most suitable for central storage is a lead acid because of the following reasons:

1. The size and weight does not really matter, because it is a fixed location. Once it is at is place it does not have to be removed.
2. Fast charge is not required because it takes 30 days to charge
3. The price is cheaper, but has a higher cycles cost. For the local people a low investment cost is more important, because they want to make profit.
4. The lead acid battery need maintenance every 3 to 6 months, but on the other it has a high overcharging tolerance. Eventually the local energy supplier only have to maintain the battery once 3 to 6 months, instead of every day to prevent overcharging.

2.3 Pricing central battery and devices

The cost for the central battery energy kit is shown in Table 2-4

Table 2-4 Pricing central battery for lead acid and lithium ion

Aspect	Lead Acid [INR]	Lithium ion [INR]
Battery cost per Kwh	10908,00	50911,00
Cost per Kwh per cycle	55,66	30,60
Energy kit	270,00	270,00
16 LED solar lamps	416,00	416,00
Battery of 2,48 Kwh	450,86	2104,32
100 meter cable	154,17	154,17
Total price per month (inclusive 30% margin)	1291,03	2944,49
Battery payback in years	5,00	5,00

To show that the assumption that lithium batteries don't result in profit, Table 2-5 is made.

Table 2-5 Profit per month for lead acid and lithium batteries

Month	Average a month	Price	Profit lead acid	Profit lithium
January	16	90	149	-1504
February	16	90	149	-1504
March	16	90	149	-1504
April	16	90	149	-1504
May	16	90	149	-1504
June	16	90	149	-1504
July	11	90	149	-1504
August	15	90	149	-1504
September	13	90	149	-1504
October	16	90	149	-1504
November	16	90	149	-1504
December	8	90	149	-1504
Annually profit			1788	-18054

Lead acid is far more payable than the lithium variant, however the profit is much lower compared to the current situation.

2.4 Losses

In the central storage scenario the local energy suppliers are connected to each other with cables. Through cables the energy is distributed but this also results in losses.
With Pouillet his law the voltage losses can be calculated.

$$R = \rho \frac{l}{A}$$

where
ρ is electrical resistivity
R is the electrical resistance of a uniform specimen of the material (measured in ohms, Ω)
l is the length of the piece of material (measured in meters, m)
A is the cross-sectional area of the specimen (measured in square meters, m2).

Table 2-6 Overview of voltage loss through cable per length, voltage and thickness of the cable.

Distance [m]	5 Volt		12 Volt		24 Volt		60 Volt	
	2,5 mm²	4mm²	2,5 mm²	4mm²	2,5 mm²	4mm²	2,5 mm²	4mm²
1	0,33%	0,21%	0,14%	0,09%	0,07%	0,04%	0,03%	0,02%
10	3,34%	2,09%	1,39%	0,87%	0,70%	0,43%	0,28%	0,17%
100	33,40%	20,88%	13,92%	8,70%	6,96%	4,35%	2,78%	1,74%
500	167,00%	104,38%	69,58%	43,49%	34,79%	21,74%	13,92%	8,70%
1000	334,00%	208,75%	139,17%	86,98%	69,58%	43,49%	27,83%	17,40%

The losses can be increased when the distance is shorter, the cables are thicker of the voltage is higher. Losses higher than 100% means that at the end no However, these solution are theoretical possible, the energy kit does not support 60 volt yet and a distance longer than 30 meter is not possible with the 5 volt USB charging cables.
Connecting local energy supplier through cables is only effective, when the distance is shorter than 100 meter. Therefor the added value of the cable, to exchange energy, is not very useful because of the short distance. Therefore, the reminder of this scenario will focus on the balancing the home energy supply demand of one local energy supplier.

Besides voltage losses through the distribution lines, also the power loss increase with the length of the cable. This is calculated with the following formula:

$$P_{loss} = \frac{I^2 * R}{p}$$

I = ampere
R = internal resistance of the battery (10mΩ is used from (Andersson & Collin, 2009)
P= Watt over cable

Table 2-7 Power loss for coper cables for different voltage, lengths and thickness for 1,25 watt

Distance [m]	5 Volt		12 Volt		24 Volt		60 Volt	
	2,5 mm²	4mm²	2,5 mm²	4mm²	2,5 mm²	4mm²	2,5 mm²	4mm²
1	0,01%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
10	0,08%	0,05%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%
100	0,84%	0,52%	0,06%	0,04%	0,01%	0,00%	0,00%	0,00%
500	4,18%	2,61%	0,30%	0,19%	0,04%	0,02%	0,00%	0,00%
1000	8,35%	5,22%	0,60%	0,38%	0,08%	0,05%	0,00%	0,00%

The power losses are lower than the voltage losses. The battery will also losses some of his power due to the self-discharge rate. Depending on which battery is used, the discharge rate differs as shown in Table 2-3..

All together there are voltage losses, power losses and self-discharge losses. Depending on the cable length and battery choice, the losses differ from 1% to 50%.

For the central storage 12 volt is used because of the following reasons:

1. 5 volt results in high losses for short distance (100 meter, 21% loss)
2. 24 volt is not always possible to reach because the pv panel provide 12-24 volt.
3. Working with 60 volt is ideal because of low voltage losses, however this is only possible when more than 4 pv panels are applied.
4. 12 Volt can cover a distance between 100 and 500 meter with less than 44% losses if a 4 mm² cable is applied. Thicker cables will result in less losses.
5. 12 Volt is commonly used for home devices such as a fan and television.

3 Scenario 2: Small storage devices

This chapter described the calculations for the second scenario regarding the battery capacity, type, general losses an pricing.

3.1 Battery capacity

For the second scenario, with a distributed layout, smaller batteries are used. Rural Spark uses battery of 20 Wh for their pilot. The starting point is to cover the daily demand, which is 16 LED lamps.

Table 3-1 Average number of chargeable lamps per month

Month	Maximum number of lamps	With two battery packages of 20 Wh (2x4 lamps)
January	16	24
February	16	24
March	16	24
April	16	24
May	16	24
June	16	24
July	11	19
August	15	23
September	13	21
October	16	24
November	16	24
December	8	16

Most time of the year it is possible to charge 16 lamps, but the second half of the year it become a little difficult. With a 20 Wh battery, 4 lamps can be charged and this result in the worst case in 12 LED lamps. A large battery could be use full, but only for a couple of weeks per year. A second battery of 20 Wh is also a solution.
20 Wh for the small battery storage device is a good starting point reasoning, if the local energy suppliers get 2 batteries with their energy kit.

3.2 Battery choice

Table 2-3 is used to determine the best choice as battery. Lithium batteries are the best choice for small storage devices because :

1. The specific energy density is much higher than lead acid, which result in small and more mobile batteries. This is an advantage, because the battery packages are exchanged.
2. Fast charge is useful, because it is about small amount of energy and short charging time.
3. The battery discharge rate is lower than of the lead acid discharge rate.

4. The investment cost are higher, but the positive point should cover this. The price differ almost 100 INR.
5. The lithium battery requires extra attention every day to prevent overcharging. A battery management system can help with this (Muneer, 2014)

Table 3-2 Characteristics of Lead Acid and LiFePo4 batteries (Muneer, 2014).

Aspect	Lead Acid	LiFePo4
Specific energy density (Wh/Kg)	30-50	90-120
Cycle life	200-300	1000-2000
Fast charge	8-16 h	1 h or less
Overcharge tolerance	High	Cannot tolerate
Self-discharge from start	5% per month	2-3% per month
Maintenance requirement	3-6 months	Not required
Total price per month (inclusive 30% margin)	913,62	1002,11
Cost per Kwh per cycle	55,66	30,60

3.3 Pricing small storage devices

Table 3-3 shows how the price of the storage devices is calculated. For the total price, the battery cost per kWh is multiplied with the required amount of Kwh and a margin of 30% is added.

Table 3-3 Pricing of the small storage devices of 20 Wh

Aspects	Lead acid [INR]	Lithium [INR]
Battery cost per Kwh	10908,00	50911,00
Cost per Kwh per cycle	55,66	30,60
Energy kit	270,00	270,00
16 LED solar lamps	416,00	416,00
Battery of 20 Wh in INR	16,78	84,85
Total price per month (inclusive 30% margin) in INR	913,62	1002,11
Battery payback time in years	1	1

3.4 Smart technologies

The smart technologies which are elaborated a little future are:
1. The smart meter to match supply and demand
2. The smart meter to calculated prices
3. The smart meter to obtain and send information about maintenance
4. Integrated communication and field area network to communicate and distribute information

Matching supply and demand
The data that need to be obtained is how much generation per hour, or per day. This can be measured real time, or a standardized weather data sheet can be used.
With this data the number of chargeable lamps, battery packages and price can be determined.

Number of lamps.

- When the generation is low than the minimum demand
  Divide the generation by 5 Wh (one lamps need 5Wh). This number of lamps can be charged.
- When the generation is equal to the minimum demand
  Charge all 16 lamps.
- When the generation is higher than the minimum demand
  Charge all 16 lamps and calculate how much extra lamps and/or battery packs can be charged.
  The available generation minus the minimum demand (80 Wh) divided by 5 Wh (one lamp) or 20 Wh (battery package) .

Price

There are two possible payment methods for the local people:

1. Daily payment for the lamps
   When the local people pay daily, the daily price variate depending on the generation.
   a. If the generation is lower: multiply the normal costs of the lamp (2 INR) with 16 and divide it with the available chargeable lamps.
   b. If the generation is equal than the minimum demand: the price is minimum 2 INR, or any price which is communicated with the local people.
   c. IF the generation is higher than the minimum demand: the price is calculated by dividing 2*16=32 INR by the number of lamps which can be charged. The local energy supplier can also agree that the price will not become lower than the set minimum of 2 INR.
   Battery package are also calculated the same why. The extra generation beside the minimum demand, divide by 5 INR. Or any minimum price the local energy suppliers agreed on.

Table 3-4 overview of data processing for the price and amount of lamps

Aspect	Data processing	Result
1. Number of chargeable lamps or batteries	- Generation < minimum demand - (16 lamps=80 Wh a day) Divide the generation by 5 Wh (one lamps need 5Wh This number of lamps that can be charged. - Generation = minimum demand - Generation < minimum demand The available generation minus the minimum demand (80 Wh) divided by 5 Wh (one lamp) or 20 Wh (battery package) .	- Charge the required amount of lamps - Charge all 16 lamps - Charge all 16 lamps and if required extra lamps or battery packages
2. Price	- Generation< minimum demand Multiply the normal costs of the lamp (2 INR) with 16 and divide it with the available chargeable lamps. - Generation = minimum demand The price is minimum 2 INR, or any price which is communicated with the local people. - Generation > minimum demand: Divide the number of lamps that can be	- Higher calculated price - Minimum price - Lower price

		charged with the price of the lamps multiplied with the amount of lamps. - Battery package are also calculated the same way. The extra generation beside the minimum demand, divide by 5 INR. Or any minimum price the local energy suppliers agreed on.	

Maintenance (and usage)

It is important, as mentioned, that the battery requires a smart approach in order to not overcharge and make the system sustainable. In order to do this the local energy suppliers should maintain the Energy Kit. An overview is given in Table 3-5.

Table 3-5 Overview of maintenance action and the frequency

Component	Action	Frequency	Comments
PV panel	Cleaning Checking position	Four weekly	The panel generates at its best when the panel is clean from dust. The optimal angle position differs from season ("Solar Angle Calculator | Solar Panel Angle Calculator," 2015)
Cables	Checking of damages	Four weekly	Every four weeks the local energy suppliers has to do the payment at the local agents shop. This is the moment to mention defects or ask a new cable.
Spark Station	Keep dust free	Daily	
LED lamps and other devices	Check if charging and working properly	Daily	Checking if the devices work properly ensures the income and comfort.
Battery	Prevent overcharging	Daily	An indicator should show when the battery is fully charged an should be disconnected.

Table 3-5 shows that some of the components need daily attention such as the lamps and other electric devices to ensure the income and comfort. Other components needs regular attention, to ensure it is working properly. A good moment is to check the PV panel and cables before doing the payment. The local agent can give instructions to the local energy supplier to fix it or give new component when necessary.
A very important aspect is to check whether the lithium battery is not overcharging. Literature suggest to implement a battery managing system to control the charging (Muneer, 2014).

Information exchange

In the previous parts some aspects of information exchange is named. Technically it is important that it is clear how to deal with the extra generated energy which is stored in the lithium battery. The battery cannot be overcharged an information need to be given about the state of the battery. This can be done through a indicator light which turns on green when it is fully charge and red when it is charging.
The information about social-economic parts are separated in pricing, maintenance and payment method.

Table 3-6 Overview of information exchange for different aspects and subjects

Aspect	Information	Stakeholders
Technically	**Knowledge about amount of available energy**	Local energy supplier and local user

	With the addition of the battery, the local energy supplier should know how much energy is stored in the battery, how much can be used and at which moment. **Prevent overcharging** The lithium battery cannot tolerate overcharging, therefor an indicator with, for example, a green light when the battery is fully charged and a red light when charging is required.	Local energy supplier
Pricing	**Variable pricing** When energy is scare, a higher price can be asked. The local energy suppliers need to know in which months this is required. **Error! Reference source not found.** shows the average number of chargeable lamps per month.	Local energy supplier and local user
Maintenance	**Maintenance of the Energy Kit** A maintenance schedule need to be followed to maintain the energy kit. The local agent is also involved in this schedule, because he is responsible for the instruction, repairs and materials.	Local energy supplier and local agent.
Payment method	**Fulfill payment** To local energy supplier walks to the local agent to fulfill the payment and receive an activation code. This is the only way to fulfill the payment and exchange the activation code.	Local energy supplier and local agent

Table 3-6 shows the information required for each aspect and stakeholder. Information about the amount of energy combined with the pricing, is important for both local energy supplier and local users. Prevent overcharging is important to maintain the battery for storage. The information regarding maintenance is important for the local energy supplier and the local agent in order to make the Energy Kit more sustainable.
The payment method still requires walking and oral information exchange. This is time consuming according to the local energy suppliers and local agents.

Table 3-7 Integrated communication systems and an explanation according to (Güngör et al., 2011)

Integrated communication system	Advantages	Disadvantage
ZigBee	Good option for metering and energy management ideal for smart grid implementations Simple, mobile, robust, low bandwidth requirement, low	low processing capabilities, small memory size, small delay requirements and being subject to interference with other appliance. Interference

	cost of deployment. Load control and reduction Demand response Real-time pricing Real-time system monitoring Advanced metering support Easy network implementation Operation within an unlicensed spectrum	detection schemes, interference avoidance schemes and energy-efficient routing protocols, should be implemented. Coverage range: 30-50 m
Wireless mash	cost effective solution dynamic self-organization, self-healing, self-configuration, high scalability services. Good coverage in urban and suburban areas multihop routing. signal repeaters and adding more repeaters to the network can extend the coverage and capacity of the network. Advanced metering infrastructures home energy management	Network capacity, fading and interference Node cost, Third party company is required to manage the network, encryption techniques are applied to the data for security purposes loop problems causing additional overheads in the communications channel that would result in a reduction of the available bandwidth.
Cellular network communication	Cellular networks already exist. No extra cost for building the communications infrastructure data gathering at smaller intervals, a huge amount of data will be generated and the cellular networks will provide sufficient bandwidth for such applications. secure the data transmissions with strong security controls. coverage has reached almost 100%. Support AMI, Demand Response, Home Area Network (HAN) applications. Anonymity, authentication, signaling protection and user data protection security services are the security strengths of GSM technology [37]. Lower cost, better coverage, lower maintenance costs, and fast installation	Some power grid mission-critical applications need continuous availability of communications.

	1-10 Km coverage range	
Power line communication	-	Use exciting power lines
Digital subscriber lines	-	Use exciting of the voice telephone network

The last two option are not applicable in rural India because it lacks exciting power lines and telephone network.
More interesting is ZigBee, because it is cheap and easy to implement. It has the required specifications, such as load control and reduction, if the network become more advantaged.
Wireless mesh is very suitable for rural areas because the network can expend easily because new nodes can join the network and act as an individual router. The disadvantage is that the node cost are high, and a third party is required to manage the network. Rural Spark could take on this task.
The most interesting is properly the cellular network communication which uses GSM, GPRS, 3G and Wimax. The big advantage is that the cellular network already exist, therefor no extra cost are required to build the network. The high coverage range is suitable for rural areas.
The most promising technology for communication is cellular network communication, in combination with GSM technology which has lower cost, better coverage and lower maintenance cost. (Güngör et al., 2011) also state that this is the best candidate as a smart grid communication technology for demand response and advantage metering infrastructures.
The payment method doesn’t change, however the actions remain the same, the local agent need more knowledge and products in stock to help the local energy suppliers with defects and has the possibility to activate the Spark Station on remote.