MSc Environomical Pathways for Sustainable Energy Systems - SELECT

MSc Thesis

From Diesel to Solar:

A Franchise Model for the Replacement of Diesel Generators with Solar PV systems for Micro-grids in Rural India

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Abstract

India has the highest population without access to electricity. To tackle the problem, the Government of India has been focusing on the extension of the national grid. However, the generation capacity remains insufficient providing low quantum and quality of electricity. Rural areas are the most affected by this problem. Most of the villages suffer from power outages of 14 to 20 hours per day. Local entrepreneurs have found an opportunity in this gap. They build their own grids and supply electricity to households or markets running a diesel generator (DG).

Renewable energy systems, like solar photovoltaic (PV) systems, are not sensitive to the change in fuels price and are more environmentally friendly than DG. Nevertheless, DG operators can't afford these systems and can't get finance. Therefore, this thesis proposes a franchise model to allow the conversion of DGs to solar PV systems. Data from surveys about electrification status and demographics done in the state of Bihar was used to understand the characteristics of the villages where DG operators exist. Additionally, ten DG operators were interviewed to better understand their business model. From the data collected, two standardized solar PV system designs were proposed, one for villages (4.2 KW) and one for markets (6.72 KW). The cash flows for the franchisees and the franchiser were forecasted, showing that the business is profitable for both. The Internal Rates of Return (IRR) for the franchisee were 52% for the households' system and 35% for the markets' system. Furthermore, the IRR for the franchiser were 17% for the households' system and 35% for the markets' system. The roles and responsibilities for each stakeholder were defined and a risk analysis was performed.

This franchise model provides a scalable solution for the implementation of solar PV systems for rural electrification. The problem of lack of finance is being addressed and the technical risks are diminished by having a standardized system design and operation. To prove the viability of the model 5 pilot plants will be installed during the next year, after which the model will be refined and scale up.

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1. Glossary

AC	Alternative current
B2B	Business to Business
BAU	Business as usual
BPL	Below Poverty Line
CAPEX	Capital Expenditure
CFL	Compact Fluorescent Lamp
CO2e	Equivalent Carbon Dioxide
DB	Distribution box
DC	Direct current
DG	Diesel Generator set
ESCO	Energy Service Company
GDP	Gross Domestic Product
GW	Gigawatt
INR	Indian Rupees
IRR	Internal rate of return
JNNSM	Jawaharlal Nehru National Solar Mission
KWh	Kilowatt-hour
LEC	Levelized electricity cost
LED	Light Emitting Diode
MCB	Miniature circuit braker
ME	Micro-enterprise
mL	Mililitres
MT	Megaton
NPV	Net present value
PPE	Power Plant Economics
PV	Photovoltaic
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
ROI	Return on Investment
SPEED	Smart Power for Environnmentally-sound Economic Development
TARA	Technology and Action for Rural Advancement
W	Watt

2. Introduction

The lack of access to electricity is one of the major problems of India, linked to health issues and a deficient education. India has the largest population without electricity access. Rural areas are the most affected, with less than 50% of the households electrified [1]. To increase the electrification rates, the Government of India has created many policies in the last years, focusing mainly in the national grid extension. Nevertheless, the problem roots in the deficit of generation capacity. Therefore, many households connected to the national grid suffer from frequent shortages [2]. This gap has been perceived as opportunity by local entrepreneurs who build micro-grids and generate electricity with DG (Diesel Generator Sets).

This project studies the possibility of exchanging the DG's used by the DG operators with solar PV systems through a franchise model. It was done with the support of cKinetics, a specialized sustainability advisory firm working with investors and business in emerging markets. At the moment, DG operators are not considered bankable; besides renewable energy projects require high initial investments and have long payback periods. Therefore, the franchise model proposed allows the current DG operator to hire a solar PV system and own it after a period of time. In this way, DG operators provide the "last mile connectivity", being in charge of the operation, distribution and collection of revenues. Furthermore, this model would contribute to reduce the use and dependence on fossil fuels and can provide more availability and quality of the service.

To make the model feasible, the solution should be scalable and should mimic the current cash flows of the DG operator. Therefore, this thesis proposes a standardized product and the business and financial model required to make the retrofit profitable for the franchiser and the franchisee (DG operator).

cKinetics is also a partner of the SPEED (Smart Power for Environmentally-sound Economic Development) project. SPEED project has been working for the electrification of Bihar for two years. They have been collecting data about demographic characteristics and grid connectivity status of rural settlements. During the development of this thesis, Gopalganj, Araria and Supaul districts were visited and 10 DG operators were interviewed. This allowed a better understanding of their current business model and be able to compare it with the proposed one. This model will be applied to 5 pilot plants financed by the Climate and Development Knowledge Network (CDKN), where cKinetics will act as the franchiser. After one year, the outcomes of the testing will be used to refine the model and roll-out the business.

3. Theoretical Framework

3.1. Rural Electrification Status in India

3.1.1. Electrification Coverage

India has one of the fastest growing economies of the last decade, increasing at an average of 8% per annually since 2006 [3]. The Gross Domestic Product (GDP) growth is closely linked to an increase in electricity consumption; however, this has not been the case for India since there is a lack of resources to ensure the supply and distribution to meet the growing demand.

Almost 50% of the total households in India (around 400 million people) don't have access to modern electricity; most of them in the rural areas. Just seven out of India's 27 states have all its villages electrified; in the majority of the other states more than 40% of the villages remain un-electrified. Nevertheless, it is important to remark that declaring a village electrified doesn't mean that 100% of its households have access to electricity. According to Indian regulations, if basic infrastructure, such as distribution transformer, is established and electricity is provided to public buildings and at least 10% of its households, a village is considered to be electrified. There are no other criteria related to the quantum or quality of the provided electricity or specifications of whether the electricity should be for lighting or should supply other needs. In most villages the supply is single phase and is just enough to provide lighting and some fans. Therefore, even if seven states have declared that all its villages are electrified, four of these states have more than 25% of its rural households un-electrified. Furthermore, even if just 140 000 villages out of 600 000 (23%) are remaining to be electrified, 55% of rural households are not electrified [3] [4].

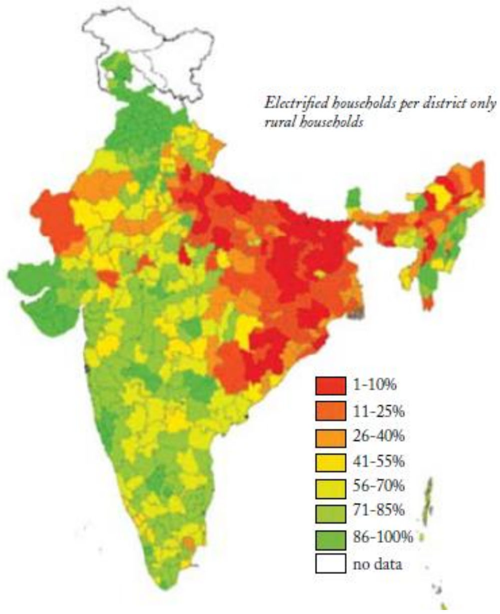

Figure 1. Electrified rural households per district [5]

Figure 1 shows the household electrification rates in India. It can be seen that the problem is more acute in the northeast region of the country where less than 25% of the rural households are electrified. From these states the ones with the largest populations and the lowest electrification rates are presented below, in Table 1.

Shortlisted states	Total population (in millions)	% of rural population BPL	% of rural households having electricity access	Annual per capita electricity consumption (KWh)
Bihar	103.8	55.3%	10%	117.5
Uttar Pradesh	199.6	39.4%	24%	386.9
Jharkhand	33.0	41.6%	32%	750.5
Odisha	41.9	39.2%	36%	837.5
National Average			**55%**	**778.6**

Table 1. Current electrification status and consumption of electricity in selected states [6]

It can be seen that Bihar is the state with the lowest percentage of electrified rural households; therefore, it also has the lowest annual electricity consumption per capita. Besides, Bihar is one of the poorest states, with more than half of its population below poverty line. It can be concluded that Bihar is the state with the highest need of electrification and economic development.

As mentioned previously the lack of supply is one of the main causes for the low electrification rates. India has a total power generation capacity of about 245 Giga-watt (GW) (April 2014). However, there is a deficit of 12% on average and progressive states see a gap of up to 15% [7]. Every year this insufficiency gets higher since the generation sector grows around 4% per annum, while the demand increases at a faster rate of 6 to 7%. Therefore, even if the government has been struggling to extend the grid there is not enough power to meet the demand. On the other hand, the transmission and distribution losses in the Indian grid of about 30% are 5 to 6 times higher than the global average, enhancing the power deficit problem. These losses are due to theft, old and poor infrastructure, lack of proper metering and bill collection system, among others [3].

It is important to remark that although India suffers from a deficit of power supply, the gap should be met with clean energy power plants, even if it requires more time and money. India is currently the fourth largest carbon emitter in the world with a total emission of around 1900 Mega-Tons (MT) of CO2e (Equivalent Carbon Dioxide). The energy sector contributes to 67% of these emissions, amounting to 1260 MT CO2e. Therefore, it is crucial that this country adopts and pursues energy policies which reduce its dependence on fossil fuel and provide green and clean energy as far as possible [3]. At the moment, thermal power (coal, gas, and diesel) still dominates the Indian power sector with installed capacity of 114GW (65.1%) followed by hydro power (38GW, 21.6%), nuclear power (5GW, 2.7%), and renewable energy (18.5GW, 10.6%) [4].

3.1.2. Quantum and Quality of Electricity Supplied to Rural Households

Due to the lack of supply of electricity, even if a rural household is grid connected, a 24 hours provision of electricity is not ensured and the power received is usually just for lighting purposes. All Indian consumers face frequent power disruptions and power cuts that range from 2 to 20 hours on a daily basis and the rural areas are the most affected because priority is always given to the energy demand of the urban areas. Power outages of around 14 to 20 hours per day are the standard in rural areas. Since having power is the exception and not the rule, the villagers count the hours of electricity they get instead of the hours of power shortage. In addition, some villages receive electricity during the night or daytime, when electricity just for lighting purposes is useless. [3]

As mentioned before, the definition of electricity access, especially in the rural context, is reduced to access to electric lighting. Nevertheless, this hinders the contact to a myriad of other energy services, ranging from milling, water pumping for irrigation, drinking and sanitation, and other enterprises. In the current definition of electrification provided for the government, even if the 100% villages and 100% household electrification is met, all the energy requirements, besides lighting, will remain unmet. [3]. This leads to a dependence on kerosene and diesel to provide all the energy services remaining at a higher economic, environmental and social price [4].

3.1.3. Current Policies for Rural Electrification and Renewable Energies

The Indian Energy Act of 2003 includes various sections to encourage rural electrification and to promote the use of renewable energies. From these, the Indian government launched in 2005 the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) programme, which aimed to electrify 100% Indian villages by 2009 and 100% households by 2012 [3]. The programme also includes the provision of free electricity connection to 23 400 000 people below the poverty line in more than 100 000 un-electrified villages through the extension of the existing grid and augmenting the infrastructure [4]. Even if the timeframe wasn't met, the programme is still running.

The same act establishes the regulation for the distribution of electricity from off-grid renewable energy systems in rural areas, specifying that these type of systems don't require any license and the charged tariff would be the result of the mutual agreement between the generator and the consumer. Nevertheless, if any subsidy from the Government or other agencies is received, the benefit must be fully passed on to the consumer [4].

Another programme that emerged from this act is the Jawaharlal Nehru National Solar Mission (JNNSM). This programme promotes the off-grid application of Solar Energy, including hybrid systems to meet lighting, electricity and heating/cooling requirements. For this the Ministry of New and Renewable India would provide financial support through a combination of 30% subsidy and/or 5% interest bearing loans. [4]

However, even though many programmes and schemes have been launched by the government to promote rural electrification in the last decades, they don't provide enough clarity to the participants and entities in order to bring the off-grid renewable energy generation for rural electrification into mainstream [4]. Another issue is that these policies focus only on creating infrastructure for rural electrification, but don't address the issue of enhancing access to electricity, providing a service of good quality or enough quantity [8].

3.2. Rural India Villagers: The Customer

3.2.1. Current Sources of Lighting and Power

Kerosene is the preferred source for lighting in rural households of India. The monthly kerosene consumption per households ranges from 3 to 9 litres of kerosene, with an average of 4.5. The price per litre of kerosene ranges from Indian Rupees (INR) 20 per litre, the subsidized price for Below Poverty Line (BPL) households, to INR 40. These prices can differ in different states depending on the existing taxes and surcharges [4]. The next figure shows the percentage of households using kerosene as the main source of lighting in each state of India.

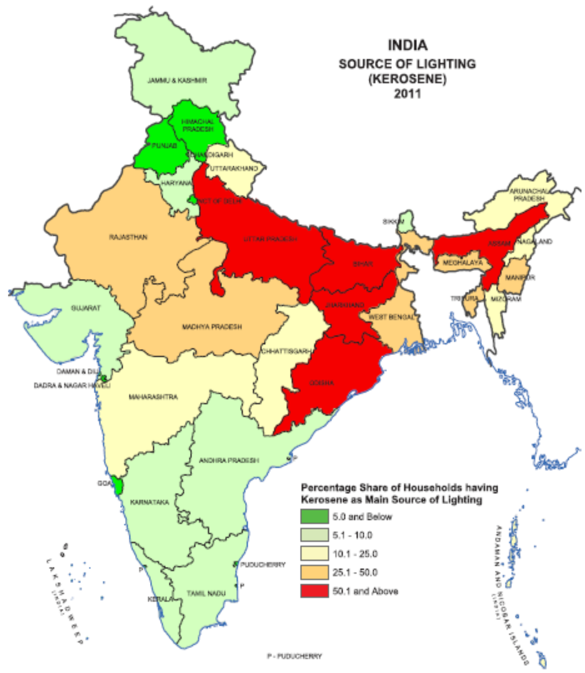

Figure 2. Percentage of households using kerosene as the main source of lighting in each state of India [9]

For commercial loads, portable generators using diesel or kerosene are often used to meet the power demand for electrical or mechanical power applications, like in flour mills and irrigation pumps. The efficiency of these machines is very low due to their small capacity and part load operations, consuming around 300 to 500 millilitres (mL) per KWh, which is almost 5 times the grid price. These portable generators are not only for private use; many local entrepreneurs are using their generators to provide lighting and other energy services through pico-grids to households and small businesses, charging fixed rates per day or month. Approximately INR 85 to 90 per month per household is charged for 3 hours of electricity with which the user gets lighting using an 8 to 10 watt (W) Compact Fluorescent Lamp (CFL). Other services, like powering television, computers and printing machines, are also provided in some cases [4].

Due to the low quantity and quality of electricity received in most rural areas, the use of kerosene and portable generators is also common in already electrified villages, where their dwellers have to rely in these other sources of energy as a backup. Thus, the cost of lighting for a rural electrified household includes the cost of grid supply and kerosene or diesel [8].

3.2.2. Ability and Willingness to Pay

Nowadays, to get grid connected, villagers have to pay a onetime charge of INR 1500 for non-metered connections and INR 2000 for metered connections. Afterwards, non-metered connections have flat rates that vary from INR 75 to INR 100 per month and metered connection pay between INR 2 to INR 3 per kilowatt-hour (KWh), depending on the state, region and season. This tariff is highly subsidized; it is just one third of the urban domestic tariff and one sixth of the urban commercial one. Nevertheless, despite the high subsidies, the erratic and poor quality supply of electricity causes the average rate that a rural household pays for the service to be almost the same as what an urban household pays [3].

Several surveys report that Indian rural villagers are willing to pay up to INR 40 per KWh. An interesting remark is that the customer is willing to pay more when a fixed tariff per period of service is presented, rather than when the cost is a function of the electricity units consumed. Therefore, villagers are willing to spend between INR 100 to INR 120 per month, usually getting just 2 to 3 kWh for lighting [10]. The willingness to pay also varies across regions and people living in villages where a diesel generator is already providing the lighting have higher willingness to pay for the service [4].

Due to the poor quality and quantity of grid electricity, villagers are usually willing to pay more for less outages and better quality of the service. This is supported by the fact that people is currently paying high tariffs to get electricity from diesel generators (Bose and Shukla 2001; Barnes and Sen 2002; Mukhopadhyay 2004). A higher quality and quantity of electricity supply can have a positive impact on rural incomes, which can balance the cost of the service. If electricity supply is provided to income generating activities, the ability to pay for the service is further improved [10].

3.2.3. Electricity Requirements

Table 2 presents the usual load and energy requirements in a rural setup.

Category	Load (W)	Duration	Monthly energy demand (KWh)	Number of connections per village	Total Village demand (KWh)
			Domestic		
Lighting	25 - 35	4 - 6 h	5 - 6 kWh	100 - 500	**500 - 3000**
Other	50 - 150	2 - 3 h	6 - 9 KWh	100 - 500	**2500 - 3750**
Total domestic energy requirement					**3000 - 6750**
			Commercial		
Lighting	20 - 100	4 - 6 h	12 - 18 kWh	2 - 8	**30 - 120**
Equipment	100 to few thousands	4 - 6 h	150 - 750 kWh	1 - 3	**300 - 1500**
Total commercial energy requirement					**330 - 1620**

Table 2. Usual load and energy requirements in a rural setup [4]

In most un-electrified villages the main electricity requirement is for lighting, equivalent to a load of about 25 to 30 W for 2 to 3 CFL of 5 to 15 W each, or 80 to 120W in case of use of cheaper incandescence bulbs. After a certain period, productive loads[1] (loads that support income generating activities) get developed. Among the commercial or productive loads, it is common to find cyber cafes and printing studios. An average consumption of these loads is presented below:

[1] Productive loads are considered as the ones that support income generating activities. For the purpose of this study, lighting loads for shops or other businesses are not included as productive loads, since they are similar to the households' requirements.

Product (Stand-by mode)	Average (W)
Computer Display (LCD)	27.61
Computer (desktop)	73.97
Multi-function Device (inkjet)	9.16
Printer (inkjet)	4.93
Fridge (130 L)	300

Table 3. Electricity consumption of some productive loads

[11]

Other typical household and productive loads in Indian rural villages are:

- Cell phone charging (5 to 10 W)
- Fan (50 to 60 W)
- Grinding (0.5 to 3.5 kW)
- Oil expelling (5 to 15 kW)
- Refrigeration and ice making (1 to 10 kW).

[4]

3.3. Technologies for Decentralized Rural Electrification

3.3.1. Diesel Generators

Diesel generators sets (DG) are cheap and easy to install and run technology for decentralized distributed generation. In India they are quite popular in off-grid areas, supplying individuals, businesses and micro-grids; while in grid connected areas they are used as backup. Around 10 GW of diesel generator sets are installed in India, most of them operating at very low load factors [10].

Due to the low electrification rates and quality of grid electricity supply in rural India, many entrepreneurs are providing electricity using DGs. They are known as DG operators and serve households and marketplaces with electricity for lighting at around INR 4 per day for 3 to 4 hours during the evenings [1]. They can also provide electricity to power appliances with higher demands and productive loads in markets during the day. Besides, they build their own grid using local materials, like bamboo sticks, and wires. At the moment, there are no regulations regarding pricing, quality of service or safety issues applicable to the DG operators and their grids.

The cost of diesel generators' installation and operation is highly dependent on the size of the system and on the power demand. The following table presents the average operation and maintenance cost of a 10 KVA diesel generator.

Particular	Consumption per Hour (L/h)	Consumption per Year (L/y)	Cost per Unit (INR/L)	Amount Per Year (INR)
Diesel (HSD)	2	5760	60	345,600
Mobil-Oil		117	175	20,440
O&M				86,000
Total				**452,040**

Table 4. Average operation and Maintenance costs of a 10 KVA diesel generator [7]

The total output of an 8-kW system is approximated at 20,700 KWh per year, assuming a 90% capacity factor. The total cost of power is therefore INR 21.80/kWh. [7]

In contrast to solar photovoltaic (PV) systems, diesel generators have a very low initial capital investment and can provide energy on demand. Besides they supply Alternative Current (AC), not requiring the use of an inverter. On the other hand, the annual operating costs of DGs are much higher due to fuel price (which is increasing every year) and the provision of fuels can be an arduous task in rural areas. Furthermore, the DGs have a shorter lifetime (3 to 5 years) compared to solar PV systems (up to 20 years). It is also important to consider the great amount of carbon emissions from diesel (2.64 kg/L diesel) which contribute to global warming and produce respiratory diseases [12].

3.3.2. Solar PV

Solar energy has become a very popular renewable energy technology in the last decade, mainly because the drop of its prices and the simplicity of its installation and maintenance. Solar photovoltaic panels convert the radiant energy of the sun into electricity using semiconductor-based materials (solar cells). The amount of electric current generated depends on many factors such as solar material of fabrication, exposed area, ambient temperature, and others.

India, located in a tropical region, receives a great amount of solar irradiation throughout the year, having the potential to offer an improver power supply and enhance energy security. Most parts of India has around 250–300 sunny days in a year and receive about 4–6.5 kWh (kilowatt-hour) of solar radiation per square meter per day.

The PV manufacturing capacity of India increased from less than 60 MW to more than 1 GW from 2005 to 2009, setting India as a possible global leader in the market. This was a first step towards investments along the PV value chain: silicon wafers, PV modules and cells, and balance of system components [13]. To boost the investment and push the solar market in order to reduce the power deficit in the country, the Indian Government has launched the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010. The programme should be implemented in 3 phases resulting on an installed capacity of 20 GW connected to the grid and 2 GW of off-grid solar applications, plus 20 million square meters of solar thermal collector area and solar lighting for 20 million households by 2022 [14]. Figure 3 depicts the implementation plan of the JNNSM.

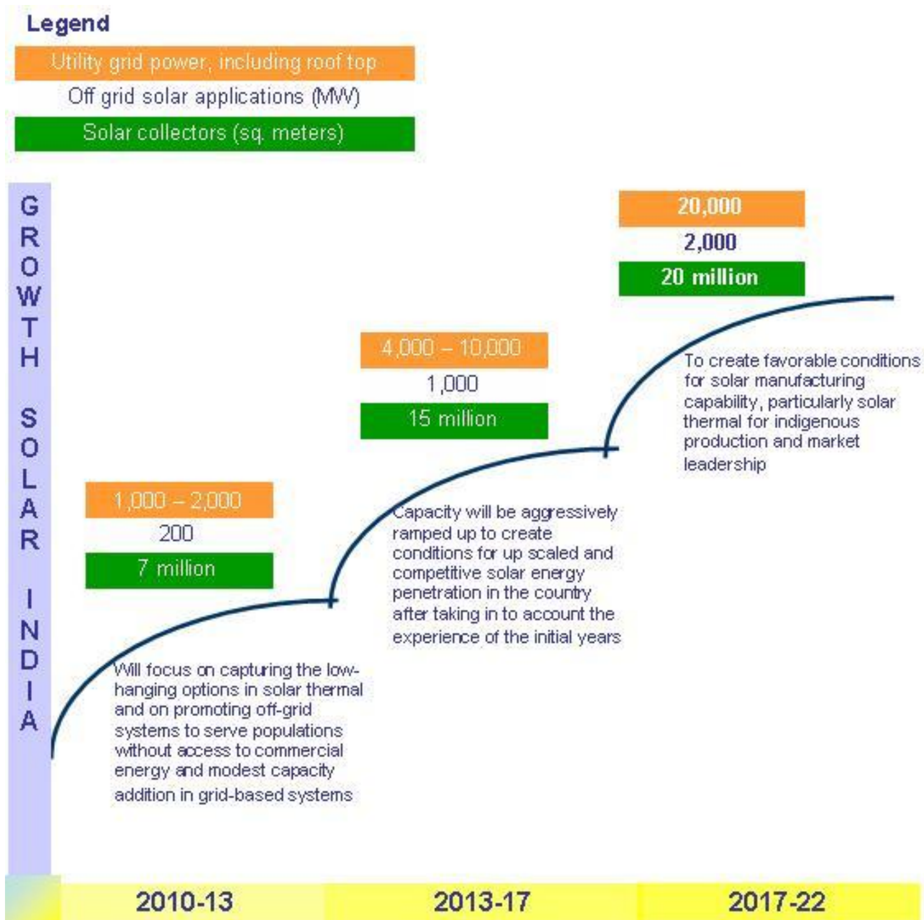

Figure 3. JNNSM (© Solarishi / Wikimedia Commons / CC-BY-SA-3.0)

India's solar installed capacity was 17.8 MW before 2010. After the announcement of the JNNSM, this value increased to 506.9 MW by the end of phase 1 in March 2012. Competitive bidding for grid-tied project under the mission led the prices as low as INR 7.49 per kWh, approaching grid parity with fossil fuel powered electricity. Phase 1 also brought new players into the Indian solar market [15] and increased the module manufacturing capacity to 2 GW [16].

Regardless of the government support, the market is struggling due to the high capital requirements, the low bankability and the lack for grid parity. Besides, the high transmission and distribution losses are a challenge for remotely located solar plants [13]. The manufacturing ecosystem is still weak. It lacks scale, vertical integration and research and development of technology. Furthermore, the land scarcity due to the low per capita land availability and the lack of industry-government cooperation are other challenges faces by the PV market in India [16].

3.3.3. Micro- grids

When it comes to the electrification of an isolated village, grid extension can be too expensive, unless the village has enough demand to reach critical mass. In these cases, micro-grids are an ideal alternative. These are independent entities that can be controlled and managed without presenting threats to the conventional grid, providing more reliable electricity as any outages or interruptions to electricity supply can be quickly identified and corrected. Furthermore, having the site of power generation closer to the load also reduces transmission and distribution losses [12].

Micro-grids comprise three subsystems: the production, the distribution, and demand subsystems.

1. Production: This subsystem includes the generation equipment (could be a diesel generator, solar panels, wind turbine, among others), converters (rectifiers or inverters), storage system (batteries) and control components. This subsystem determines the capacity of the system and connects all the components through the bus bar at the required voltage for the distribution subsystem.

2. Distribution: This subsystem includes all the components to distribute the electricity to the users by means of the micro-grid. The distribution system can be based on Direct Current (DC) or Alternative Current (AC) and single or three phase. This decision affects on the cost of the project and will mainly determinate the devices which can be used. The choice of AC or DC mostly depends on the technologies to be coupled in the system as well as whether batteries will be used in the system. Single-phase distribution grids are cheaper than three-phase ones, but the later allow greater opportunity for commercial enterprises to obtain power and the possibility of future inter-connection to the national grid.

3. Demand subsystem. This subsystem includes all the components on the end-user side of the system, such as meters, internal wiring, grounding, and the devices that will use the electricity generated by the hybrid power plant.

Each subsystem can vary greatly in its components and architecture according to the availability of resources, desired services to provide, and user characteristics [12].

3.4. Current Challenges for Rural Electrification with Renewable Energies

Technology is no longer a challenge when it comes to micro-grids. Most of the challenges are related to the political, financial and social environment around the project and that affects its long term sustainability.

The low load and energy requirements of the off-grid rural electrification projects cause a lack of interest from the distribution utilities. They involve large capital investment and therefore higher cost of electricity generation that usually is not compensated due the low collection efficiency. If the project is commissioned, the maintenance of operation of the project is another challenge; people are not trained to undertake simple care and maintenance of the equipment and if there is no sense of ownership from the users they tend to treat the systems as temporary solutions [4] [3]. Therefore, even consumers show a high ability and willingness to pay; credit constraints, lack of technical capacity, lack of awareness and under-developed market distribution all contribute to limited deployment of renewables for rural electricity [10].

The next table, Table 5, shows the PEEST (Political, Economic, Environmental, Social and Technical) factors that affect the success and sustainability of renewable energy micro-grids for rural electrification in India.

Political	• Lack of clarity on government's policies. • Difficult land acquisition process and ownership.
Economic	• The funding process is not clear. • Lack of consumer subsidies. • Unknown cost to user over time.
Environmental	• Lack of land banks. • Complicated permitting process.
Social	• Lack of consumer awareness and education. • Household energy use patterns and behaviours. • Workforce readiness, local employment and training capacity.
Technical	• Unbalanced distribution systems. • Future integration to the grid. • Lack of training.

Table 5. PEEST factors of the implementation of renewable energy micro-grids for rural electrification in India [7]

3.4.1. Financing Renewable Energies for Rural Electrification

Project financing is one of the biggest challenges for renewable energy projects. Domestic banks still perceive significant risks in this kind of projects and have high interest rates. Furthermore, international lending institutions have more rigorous selection requirements. These obstacles increase the dependency on grants for the deployment of the renewable energy projects [15].

Regarding renewable energy projects for rural micro-grids, around USD 82 million is available in the form of technical assistance, subsidies, commercial loans, subsidized loans, equipment finance, and equity investment. From this, 87% is donor capital and just 13% is returnable capital. This shows the low interest from private investors in this kind of projects. Furthermore, the amount of debt available is limited and just accessible by established firms. New companies trying to enter the market are more likely to get equity, since financing institutions are not aware of the risks associated with the sector, related to technology, business model and regulations. According to the report developed by cKinetics, Financing Decentralized Renewable Energy Mini-Grids in India, there is a mismatch between the accessible capital and what is needed. The available capital is meant for low-risk and low-return capital, or high-risk and high-return capital business models. The high-risk and low-return capital required for the deployment of distributed renewable energy mini-grids is missing [6].

3.5. Business models for Rural Electrification

According to Thirumurthy and Harrington, the following business models can work well in a rural community setting and can provide a good overview to what is being employed under JNNSM across India [7]:

1. Community-based model, where the renewable energy system is owned and operated by the local community

2. Private sector-based model, where the system or many of the components of the system are owned by a private entity

3. Utility-based model, where the utility owns and operates the system

4. Hybrid model, in which there is a combination of community, private, and utility ownership.

All of the models have advantages and disadvantages that make them more or less suitable for different locations. The current study focuses on a private sector based business model. This one is the most efficient model for providing electricity, ensuring the long-term operation and maintenance through technical ability to address problems. Nevertheless, the lack of funding can be the main flaw of this approach.

3.6. Sustainability of Renewable Energy Projects for Rural Electrification

To ensure the long term sustainability of the project, there are many technical and social considerations to be made. Local conditions should shape the project, respecting local traditions and leadership structures, instead of the local people adapting to the project. Local participation is essential. The involvement of local leaders and other stakeholders in the decision making process can ensure the users' satisfaction. They can help to assess electricity needs, monitor the project, organize the community, enforce the rules, help to develop local productive enterprises, among others [12]. The participation of the community can provide a better suited tariff system and demand side management. On the other hand, training of local operators and users is required to ensure the correct operation of the system and in order to give maintenance and troubleshooting as fast as possible and provide a reliable service [3].

From a technical perspective it is important that the system supports the creation of productive services and businesses; this enhances the local economy and ensures stable revenues. It is remarkable that businesses fed by small diesel generators indicate significant potential for utilization and the willingness to pay for electricity service. In addition, the over sizing of the system to allow for future demand growth is essential, since the number of user connections can be low at the beginning, especially in regions where no other projects have been installed previously, but it can grow fast due to the change in social dynamics one the village is electrified. Over-sizing some components, such as the wiring and the converters, by 30% can be a good practice [12].

Other business approaches to increase the sustainability of these projects are the development of turnkey systems and bundling projects. Standardized systems and clusters of projects can catalyze micro-grid development, making it easier for taking advantage of economies of scale, financing structures, reducing overheads and making the human building capacity easier [7]

The high upfront cost of renewable energy technologies can be a risk for the development of rural electrification projects. Therefore, the implementation of energy efficiency practices can be useful to reduce the size of the system and consequently the investment costs. Nevertheless, this can be a difficult task in rural areas, where their situation pushes for technology choices with a short term and least cost basis in mind. For example, they would rather buy an incandescent bulb, instead of a CFL; which increases the overall demand and the size of the system. The energy efficiency measures (demand side management measures) to reduce the anticipated energy demand require intensive and sustained interaction with the users; it is an issue that involves capacity building and training, more than technical skills [12].

3.7. SPEED programme

"Smart Power for Environmentally-Sound Economic Development (SPEED) seeks to identify and showcase scalable business models and implementation plans for addressing energy access and triggering economic activities in underprivileged areas of the developing world, while simultaneously providing diesel-replacement opportunities to telecom towers and farmers who still use diesel-driven pumps and lighting" [17]. This project started in 2009 with the support of Rockefeller Foundation, and executed by several partners in India, like cKinetics and Technology and Action for Rural Advancement (TARA). It is one of the many projects in India that aim to overcome the current challenges for rural electrification using renewable energy powered mini-grids.

Engaging the telecom tower industry and Energy Service Companies (ESCOs), SPEED intends to deliver clean electricity to not electrified or under electrified communities in India. Using the telecom towers as anchor loads, reliable electricity supply will be provided to micro enterprises, in order to trigger economic development. The first phase of the SPEED programme (2009 – 2010) aimed to formulate the concept and assess the gap. During the second phase (2011 – 2014), pilot projects to validate the model are being established. To achieve this, many on-ground data about the demographics, electrification status, economic activities, and natural resources of the villages has been collected. From the outcomes of phase 2, the goal is to scale up for 1 000 villages in a time frame of three years (2015 -2018), and to 100 000 in ten years [17].

4. Diesel Generator Operators

Due to the low electrification rates and the low quality and quantum of electricity provided to rural households connected to the national grid, local entrepreneurs have built their own grids to provide the service. These micro-grids are built from local materials, like bamboo sticks, and are powered with DGs. These local entrepreneurs are known as DG operators and provide electricity for lighting to households and sometimes for running productive loads in markets. This chapter intends to give an overview of the current situation of DG operators in rural India, their characteristics, business models and major challenges.

4.1. Current Status

As part of the SPEED project, more than a hundred villages in the northeast of India were surveyed to evaluate their need and potential for electrification with renewable energy powered mini-grids. The evaluation included different parameters related to demographics, as the number of households, average income and occupation of the villagers; and electrification status, as the number of hours that they get the service and the alternatives for the grid electricity they currently use.

This thesis focuses on the state of Bihar; therefore only the villages located in this state were studied. The following table shows the number of villages surveyed in each of the districts under study. These districts were selected due to the already existence of ESCOs working in the district or willing to work in it.

District	Number of villages surveyed
Araria	15
Bhojpur	3
Gopalganj	35
Purnia	1
Saran	9
Supaul	15
Vaishali	17
Total	**95**

Table 6. Number of villages surveyed in each district under study (2014)

The 95 villages under study have been classified depending on the reported average amount of electricity supply: less than 5 hours, less than 10 hours and more than 10 hours. If none of the households was grid connected, it was classified as not electrified.

	Number of villages	Percentage
More than 10 hours of electricity	8	8%
Less than 10 hours of electricity	13	14%
Less than 5 hours of electricity	39	41%
Not electrified	35	37%
Total villages	**95**	**100%**

Table 7. Electricity supply status of the surveyed villages (2014)

Table 7 shows the result of the mentioned classification. It can be noticed that most of the surveyed villages were not electrified or were getting less than 5 hours of electricity supply. Both these categories summed up 78% of the total villages.

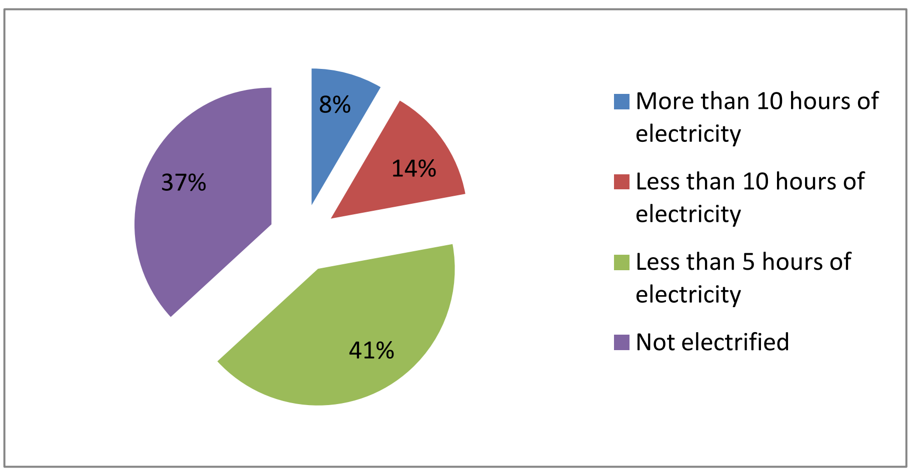

Figure 4. Electricity supply status of the surveyed villages (2014)

It is important to remark that the classification was made according to the information provided by the villagers and their perception of the amount of hours that they get electricity. Furthermore, this is an average value that varies from day to day and also depends on the season (since the presence of rains influences the availability of power). Not just the amount of hours of service are irregular, the timings are not certain either. There is no official data regarding the amount of hours of supply each village gets or load shedding schedule for the state of Bihar. On the other hand, mentioning that a village gets a certain amount of hours of electricity does not mean that 100% of the households of the village are getting the same amount of electricity or that they are grid connected. In most of the cases, not all the households of one particular village are connected to the grid.

The presence of DG operators was also surveyed as part of the SPEED program, as this is an important parameter to measure the villager's willingness to pay for reliable power sources and their behaviour towards it. These DG operators are local entrepreneurs that provide electricity through self-made micro grids to households or shops in rural communities. The data collected regarding the DG operators was related to the amount of electricity each village gets. Table 8 shows the number of villages having a DG operator and their electrification status. It can be seen that 49 (52%) out of the 95 surveyed villages have at least one DG operator. It is also noticeable that the presence of DG operators is most common in villages getting less than 5 hours of electricity supply – 69% of these villages have at least one DG operator.

Electrification status of villages where DG operators exist	Number of villages having a DG operator	Percentage having a DG operator
Total villages having a DG operator	49	52%
More than 10 hours of electricity	4	50%
Less than 10 hours of electricity	5	38%
Less than 5 hours of electricity	27	69%
Not electrified	13	37%

Table 8. Electrification status of villages where DG operators exist (2014)

It is interesting to see that the existence of DG operators is more common in villages that are already grid connected than in not electrified villages. This can be due to the changes in social behaviour that the access of electricity creates – people that get access to electricity tend to get used to the comfort that it provides and increase their use of electrical devices. Therefore, 50% of the villages getting more than 10 hours of electricity supply have a DG operator. In their case, even if they are getting many hours of electricity supply, the irregularity on the timings and the fact that not 100% of the households are grid connected make them require a DG operator to use their electrical appliances, as they are used to.

Another parameter evaluated was whether the DG operator was serving households or shops. During the surveys it was noticed that when the customers were households, the DG operator was generally providing electricity only for lighting purposes; whilst, when the customers were shops, the DG operator can provide electricity for lighting or for other appliances, for example computers, printers, small welding machines, fans and others. The next table shows the division of the DG operators depending on the loads they serve.

Electrification status of villages where DG operators exist	DG operators serving households	DG operators serving shops
More than 10 hours of electricity	1	4
Less than 10 hours of electricity	3	4
Less than 5 hours of electricity	13	18
Not electrified	6	8
Total general	**23**	**34**

Table 9. Type of customer served by the DG operators (2014)

Sixty percent of the DG operators serve shops, disregarding the electrification status of the villages; this supports the idea that electricity is a need for economic development and that serving loads that create revenue maintains and ensures the willingness and ability to pay for electricity services.

In most of the villages the difference between the number of DG operators that serve each type of customer is low, being a proportion of 40% for households and the rest for shops. Nevertheless, in the villages getting more than 10 hours of electricity the proportional difference is higher, and 80% of the DG operators serve shops. This can indicate that in villages getting a sufficient amount of hours of electricity, people performing business related activities is willing to pay for a reliable service at certain hours and that the supply timing is not that crucial for households, since they can use their electrical appliances whenever it is available.

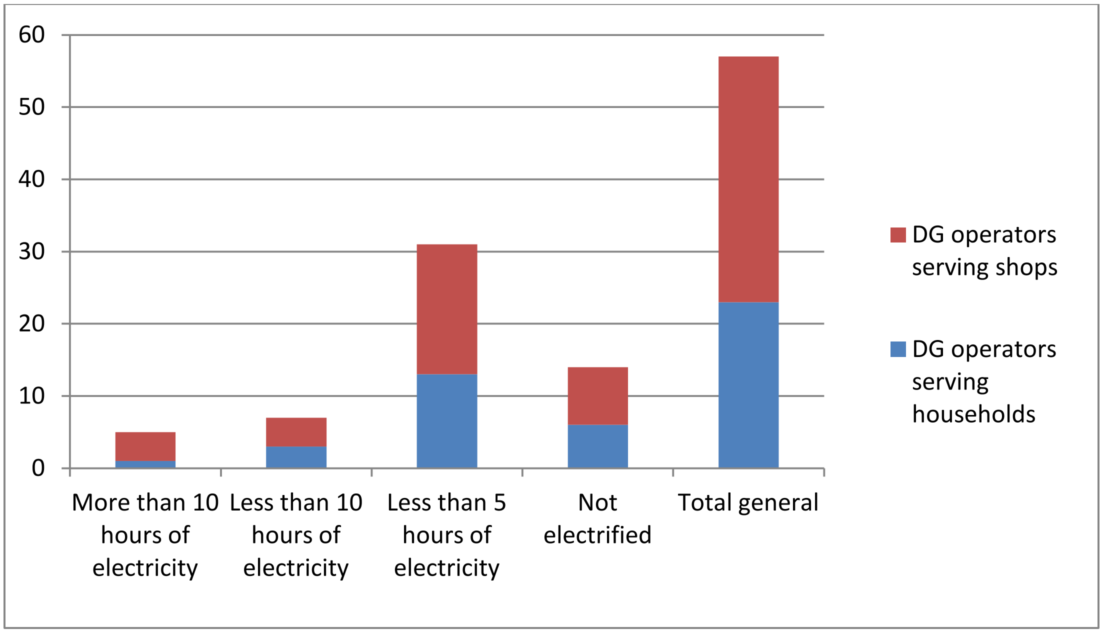

Figure 5. Type of customer of the DG operators in the surveyed villages (2014)

Regarding the type of costumer, it was found that the DG operators serving households have around 300 connections, while the ones that serve shops have approximately 150. It is important to mention that this information was the result of the perception of the villagers or the DG operators, who were willing to provide just an estimate number of their served customers, but not the exact value. During the surveys, it was also noticed that most of the DG operators charge a daily tariff that can range from INR 3 to INR 5, from households where they mostly provide just electricity for lighting; and from INR 5 to INR 25 for shops, where sometimes they provide electricity for the use of fans. The tariff for shops can be even higher (up to INR 100) if the loads served include computers, printers or others.

	Households	Shops
Average number of connections	302	146
Average charge per day	4	7

Table 10. Average number of connections and daily charge for households and shops (2014)

It was also found out that the DGs operate mostly in the evenings for 2.5 to 4 hours, when they provide mostly lighting. If they provide electricity to power computers or other productive loads, they can them up to 8 hours.

4.2. **Study Cases**

A detailed interview was designed to better understand the business model of the DG operators. It was intended to find more information about the technology being used for generation and distribution of electricity, the current related costs, the number of customers and their payment modality, their revenues, among other data. The specific questions asked can be found in the Appendix (11.1.1Interview content). As part of the interview, some questions about their willingness to get a solar PV system through a franchisee model were asked; people were offered the option to operate the system and get a percentage of the revenue, or pay upfront 30% of the total cost of the system and pay a monthly fee to owe the system in 5 years. It is important to remark that the values gotten are average figures provided by the DG operators; thus to validate the accuracy of the values, further studies should be made. Furthermore, it was noticed that sometimes the DG operators were not willing to share exact details of their business model for being afraid of getting in trouble with the electricity authorities or getting competitors into their businesses. A total of 10 interviews were performed, from which 5 were selected and presented here. These were selected for being the ones that provided the biggest amount of information due to the willingness of the DG operators of sharing their numbers.

4.2.1. Chakkai

Chakkai is a village in the Araria district with more than 1000 households; most of the villagers are farmers. The village was electrified some years back; nevertheless, people are still relying on the DG operator for lighting during the evenings.

Figure 6. DG operator of Chakkai

Sanjay Kumar Biswas started his business as a DG operator in 2011. He got an old and ruined genset as a present from his family and spent INR 5000 to fix it. He decided to serve households with electricity for lighting. In the beginning he got 300 customers; when the grid came 2 years ago, he lost about 25% of his customers. However, some months ago the transformer of the village broke down and he got even more clients than in the beginning. At the moment he serves around 325 households with one lighting point during 3.5 hours in the evening; he asks his clients to use an 11 W CFL and they can also connect a device to charge their mobile phones, making their allocated load of about 20 W. He charges INR 100 per month at the beginning of the month to avoid the trouble due to delays of payment.

Type of load	Number of connections	Power (KW)	Hours of service	Price (INR)	Frequency of payment
Households	325	11 W + charging point (up to 20 W)	3.50	100.00	Monthly

Table 11. Connection characteristics of the Chakkai DG operator (2014)

Sanjay uses kerosene instead of diesel to run his genset, thereby reducing its operational costs. He buys kerosene at around INR 40 per litre and uses 1.5 litres per hour. Regarding other costs, he does not pay anyone to maintain his engine, he does it by himself and spends about INR 3 500 per month in oil.

Cost of fuel (INR)	INR 7 000 per month
Maintenance cost (INR)	He changes the oil
Oil for genset (INR)	INR 3500 per month

Table 12. Operation and maintenance costs of the DG operator of Chakkai (2014)

The 325 connections are equally divided into the three phases provided by the generator. He controls the load in each of the phases checking their amperage so he can notice if any of his clients is connecting more than the allowable load.

Figure 8. Voltage and amperage board and CFL and lighting point allowed

Regarding his revenues, he charges an INR 100 connection fee and he is getting a profit of around INR 30 000 to INR 35 0000 per month.

4.2.2. Matehari

This is a village in Araria, with around 250 households. It is currently grid connected, but the villagers just get around 2 to 3 hours of electricity. Matehari is next to a national highway, which makes its market very busy and always crowded; to keep the business activities running even during the evening hours and when the electricity supply is not there they are connected to a DG operator.

The DG operator of Matehari is Sakar Hussain. He provides electricity for lighting to shops in the market area and to households around it. He has around 225 connections in total, charging INR 125 per month or 2 L of kerosene for 3 hours of service. His customers must use an 11 W CFL and can connect a mobile phone charging point to it.

The payment with kerosene is a practice that is widespread in other villages in Araria. BPL people have access to subsidized kerosene, paying just INR 20 per litre instead of INR 40; the DG operators accept two litres of kerosene in exchange for the electricity for lighting, and can use the kerosene to run their gensets or resell it at least at the normal price (INR 40). This is an issue that modifies the awareness of the amount paid by the end consumer, since he or she perceives to be paying INR 40 per month (2 litres of kerosene at INR 20 each), while the actual price is higher; and in the case of the removal of this payment scheme, it is possible that they won't be willing to pay more than the INR 40 that they are currently paying.

Type of load	Number of connections	Power (KW)	Hours of service	Price (INR)	Frequency of payment
Households	95	11 W + charging point (up to 20 W)	3	125 or 2 L of kerosene	Month
Shops	130				

Table 13. Connection characteristics of the Matehari DG operator (2014)

Out of his 225 connections, 200 pay regularly; the ones that don't pay are disconnected from his mini-grid. He spent INR 12 000 in wiring for the deployment of the mini grid. He has one employee who helps him to collect the money, run the genset and in other duties of his auto mechanic workshop; his monthly salary is INR 2000. Even though he accepts kerosene as payment for the electricity he provides, he doesn't use it to run his engine since he says that there is enough demand for the kerosene and he gets more revenue from selling it than from using it. He uses 160 L of diesel per month, spending around INR 10 000. Since he is a mechanic, he provides maintenance for the genset himself and he uses the remaining oil from the cars to which he provides maintenance at his workshop.

Litres of diesel per month (L/month)	160 (INR 10 000)
Maintenance cost (INR)	He changes the oil
Oil for generator (INR)	He uses the oil from the cars he maintains

Table 14. Operation and maintenance costs of the DG operator of Matehari (2014)

He divides the 225 connections in three phases. He can check the balance of the loads, and supply and demand from the sound of the rotation of the motor. When the demand increases the motor runs slower, making a specific sound, then he disconnects each of the three phases to determine in which of the phases the problem is.

Figure 9. DG operator of Matehari checking the load balance (2014)

He commented that his monthly profit is around INR 15 000. When he was asked about his willingness to get a solar PV system, he showed to be interested; besides, he mentioned that he would be willing to make the upfront payment and pay a monthly fee in order to own the system after some time.

4.2.3. Hardiya

The market of Hardiya is a village in Gopalganj, having around 100 households. Around 35 households and 45 shops are grid connected, but they are only getting 2 to 3 hours of electricity per day.

Ophra Kish is the DG operator of the market; he started his business 10 years back. He provides electricity for lighting to shops. At the beginning he wasn't willing to share too many details about his business; later he informed that he has around 70 shops connected, and that he provides them with one lighting point of around 15 W, he charges them INR 6 per day. He doesn't have a disconnection policy; he thinks trust is very important, so even if they customers get delayed he doesn't disconnect them.

Type of load	Number of connections	Power (KW)	Hours of service	Price (INR)	Frequency of payment
Shops	70	Up to 15 W	3	6.00	Daily

Table 15. Connection characteristics of the Hardiya DG operator (2014)

He provides one phase connection to each of his customers and checks the load in each line with an ampere meter. He provides the maintenance to his genset himself, spending INR 600 for 3.5 litres of oil every 100 h. He uses around 1.25 litres of fuel per hour; as fuel he adds kerosene to diesel getting a mixture of 30% kerosene and 70% diesel, this lowers his operational costs.

Litres of fuel per day (L/day)	3.75 (70% diesel, 30% kerosene)
Maintenance cost (INR)	He changes the oil himself
Oil for generator (INR)	INR 600 (3.5 L) every 100 h

Table 16. Operation and maintenance costs of the Haridya DG operator (2014)

When he was asked about his willingness to get a solar PV system, he said he would like to get one; nevertheless he pointed out that the decision of just operating it or owning it would depend on the amount that should be paid up front. He would like to go for a hire-to-own scheme, but he is worried that he won't be able to get the upfront payment.

4.2.4. Lokhariya

Lokhariya is an un-electrified village of the Araria district with around 500 households. To supply their lighting needs during the evening they rely on a DG operator. The mini-grid has around 250 households connected. The customers are allowed to use an 11 W CFL and a mobile phone charging point for 3 hours, and pay 2 litres of kerosene or INR 100 per month for this service.

Type of load	Number of connections	Power (KW)	Hours of service	Price (INR)	Frequency of payment
Households	250	11 W + charging point (up to 20 W)	3	100 or 2 litres of kerosene	Monthly

Table 17. Connection characteristics of the Lokhariya DG operator (2014)

Naran Daaz is the DG operator of Lokhariya. He gets approximately 450 litres of kerosene per month, since 25% of his clients usually don't pay on time. He uses approximately 200 L of kerosene per month to run his genset, and sells the rest at INR 50 in the nearest market.

He and his family check the lines every day, to make sure that anyone is connecting more than the load allowed. If this happens he disconnects the user. He also checks the load connected measuring the current delivered to each of the lines at any time. Besides his operational and maintenance costs for oil changes, he also spends INR 4000 every six months to replace the grid.

Cost of fuel (INR)	200 L of kerosene per month
Maintenance cost (INR)	INR 1 000 every 4 months
Oil for genset (INR)	INR 700 (3.5 L of oil) every 100 hours
Other costs (INR)	INR 4000 every six months, for grid replacement

Table 18. Operation and maintenance costs of the DG operator of Lokhariya (2014)

4.2.5. Mahdopur and Harihalpur

Mahdopur and Harihalpur are neighbouring villages in Chattapur block of Supaul. Both of them are un-electrified and share the same marketplace. There are four DG operators serving these villages: one for the market, one for the local bank and two for the households in each village. The shops in the market served by the DG operator were surveyed in order to have a better understanding of their loads; nevertheless it was not possible to interview the DG operator.

Figure 10. Tailoring shop requiring just lighting

The market has more than 100 shops, 90 of them are shops that only require lighting. They pay INR 7.00 for 4 hours of lighting using an 11 W to 18 W CFL; the usage of a mobile charging device is also allowed. Among these types of shops are tailoring shops, general stores and sweet shops.

There are also stores having higher loads, like printers, computers, fridges, mobile phone charging service and small soldering machines. To these stores, 12 hours of electricity per day is supplied and different tariffs apply.

The following tables summarize the loads and tariffs for these shops.

No	Hours of supply	Computer and LCD monitor (100 W)	Printer (100 W peak and 10 W stand by)	Small soldering machine (500 W peak)	Mobile phone charging (100 W)	Fan (60 W)	CFL (30 W)	Fridge (300 W)
1	12	1	1		1	1	1	
2	12	1	3	1		1	1	
3	12	1	1			2	2	
4	12	1	2			1	1	
5	12	1			1			
6	12	1	2	1		1	1	
7	12	1			1	1	1	1

Table 19. Shops loads in Mahdopur and Harihalpur market (2014)

The peak load and energy consumption for each electrical appliance was obtained from the Lawrance Berkeley National Laboratory data, and presented on the first section of this report.

No	Daily payment (INR/ day)	Monthly payment (INR per month)	Total peak load (KW)	Average daily units consumed (KWh)	Unit cost (INR per KWh)
1		3,000.00	0.39	3.65	₹ 27.40
2		3,000.00	0.54	2.84	₹ 35.21
3		3,000.00	0.38	3.53	₹ 28.33
4		3,000.00	0.39	2.62	₹ 38.17
5	60.00		0.2	2.4	₹ 25.00
6	90.00		0.44	2.67	₹ 33.71
7	90.00		0.29	3.48	₹ 25.86

Table 20. Shops tariff in Mahdopur and Harihalur market (2014)

From this data and knowing the amount paid by the shop owners, the cost per KWh of electricity was obtained for each case. On average, each shop pays INR 30.53 per KWh. Nonetheless, the shop owners are not aware of the unit price, since a packaged and affordable service is presented to them. Another important remark is that the DG operator charges the same amount for different loads, and cross subsidizes them in order to obtain a profit.

Figure 11. Studio and mobile phone repairing in Mahdopur and Harihalpur market (2014)

These types of customers can be considered as productive loads, since business are being served and can exist thanks to the electricity provided. Since they are generating an income from the electricity consumed, they have the willingness to pay for it and also the ability. This creates a sustainable business for the consumer and the provider of electricity.

The market on Mahdopur and Harihalpur is a clear example of how electricity boosts and sustains economic activities.

4.3. **Key findings**

A total of ten interviews were performed to DG operators for households and market areas in Araria, Gopalganj and Supaul. The summary of those interviews can be found below.

	Village	Mahmudpur	Reotith	Hardiya	Kiratpura	Matiyari
HH	Connections	0	0	0	0	95
	Load provided (W)	0	0	0	0	Up to 20 W
	Hours of service	0	0	0	0	3
	Payment (INR)	0	0	0	0	125
	Electricity price (INR/KWh)	₹ -	₹ -	₹ -	₹ -	₹ 69.44
Shops	Number of connections	45	120	70	35	130
	Load provided (W)	15 W CFL plus fan	15 W CFL	15 W CFL	15 W CFL	Up to 20 W
	Hours of service	7	2.5	3	3	3
	Payment (INR)	25 per day	6 per day	6 per day	7 per day	125 or 2 L of kerosene
	Electricity price (INR/KWh)	₹ 47.62	₹ 160.00	₹ 133.33	₹ 155.56	₹ 69.44
Productive loads	Number of connections	12	0	0	0	0
	Load provided (W)	Up to 500 W	0	0	0	0
	Hours of service	7	0	0	0	0
	Payment (INR)	100 per day	0	0	0	0
	Electricity price (INR/KWh)	₹ 28.57	₹ -	₹ -	₹ -	₹ -
Other	Number of connections	2	20	0	0	0
	Load provided (W)	Up to 2.5 KW	Up to 100 W	0	0	0
	Hours of service	6.5	2.5	0	0	0
	Payment (INR)	12500 per month	10	0	0	0
	Electricity price (INR/KWh)	₹ 25.64	₹ 40.00	₹ -	₹ -	₹ -
Total Load served (KW)		14.375	3.8	1.05	0.525	4.5
Total KWh provided (KWh/day)		98.125	9.5	3.15	1.575	13.5
Total income per month		₹ 94,750.00	₹ 27,600.00	₹ 12,600.00	₹ 7,350.00	₹ 28,125.00
Weighted Average selling Price (INR/KWh)		₹ 43.61	₹ 142.86	₹ 133.33	₹ 155.56	₹ 69.44

Table 21. Load, way of charging, electricity price and energy provided by the DG operators serving markets (2014)

Regarding markets, Table 21 shows the size and type of loads served by each DG operator. Most of them provide just lighting, like the ones in Hardiya, Kiratpura and Matiyari; this service has an average price of INR 5.80 per day or INR 130 per KWh. Besides lighting, the use of fan is also on demand in the markets of Reotith and Mahmudpur, having an average price of INR 43.81 per kWh. The operator of Mahmudpur has higher loads connected, including photo and printing studios, mobile phone repairing shops, fridges, and even banks, having an weighted average selling price of INR 43.61 per kWh, the lowest price found on markets. It can be noted that the DG operators that provide lighting have very similar selling prices per kWh and tariffs; the price per kWh is reduced when productive loads are served.

Village	Mahmudpur	Reotith	Hardiya	Kiratpura	Matiyari
Fuel used	Diesel	Diesel	Kerosene and diesel (30/70 mix)	Diesel	Diesel
Fuel consumption per month (L)	1075	240	112.5	90	160
Cost of fuel (INR/L)	₹ 60.00	₹ 61.00	₹ 54.70	₹ 61.00	₹ 62.50
Total expenditure on fuel (INR/month)	₹ 64,500.00	₹ 14,640.00	₹ 6,153.75	₹ 5,490.00	₹ 10,000.00
Maintenance cost (INR/month)	₹ 1,875.00	₹ 450.00	₹ -	Unknown	₹ -
Expenditure on oil (INR/month)	Included in maintenance	₹ 1,200.00	₹ 600.00	Unknown	₹ -
Number of employees	0	0	0	0	1
Salary for employees (INR/month)	₹ -	₹ -	₹ -	₹ -	₹ 2,000.00
Total expenses (INR/month)	₹ 66,375.00	₹ 15,090.00	₹ 6,153.75	₹ 5,490.00	₹ 12,000.00
Total profit (INR/month)	₹ 28,375.00	₹ 12,510.00	₹ 6,446.25	₹ 1,860.00	₹ 16,125.00
Expenses/revenue	70%	55%	49%	75%	43%
Generation cost (INR/KWh)	₹ 22.55	₹ 52.95	₹ 65.12	₹ 116.19	₹ 29.63
Margin (INR/KWh)	₹ 21.06	₹ 89.91	₹ 68.21	₹ 39.37	₹ 39.81
Connection fee (INR)	₹ -	₹ -	₹ -	₹ -	₹ -
CAPEX on grid (INR)	Unknown	Unknown	Unknown	Unknown	Unknown
Size of DG (KVA)	62.5	15	6	5	5
CAPEX for DG	**₹ 830,000.00**	**₹ 60,000.00**	**₹ 15,500.00**	**₹ 35,000.00**	**₹ 50,000.00**

Table 22. Expenses and profit for each of the DG operators serving markets (2014)

It can be noticed in Table 22 that most of the DG operators in markets use diesel as a fuel, with the one in Hardiya as an example, who uses a 30/70 mix of kerosene and diesel. The maintenance costs are very different among them; most of them claim that they handle maintenance of the machines themselves and just the cost of oil is accounted. Their generation cost is also very variable since they run their gensets at different loads, and because their tariff is very similar, their margin ranges from INR 21 to INR 90 per kWh. Thus, providing an average of these values would provide the wrong idea. Notwithstanding, the relationship between expenses and income can be averaged to 58% showing that the operators are not aware of their generation or selling price, while they provide a competitive and affordable tariff and they collect the amount of money expected at the end of the day. This will just be affected by the number of loads. With more loads connected the higher income.

	Village	Bheldi	Chakkai 1	Lahtora	Lokhariya	Mahdopur
HH	**Number of connections**	325	300	150	250	250
	Load provided (W)	Up to 15 W CFL	11 W CFL plus mobile charging point (up to 20 W)	Up to 12 W CFL	11 W CFL plus mobile charging point (up to 20 W)	5 W to 35 W CFL (20 W on average)
	Hours of service	3.5	3.5	3.5	3	4
	Payment	100 per month	100 per month	2 L of kerosene per month	100 or 2 L of kerosene per month	80 or 2 L of kerosene per month
	Electricity price (INR/KWh)	₹ 63.49	₹ 47.62	₹ 63.49	₹ 55.56	₹ 33.33
Total Load served (KW)		4.875	6	1.8	5	5
Total KWh provided (KWh/day)		17.06	21	6.3	15	20
Total income per month		₹ 32,500.00	₹ 30,000.00	₹ 12,000.00	₹ 25,000.00	₹ 20,000.00
Weighted Average selling Price (INR/KWh)		₹ 63.49	₹ 47.62	₹ 63.49	₹ 55.56	₹ 33.33

Table 23. Load, way of charging, electricity price and energy provided by the DG operators serving households (2014)

Table 23 shows the number of households served and the loads provided by each DG operator. All of the DG operators charge on a monthly basis and accept cash or kerosene at an equivalent of INR 94, on average. They provide lighting for typically 3.5 hours and usually allow the use of a mobile phone charging device at an average electricity price of INR 52.70. The DG operator of Mahdopur has the lowest selling price, since he provides more hours of electricity and charges less. Their monthly income is mostly dependant on the number of connections, since they charge very similar rates.

Village	Bheldi	Chakkai 1	Lahtora	Lokhariya	Mahdopur
Fuel used	Diesel	Kerosene	Kerosene	Kerosene	Kerosene and diesel
Fuel consumption per month (L)	315	168	157.5	180	180
Cost of fuel (INR/L)	₹ 61.00	₹ 40.00	₹ 45.00	₹ 50.00	₹ 50.00
Total expenditure on fuel (INR/month)	₹ 19,215.00	₹ 6,720.00	₹ 7,087.50	₹ 9,000.00	₹ 9,000.00
Maintenance cost (INR/month)	₹ 1,000.00	₹ 3,360.00	₹ 500.00	₹ 250.00	₹ 500.00
Expenditure on oil (INR/month)	₹ 1,800.00	Included in maintenance	Included in maintenance	₹ 595.00	₹ 750.00
Number of employees	0	0	0	0	0
Total expenses (INR/month)	₹ 20,215.00	₹ 10,080.00	₹ 7,587.50	₹ 9,845.00	₹ 10,250.00
Total profit (INR/month)	₹ 12,285.00	₹ 19,920.00	₹ 4,412.50	₹ 15,155.00	₹ 9,750.00
Expenses/revenue	62%	34%	63%	39%	51%
Generation cost (INR/KWh)	₹ 39.49	₹ 16.00	₹ 40.15	₹ 21.88	₹ 17.08
Margin (INR/KWh)	₹ 24.00	₹ 31.62	₹ 23.35	₹ 33.68	₹ 16.25
Connection fee (INR)	₹ -	₹ 100.00	₹ -	₹ -	₹ -
CAPEX on grid (INR)	Unknown	Unknown	Unknown	₹ 4,000.00	₹ 12,250.00
Size of DG (KVA)	8	5	6	6	8
CAPEX for DG	₹ 35,000.00	₹ 5,000.00	₹ 8,000.00	Unknown	₹ 10,000.00

Table 24. Expenses and profit for each of the DG operators serving households (2014)

Most of the DG operators serving households use kerosene as fuel to run their gensets. In the case that they accept kerosene as payment, they use this to power their DG and reduce their fuel expenditure. The expenditure on fuel is linked to the size of the DG, bigger systems require more fuel. In spite of that, the load served is not related – in some cases more households are served with smaller gensets, resulting in the differences in generation costs. This means that the economics of the DG operators serving households is highly affected by the number of connections. The lowest ratios for expenses into revenues are found in Chakkai and Lokhariya, where the number of connections is high and the maintenance cost is low, since they do it on their own. On average, DG operators serving households get a margin of INR 25 per kWh.

For both types of electricity consumers (shops and households), it can be seen that neither the DG operator nor the customer is aware of the generation or selling price of electricity. The DG operator just makes sure that he is providing an affordable price and that he gets some profit at the end of the month. The amount of the expected profit is variable, and they see it as an extra income, since this is just a side business for them. The DG operators for markets are usually also the owners of one of the shops, and the ones for households are usually farmers. On the other hand, the customers are just expecting to get the service offered on the package and a tariff they can afford. They are not aware that they pay up to 30 times the price for grid electricity per kWh.

Other key findings from the interviews highlighted the lack of robustness of the grids used. The absence of regulations over the quality and safety of the grid built by the DG operator has resulted in lack of reliability and accidents that had endangered the villagers' life. When this occurs, the DG operator is obliged to stop providing the service. On the other hand, some DG operators have to rebuild the grid regularly due to weather conditions, increasing their cost and forcing them to leave the business. These two problems emphasize the need for a safer and more robust grid in order to serve the end consumers properly.

5. Proposed System's Design

First, a study of the solar irradiation in Bihar is presented which is required to design the solar PV systems. It was found out during the surveys that the DG operators are currently serving two types of loads (households' loads and markets' loads). Therefore, two different load models were proposed and a solar PV system to cater each one was designed (households' system and markets' system). Later, a package to estimate the costs and income for each type of load is presented in the Financial Model chapter.

5.1. Solar Irradiation

Since a standardized system is required, meteorological data that suits most of the locations is required. As known, solar irradiation, temperature, wind speed, and other parameters vary depending on location. Nevertheless, for this project one particular district of India was chosen – Bihar, so the area was determined and it limits the variability of weather data. To ensure this, five villages from the 95 surveyed were chosen randomly and their irradiation values were compared.

Month	Rajapatti (kWh/m²)	Matiari (kWh/m²)	Sukha Nagar (kWh/m²)	Itahara (kWh/m²)	Darhua (kWh/m²)	Average (kWh/m²)	Difference to mean (%)	Minimum (kWh/m²)
January	100.4	109.4	108.6	108.6	103.4	106.08	4%	100.4
February	136.4	133.1	133.1	133.1	133.1	133.76	1%	133.1
March	192	174.1	180	180	185.3	182.28	4%	174.1
April	198	172.1	182.2	182.2	190.8	185.06	5%	172.1
May	215	192.7	197.9	197.9	205.3	201.76	4%	192.7
June	172.8	146.9	156.2	156.2	160.6	158.54	6%	146.9
July	144.3	142.1	143.6	143.6	145.1	143.74	1%	142.1
August	143.6	140.6	145.1	145.1	142.1	143.3	1%	140.6
September	144	141.8	143.3	143.3	142.6	143	1%	141.8
October	151	139.9	145.1	145.1	147.3	145.68	3%	139.9
November	127.4	129.6	131	131	124.6	128.72	2%	124.6
December	115.3	130.2	130.2	130.2	120.5	125.28	6%	115.3
Yearly	**1840.3**	**1752.4**	**1796.3**	**1796.3**	**1800.6**	**1797.18**	**2%**	**1752.4**

Table 25. Solar irradiation for different villages in Bihar (2014) [18]

It can be seen that the percentage of standard deviation among the different locations is very low, with 6% as the maximum value. This means that solar irradiation is not that variable across Bihar, and a standardized system can be proposed. The minimum value for solar irradiation was also identified, for ensuring a reliable service the system was designed for the lowest values. It can be seen that during most of the year, Matiari has the lowest solar irradiation. Therefore, the design and simulation will be performed for this location.

5.2. **Load Model**

5.2.1. Households' Load

From the interviews made, it was concluded that villagers are willing to pay for lighting and mobile phone charging, and that the DG operators have around 250 connections. Usually, DG operators provide 3 to 3.5 hours of service, but in order to give an added value to the service, 4 hours of lighting will be offered. Therefore, the system for serving households considers the following load.

Load definition	**Load size**
Lighting (1 Light Emitting Diode (LED) bulb)	5 W
Mobile phone charging	5 W
Total load per household	10 W
Number of connections	250
Total load	**2 500 W**
Hours of service per day	4 h
Total energy supplied per day	**10 000 Wh**

Table 26. Loads and total energy supplied for households (2014)

5.2.2. Markets' load

In markets, lighting is required for the evening hours. One lighting point and mobile charging is proposed to be given for each shop.

Load definition	Load size
Lighting (1 LED bulb)	5 W
Mobile phone charging	5 W
Total load per shop	10 W
Number of connections	50
Total load	**500 W**
Hours of service per day	4 h
Total energy supplied per day	**2 000 Wh**

Table 27. Lighting load and energy supplied for shops (2014)

In addition, since productive loads want to be served, the system for serving markets includes the possibility to power printing studios, mobile repairing shops or shops with fridges. Table 19 shows that the typical load in this kind of micro-enterprises (MEs)[2] was 300 W (not considering lighting and fan). Therefore, the system was designed to provide a peak load of 300 W for each ME. The next table presents different options of the loads that could be connected for different types of businesses.

[2] For the purpose of this study, the businesses requiring just lighting loads are called shops and the ones requiring power for productive loads are called micro-enterprises (MEs).

Load definition	Load size
Option 1	
One desktop with LCD monitor	100 W
One printer	100 W
Mobile phone charging[3]	100 W
Option 2	
One desktop with LCD monitor	100 W
Two printers	200 W
Option 3	
One desktop with LCD monitor	100 W
One printer	100 W
Soldering machine	50 W
Fan	50 W
Option 4	
Fridge	300 W
Total load per shop	300 W
Number of connections	5
Total load	**1 500 W**
Hours of service per day	12 h
Total energy supplied per day	**18 000 Wh**

Table 28. Loads served and total energy supplied for micro enterprises (2014)

[3] Assuming that they provide the service of charging mobile phones to up to 20 customers at a time.

Therefore, the markets' system should supply 20 000 Wh per day to comply with the shops' and MEs' demand.

No transmission losses were considered in the calculation of the loads. As shown in the Appendix (11.2.1), the voltage drops are around 1%, which is considered negligible. Furthermore, these loads are peak values estimated from the surveys and what was seen on ground. The exact consumption over time is not known.

5.3. **Components Specifications and Cost**

The components' specifications and cost were obtained from the Technology and procurement guide realized by the SPEED technology team of cKinetics. This document provides the required information about products available in India with up to date prices. The data sheets with the specifications can be found in the Appendix (11.2.2).

The sizing of the system was done using PVsyst 6.2.2., a software available online that includes a big database of meteorological records for various locations and technical specifications of different components. In this case, the meteorological data of Matiari, the loads described in the previous section and the components from the Technology and procurement guide were used as input data. The software allows making simulations of the performance of the system over one year, for stand-alone, grid tied, DG grids and solar pumping projects. The option of modelling an AC stand-alone micro-grid was not available, so the stand-alone option was chosen and the inverter was considered separately. The following figure shows a simplified model of stand-alone systems.

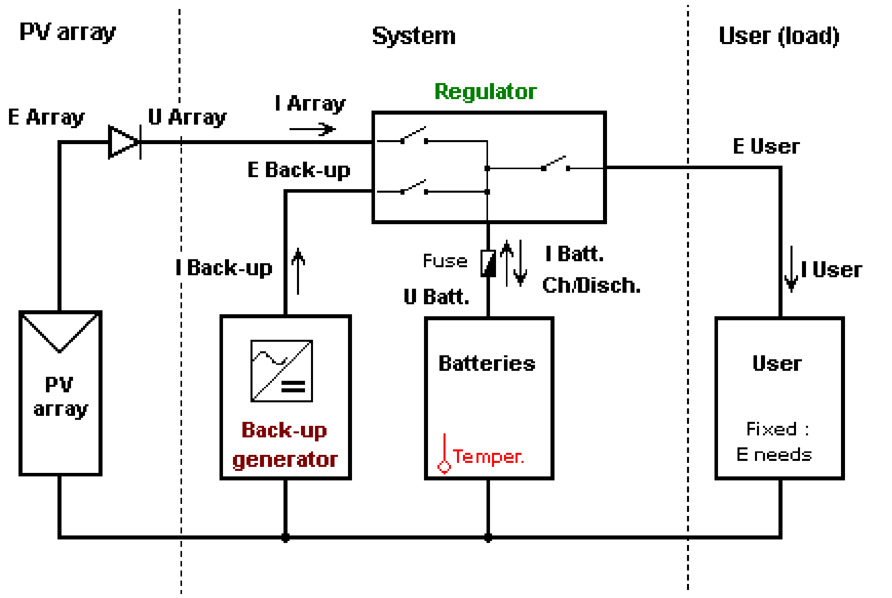

Figure 12. Simplified model for stand-alone PV systems (PVsyst)

The results from the sizing of the system for each package are presented on the next tables and figures.

Component	Model	Manufacturer	Rated capacity	Quantity required	Price per unit	Total price
Solar panel	ELV 280	Vikram solar	280 W	15	₹ 10,920.00	₹ 163,800.00
Batteries		Quanta	12 V 100 Ah	32	₹ 6,700.00	₹ 214,400.00
Charge controller	FM 60	Outback	60 A	1	₹ 29,185.00	₹ 29,185.00
Inverter	GFX 3048E	Outback	3.5 KW	1	₹ 85,800.00	₹ 85,800.00
Total			**4.2 KW**			**₹ 493,185.00**

Table 29. Households' system sizing and pricing (2014)

The households' system requires 15 panels (2 in series and 6 in parallel) for a total peak capacity of 4.2 KW. It requires 800 Ah of storage at a 48 V (32 batteries, 4 in series and 8 in parallel). The system was modelled in order to have the lowest loss of supply probability, which led to an over sizing of the system in order to serve the demand even during July and August, when the availability of solar energy is at its lowest. The other option was to increase the storage capacity, but after some tryouts it became clear that it was more expensive and less efficient than increasing the size of the PV system. Having more storage and less PV capacity had a price of around INR 140 per W and a loss of load probability of up to 15% during June, July and August; while a bigger PV system and less storage has a cost of INR 117 per W and a loss of load probability around 10% during August and 2% in July. Another important remark is that the inverter seems undersized; however, when talking to the providers they stated that the inverter capacity can be even 80% of the PV array capacity.

Component	Model	Manufacturer	Rated capacity	Quantity required	Price per unit	Total price
Solar panel	ELV 280	Vikram solar	280 W	24	₹ 10,920.00	₹ 262,080.00
Batteries		Quanta	12 V 100 Ah	40	₹ 6,700.00	₹ 268,000.00
Charge controller	FM 80	Outback	80 A	1	₹ 66,170.00	₹ 66,170.00
Inverter	GFS 7048E	Outback	7 KW	1	₹ 214,305.00	₹ 214,305.00
Total			**6.72 KW**			**₹ 810,555.00**

Table 30. Markets' system sizing and pricing (2014)

The markets' system requires 24 panels (4 in series and 6 in parallel) for a total peak capacity of 6.72 KW. It requires 1000 Ah of storage at 48 V (40 batteries, 4 in series and 10 in parallel). This design has a loss of load probability of 15% during August and 7% in July. Also for this system, it was trialled what is more economically feasible, increasing the capacity of the PV system or storage. As in the previous case, reducing the size of the system and increasing the storage (5.6 kW and 1200 Ah) augmented the missing energy to up to 19% in August, 18% in July and 8% in June without reducing the price.

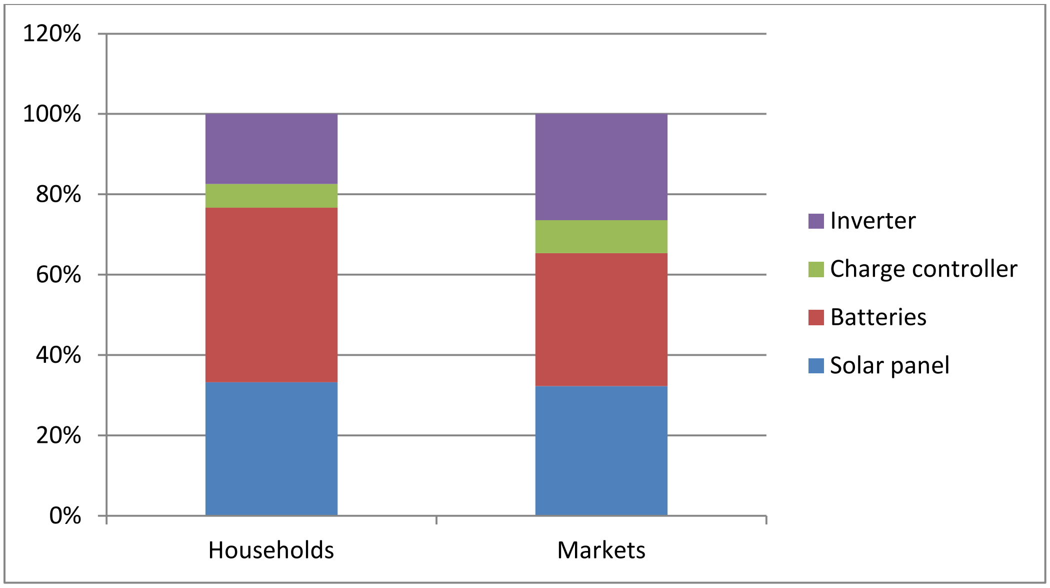

Figure 13. Cost break-up for each system (2014)

The previous figure shows the cost break-up for each system, the analysis was done using percentages to make it easier to compare. For the households' system, the batteries are the most expensive components –up to 43% of the total cost. The households' system requires a higher storage capacity per KW installed, since its demand is during the evening hours. On the other hand, the electronic components (inverter and charge controller) represent a higher cost per watt to the markets' system than to the households' system.

5.4. Simulation Results

A one year simulation (year 1991) with hourly meteorological data from Matiari was made using PVsyst. The most important results of the simulation, regarding energy use and efficiency of the systems, will be discussed.

Figure 12 shows the available solar energy for Matiari, it can be seen that it is very variable along the year. Table 25 presented the values for horizontal global irradiation for the same village, showing that the values are higher from March to May, which doesn't match with the trend for the available solar energy presented below.

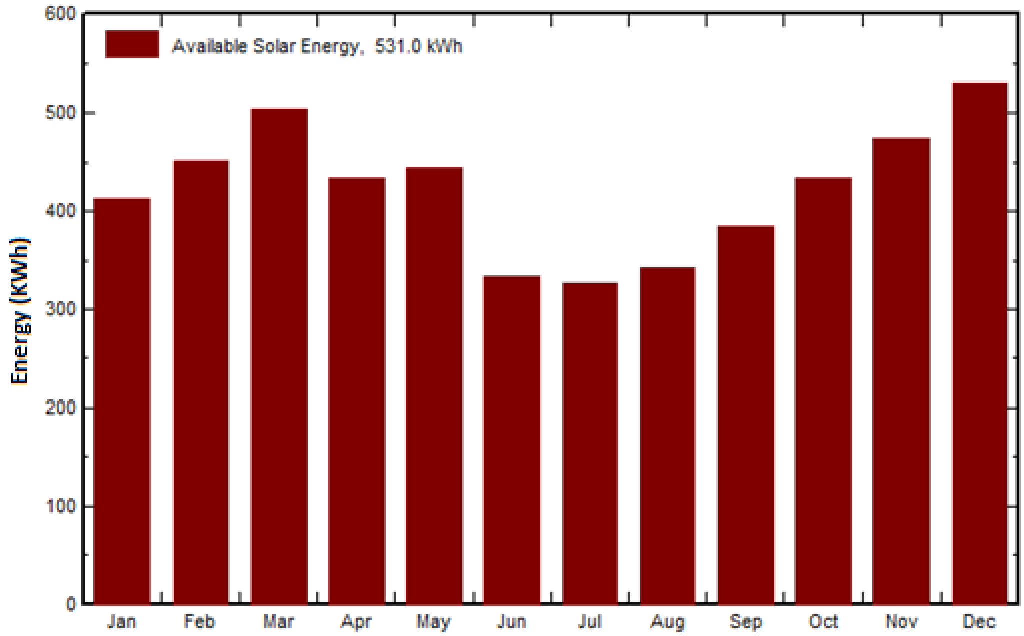

Figure 14. Available solar energy in Matiari [18]

The difference in the trends can be explained looking at Figure 15. It shows the horizontal beam and diffuse irradiation along the year. The global irradiation is the sum of the beam and diffuse irradiation. Therefore, even though the beam irradiation is low during April and May, the diffuse irradiation is high, making the global irradiation high. However, since PV systems use primarily beam irradiation for generating electricity, the available solar energy is lower than expected for those months. The same happens during June, July and August, when the diffuse irradiation is higher due to the rainy season (monsoon). This reduces significantly the available solar energy.

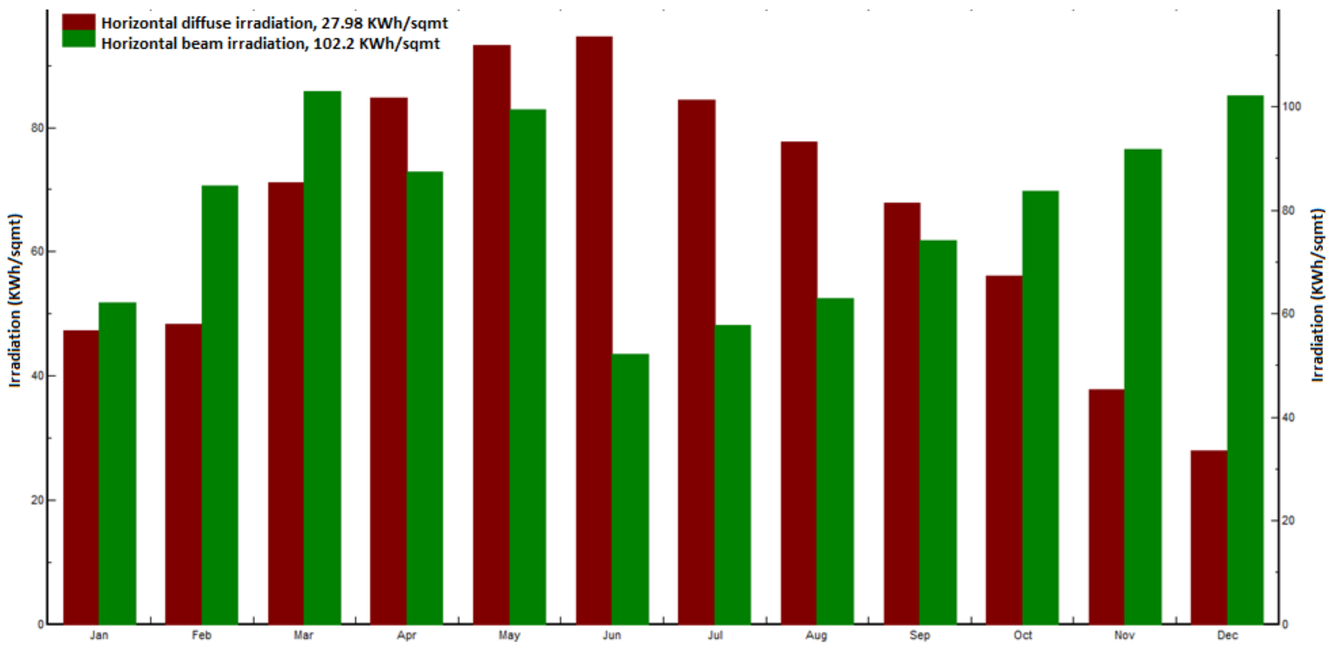

Figure 15. Horizontal diffuse and beam irradiation along the year [18]

5.4.1. Households' System

Table 31 summarizes the results of the simulation for the households' system. The high variation of the amount of available solar energy led to the over sizing of the system in order to supply all of the demand, and therefore the amount of unused energy is high (2599.1 KWh per year); almost 70% of the energy required by the user (3617.9 KWh per year). Due to the poor efficiency and high price of current storage technology, over sizing the system is the most economical solution, at the cost of more unused energy along the year. In an off-grid system as this, where the reliability has to be maintained in order to keep the trust of the end consumer, the demand should be met at all time, even at a higher cost. As a second phase of this project, new loads that can be served during the day could be found in order to reduce the amount of unused energy and increase the revenues.

Regarding the missing energy, the demand is not completely met during July and August, having 2.78 and 29.28 KWh of missing energy respectively. For these months, instead of increasing the size of the system or storage, it is recommended to implement some demand side management strategies to cope with the demand, since the amount of missing energy is very low. Reaching agreements with the customer in order to reduce the consumption during July and August in exchange of extra energy in other months, could be one alternative. Furthermore, it is important to remark that this simulation was performed using the meteorological data for a particular year (1991) and thus can vary from year to year. The last column shows the solar fraction that is the ratio of the energy required by the user into the energy provided by the solar PV system. It can be seen that in all the months, except from July and August, all the demand can be supplied by the solar PV system.

	Available solar energy	Unused energy	Missing energy	Energy provided to the user	Energy required by the user	Solar fraction
	kWh	kWh	kWh	kWh	kWh	
January	574.5	208.5	0	310	310	1
February	613.4	276.4	0	280	280	1
March	694.7	320.1	0	310	310	1
April	594.9	234.2	0	300	300	1
May	609.3	237.6	0	310	310	1
June	450.1	95.3	0	300	300	1
July	439.3	87	2.78	307.2	310	0.991
August	452.9	115.6	29.28	280.7	310	0.906
September	515.3	159.8	0	300	300	1
October	572.3	213.5	0	310	310	1
November	643.4	274.1	0	300	300	1
December	749.5	377.1	0	310	310	1
Year	**6909.6**	**2599.1**	**32.06**	**3617.9**	**3650**	**0.991**

Table 31. Households' system simulation results (2014)

Figure 16 shows the comparison between the energy need of the user and energy supplied to the user in a graphic way for easier understanding.

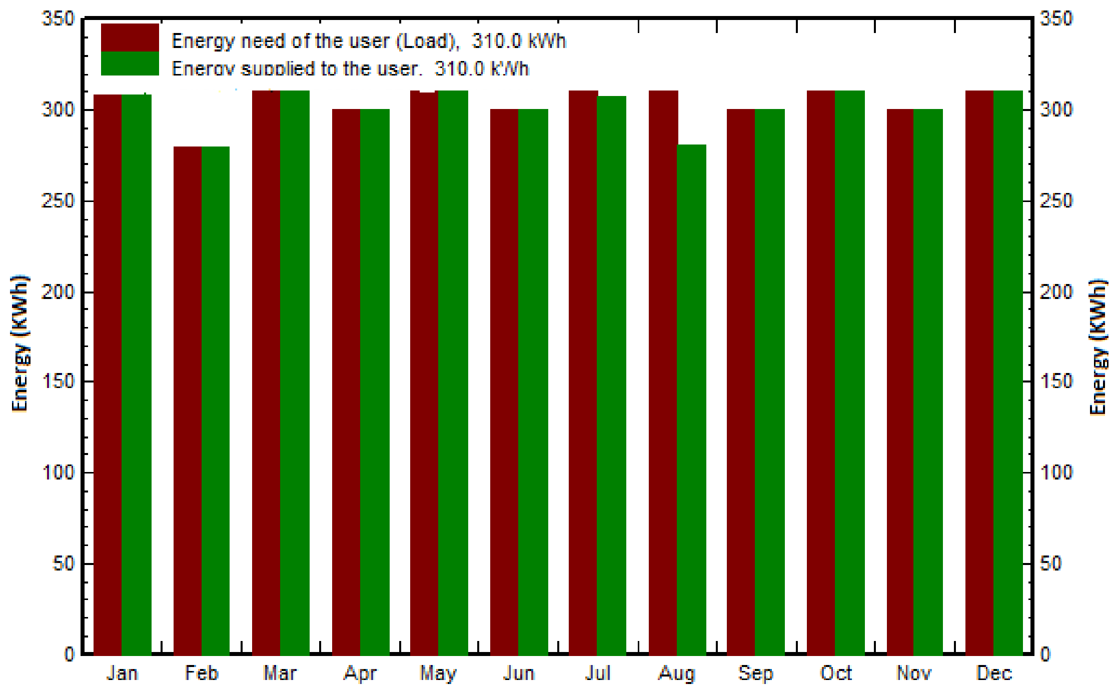

Figure 16. Energy need and supplied to the user along the year for the households' system (PVsyst)

The state of charge of the batteries was also simulated; it is between 65% and 85% most of the year, except in July and August, when the available solar energy is less and therefore the batteries are deeper discharged. The fact that the batteries are not deeply discharged the rest of the year enlarges their useful life.

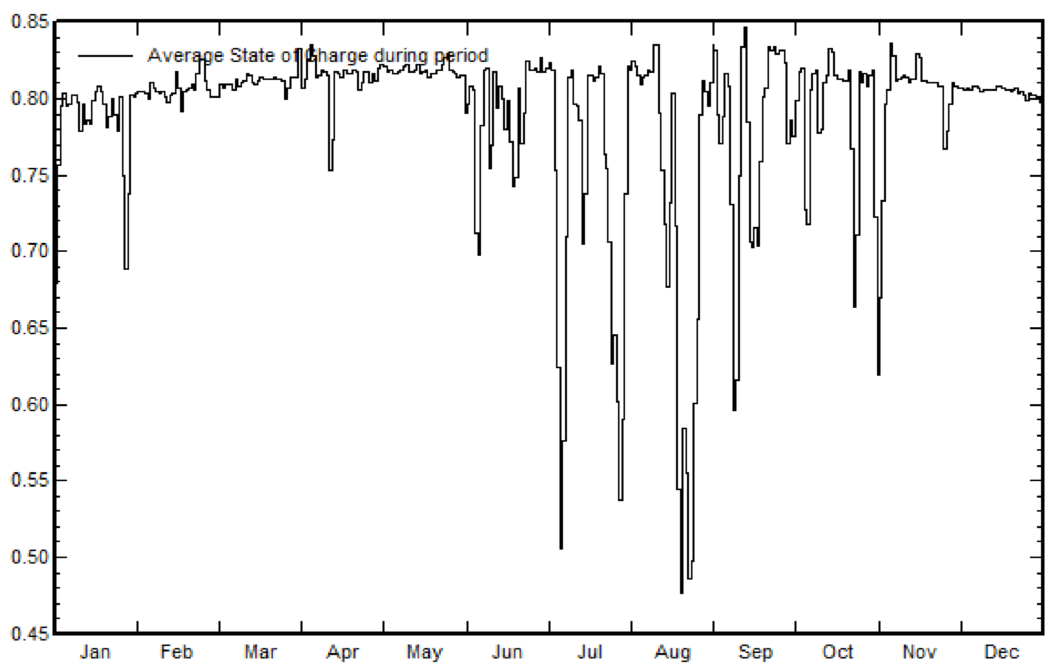

Figure 17. Average batteries' state of charge for the households' system (PVsyst)

5.4.2. Markets' System

The following table provides a summary of the markets' system simulation results.

	Available solar energy	Unused energy	Missing energy	Energy provided to the user	Energy required by the user	Solar fraction
	kWh	kWh	kWh	kWh	kWh	
January	888	210.4	0	620	620	1
February	1075	461.2	0	560	560	1
March	1309	626.4	0	620	620	1
April	1104	447.2	0	600	600	1
May	1147	473.4	0	620	620	1
June	723	76.8	0	600	600	1
July	734	103.1	27.72	592.3	620	0.955
August	810	225.2	84.23	535.8	620	0.864
September	908	270.3	0	600	600	1
October	1064	406.8	0	620	620	1
November	1166	486.7	0	600	600	1
December	1295	611.5	0	620	620	1
Year	**12224**	**4399.1**	**111.94**	**7188.1**	**7300**	**0.985**

Table 32. Markets' system simulation results (PVsyst)

In this case, the energy provided to the user is more than the unused energy since there are loads being served during the day and thus taking advantage of the solar energy while it is available. Therefore neither the PV system nor the storage capacity has to be greatly over size like in the households' case. However, some energy is missing to serve all the loads, due to the low solar energy available in July and August. Since increasing the size of the system or the storage capacity is not economical, demand side management strategies should be implemented. On the other hand, as in the households' system, new loads that can be served during the day should be found to reduce the amount of unused energy.

The next figure, Figure 18, shows the mismatch between energy required and supplied to the user by the system along the year.

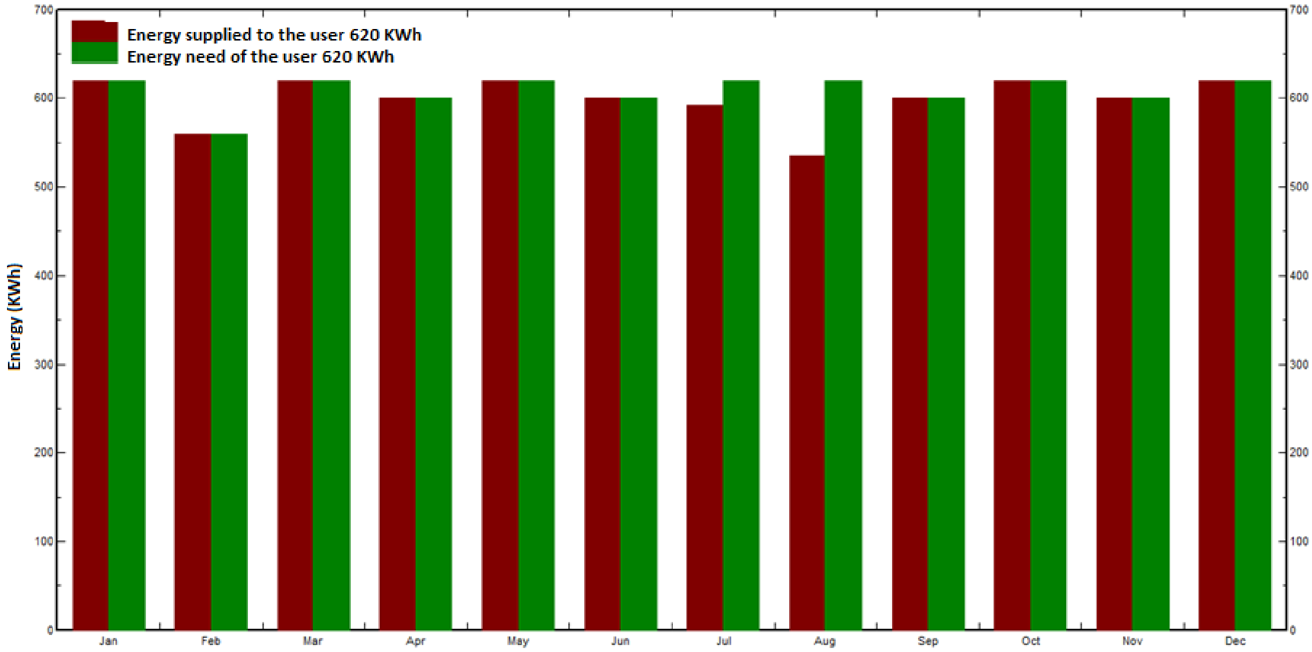

Figure 18. Energy needed and supplied to the user by the markets' system (PVsyst)

As in the previous case, the batteries are deeper discharged during July and August due to the lesser amount of solar energy available. Nevertheless, for this system the surge on state of charge is not only in those months. This demonstrates that the system is not highly oversized just to cope with the July's and August's demand.

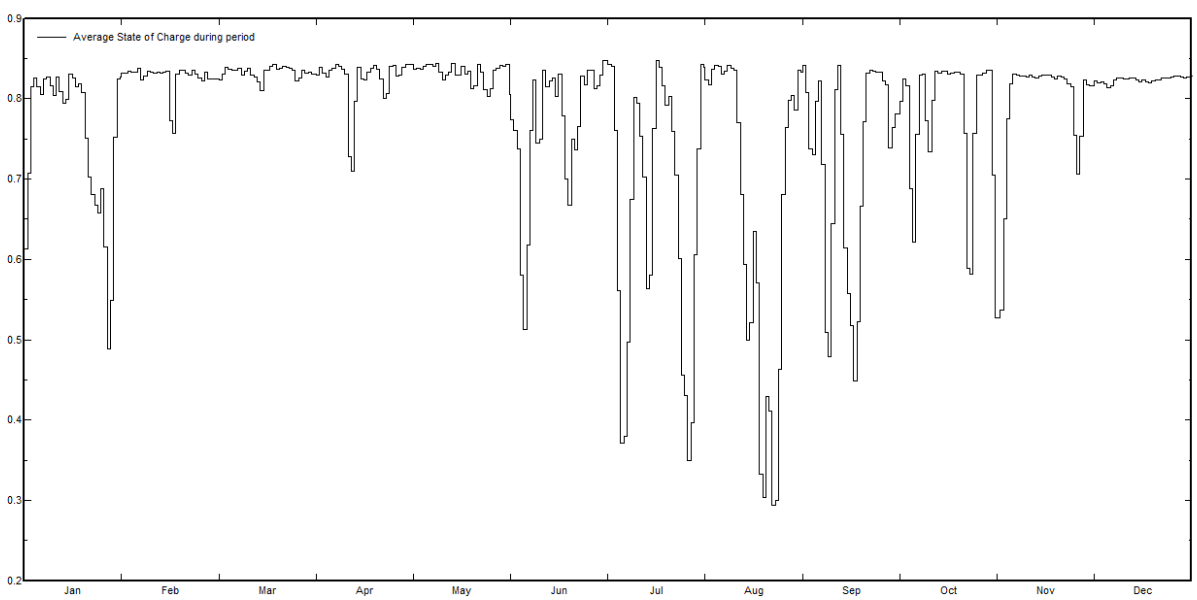

Figure 19. Average batteries state of charge for the markets' system (PVsyst)

Other costs for the commissioning and operation of each system are:

Description	Cost per KW (INR)	
Engineer, procurement and construction (Civil & Electrical)	₹	21,000.00
Structure cost	₹	8,000.00
Land lease per year	₹	792.00
Equipment maintenance per year	₹	2,000.00

Table 33. Other costs for the commissioning and operation of solar PV systems [19]

Battery replacement is another cost that should be bared during the lifetime of the system. In the Financial Model Chapter it is shown that batteries will be replaced every 4 years.

5.5. **Micro-grid Design and Costing**

For the micro-grid design and costing, the data and model of the Power Plant Economics (PPE) Tool realized by the SPEED technology team of cKinetics was used. The table below shows the characteristics and quantity of the components required. The cost of each component was provided by TARA (2014), one of the SPEED partners; the quotations are attached in the Appendix section (11.2.3). It is important to remark that this design and costing does not include the wiring and installations inside the households or shops, and should be done by the end-user.

	Specifications/Description	Unit of Measure	Rate per Unit
Poles	Each at a distance of 40 meters		1,800.00 ₹
3 core x 25 mm^2 XLPE Coated Aluminium Cables	40 meters per pole plus 5% extra	Meter	79.05 ₹
2 Core x 2.5 mm^2 XLPE Coated Aluminium Cables	20 meters per connection	Meter	7.08 ₹
Distribution Boxes	One per pole		868.54 ₹
MCB's and accessories	One per pole		116.03 ₹
Labour Charge:			
• **Erection, support and connection**	One per pole		1,300.00 ₹
• **Earthing**		Per micro-grid	1,100.00 ₹
Clamp and Miscellaneous:			
• **I-Bolt**	One per pole	Piece	68.25 ₹
• **Dead End Clamp**	Five per project	Piece	78.75 ₹
• **Suspension Clamp**	One per pole	Piece	57.75 ₹
• **Piercing Connector**	One per pole	Piece	47.25 ₹
• **Stay Wire**	10 meters per project	Per meter	50.00 ₹
• **DB Clamp**	One per pole	Piece	60.00 ₹
• **Connector**	Two per DB	Piece	12.00 ₹
• **Connection wire**	One meter per DB		15.00 ₹
• **Miscellaneous Items**		Per pole	20.00 ₹

Table 34. Components' specifications and cost for micro-grid design (2014)

Assuming that the villages or markets are dense and that 10 connections can be done per pole, the total micro-grid cost for each system was calculated and is presented in Table 35.

	Quantity for households' system	Cost for households' system	Quantity for markets' system	Cost for markets' system
Poles	25	**45,000.00 ₹**	6	**10,800.00 ₹**
4 core x 25 mm^2 XLPE Coated Aluminium Cables	1050	**82,997.52 ₹**	252	**19,919.41 ₹**
2 Core x 2.5 mm^2 XLPE Coated Aluminium Cables	5000	**35,393.40 ₹**	1100	**7,786.55 ₹**
Distribution Boxes (DB)	25	**21,713.57 ₹**	6	**5,211.26 ₹**
Miniature Circuit Breakers (MCB) and accessories	25	**2,900.83 ₹**	6	**696.20 ₹**
Labour Charge:				
• **Erection, support and connection**	25	**32,500.00 ₹**	6	**7,800.00 ₹**
• **Earthing**	1	**1,100.00 ₹**	1	**1,100.00 ₹**
Clamp and Miscellaneous:				
• **I-Bolt**	25	**1,706.25 ₹**	6	**409.50 ₹**
• **Dead End Clamp**	5	**393.75 ₹**	5	**393.75 ₹**
• **Suspension Clamp**	25	**1,443.75 ₹**	6	**346.50 ₹**
• **Piercing Connector**	25	**1,181.25 ₹**	6	**283.50 ₹**
• **Stay Wire**	10	**500.00 ₹**	10	**500.00 ₹**
• **DB Clamp**	25	**1,500.00 ₹**	6	**360.00 ₹**
• **Connector**	50	**600.00 ₹**	12	**144.00 ₹**
• **Connection wire**	25	**375.00 ₹**	6	**90.00 ₹**
• **Miscellaneous Items**	25	**500.00 ₹**	6	**120.00 ₹**
Total cost		**229,805.33 ₹**		**55,960.66 ₹**

Table 35. Micro-grid costing for households' and markets' systems (2014)

It can be noticed that the micro-grid's total cost for the households' system is more than four times the cost for the markets' system. This is due the number of connections; the households' system serves 250 connections, while the markets' system serves 55. Having a smaller grid reduces the capital expenditure and has a big impact in the financial feasibility, as will be shown in the next chapter.

6. Business Model and Analysis

The franchising model proposed by cKinetics is based in a Business to Business (B2B) concept. It intends to support local entrepreneurs currently providing electricity through micro-grids to provide a more reliable, safe and clean service using solar PV systems.

In order to scale the market and overcome the current challenges being faced by renewable energy powered micro-grids, this model considers financial innovation and a standardized operating and technical model. The financial innovation would enable the conversion through the access to credit, since current DGs lack funds and bankability to afford a solar PV system. The standardization of the operating and technical construct would mitigate the operational risks and reduce the cost of components, attracting more investors [6].

The proposed franchise includes the following stakeholders:

- Master franchiser: Provides a hire-to-own facility to the franchisee and ensures the reliability of the system. For the pilot project, ckinetics will play the role of the franchiser.
- Franchisee: For the first stage of the project, the franchisee is the current DG operator. At a later stage, it could be a developer or ESCO managing a cluster of power plants.
- Plant operations

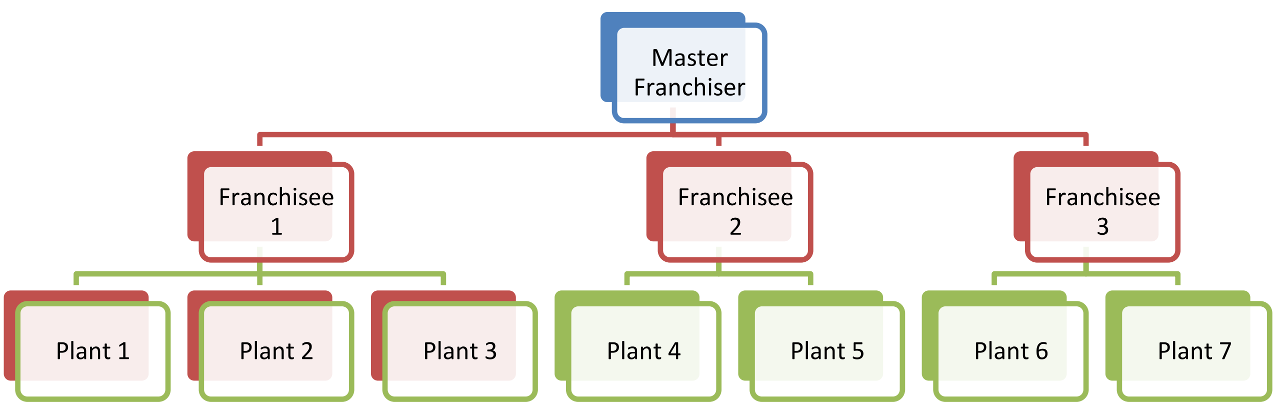

Figure 20. Stakeholders involved in cKinetics' franchising model [6]

The roles and responsibilities of each of the stakeholders should be clear and enforced in order to ensure the feasibility of the model.

Master franchiser	Franchisee
Provides a standardized system design and business model	Operates the plant
Provides training to the operator and maintains the system	Hires the asset paying a franchisee fee and owns it after 5 years
Enables access to debt and finance	Has a predefined revenue and operations model
Purchases the asset and lease it to the franchisee	Contributes equity capital

Table 36. Relationship between Master Franchiser and Franchisee (2014)

In the proposed model the franchiser acquires a debt to purchase the assets and lease them to the franchisee in exchange of a franchise fee. The franchisee should cover part of the investment (30%) and will be able to own the asset after 5 years. The franchiser should also provide operational handholding to the franchisee and maintenance to the system during the duration of the agreement. One important principle of this model is that it mimics the existing cash flows of the DG operators to ease their transition to solar PV systems.

6.1. Vision and Mission

6.1.1. Vision

"To be a trusted franchise for rural electrification that provides a reliable and affordable service at the same time that contributes to diminish carbon emissions and dependence on fossil fuels".

6.1.2. Mission

"Provide franchises that support local entrepreneurs to afford, operate and maintain solar PV systems in order to replace DGs currently serving micro grids in rural villages."

6.2. Business Model Canvas

6.2.1. Customer Segment

The customers for the franchisee model are DG operators that currently serve their own micro grid in rural villages of Bihar. They provide between 3 and 4 hours of electricity to approximately 250 households for lighting and mobile phone charging, or bigger loads for longer hours for shops in markets. They are entrepreneurs, aware of the advantages of solar PV systems and willing to take debt in order to own one. The customer has a regular monthly income and his current expenditure on fuel is higher than 6 liters per day for serving households or 9 liters for serving markets.

6.2.2. Value Proposition

- Lower operation costs: The fuel cost of a solar PV system is zero. Additionally, the maintenance costs are lower than the ones for a DG. After paying the system, the profits therefore increase substantially for the operator.
- Simplicity: A solar PV system is easier to operate than a DG. Furthermore, having the support from skilled technicians ensures that maintenance and any technical problem are solved in a simpler, faster and easier way.
- Reliability: Any technical problems can be solved fast and easy by the technicians that will be assigned for each site, this ensures the reliability of the supply for the end consumer and therefore the revenue streams for the franchisee. Furthermore, a more robust grid will be built to ensure the supply and its safety.
- Access to credit: The operator would be able to get finance to obtain ownership of an asset that otherwise would be out of reach for him. This increase in capital can support future entrepreneurial ideas.

6.2.3. Channels and Customer Relations

To have a first approach to the customer, engineers and consultants will meet DG operators and propose the franchisee scheme, explaining in detail all the aspects, advantages and risks included. If the deal is closed they will provide training to the operator (franchisee) on how to operate the system and troubleshooting. To ensure the reliability of the system, correct maintenance and fast technical problem solving, one technician will be assigned for each cluster of 15 franchisees. Each technician will be visiting regularly each of the sites of his cluster to guarantee good communication with the franchisee and correct operation of the system. Furthermore, there will be one engineer per 45 franchisees to supervise the technicians, solve major technical problems and commissioning of new sites. This ensures the reliability of the system and maintains the trust of the franchisee holders.

6.2.4. Value Chain and Key Activities

The franchiser will be the link between the suppliers, manufacturers, financial institutions and the local franchisee holders. The latter is the one providing the service to the end consumer. The franchiser will ensure the assembly and commissioning of the system, maintenance and technical problem solving. Additionally, financial support will be provided to each of its franchisee holders.

Figure 21. Supply chain (2014)

From the value chain, the key activities and the value to the local franchisee holder (customer)are derived and further explained below.

Key activities	Value added to franchisee holder
Standardised turn-key system design	Lower cost of components due to economy of scale. Simpler and faster assembly, operation and maintenance.
Contact to suppliers and manufacturers	Attain lower costs, higher quality, guarantee, reliability, and fast replacement of spare parts or other components.
Access to finance	Opportunity to afford the solar PV system and ensure financial feasibility of the project.
Assembly and commissioning on site	Ensure that the system is assembled in the right way and that is working properly from the beginning.
Training of operators	Fast problem solving, increased reliability of supply to ensure satisfaction and payment from the end consumer. Ability to exploit all the features of the product.
Continuous maintenance	Increased reliability, functionality, and quality of the service. Prevent extra costs for major problem fixing.
Provide personalized service to each franchisee through technicians	Continuous learning and support. Get information in a fast and direct way from franchiser and provide feedback, suggestions and complaints. Fast major technical problems solving.

Table 37. Key activities and value to customers (2014)

6.2.5. Key Resources and Logistics

Having a standardized solar PV system design is an important resource that can help to reduce the capital investment. The components and spare parts for maintenance, or in case of any technical problems, are easily available through the suppliers or in stock. This ensures fast problem solving and maintains the reliability of the system. Trained and skilled personnel (technicians and engineers) that provide close assistance to the franchisee holders will guarantee good communication and the satisfactions of the customer. The technicians should be staying near the surroundings of his cluster in case of any emergency. Furthermore, having the access to investment capital is required to afford the upfront payment of the systems and run the business.

6.2.6. Key partnerships

Manufacturers and suppliers are key partners to ensure the availability of spare parts in case repairing or replacing is needed. They should also maintain components of the solar PV system in stock for the assembly of new power plants. The good relationship with these partners would guarantee lower prices and better quality of components. At the moment, a first approach to SMA, Outback, Vikram Solar, Hi-power and other local manufacturers and suppliers has been made.

Access to finance is a major challenge for renewable energy projects. Thereafter, banks and financing institutions are important partners. The franchiser needs to acquire a debt to be able to purchase the assets and roll-out the business. As a result, access to funds with low interest rates and long tenure periods are pursuit. These partners have already been identified. CDKN will fund the pilot project and Rockefeller Foundation, through the catalytic facility managed by cKinetics, will ensure the funds to roll-out the business.

6.2.7. Cost Structure and Revenue Streams

The capital costs for the franchiser are the ones related to the system components (solar panels, grid, batteries, and inverters, among others) and the man power to assemble it. For running the business, salaries, travelling costs of the technicians and engineers to the different sites where the operators are located, maintenance of the systems and the loan interest should be paid.

To afford these costs, the franchiser gets the monthly franchisee fee from each operator and a balloon payment at the end of the five years contract, if that is the case.

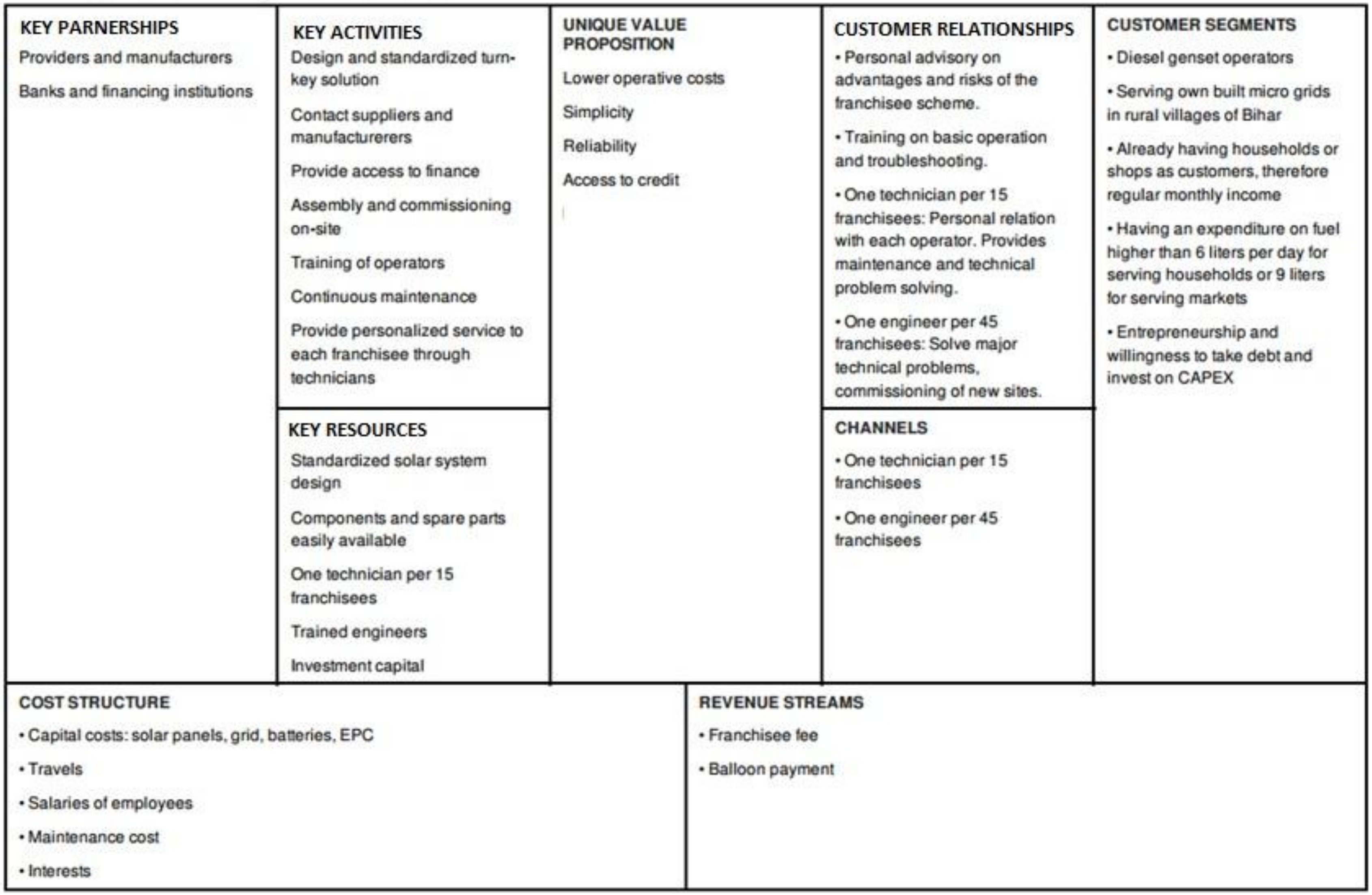

Figure 22. Business model canvas (2014)

6.3. **Porter's Five Forces Analysis**

6.3.1. Threat of New Competition

At the moment there are many players entering the rural electrification market. Nevertheless, they perceive the current DG operators as competitors and none of them are focusing on diesel replacement with solar PV systems. Therefore, the likelihood of new competition seems very low. Being the firsts to enter the market also provides first mover advantages.

6.3.2. Threat of Substitute Products or Services

Grid extension and micro grids set up by private companies can replace DG operators. The Government is extending the grid in a fast pace, offering free connections and supply to BPL consumers. Bihar is proposed to be completely electrified by 2015. Nevertheless, grid supply is not reliable, the service is erratic and a village can be declared electrified with only 10% of households connected. Additionally, many private companies are entering the rural electrification market. However, they are just nascent companies, growing at a small pace and struggling to get bigger market shares. These leave a potential market for the conversion of DG operators to solar PV systems. Furthermore, the replacement of DG with solar PV systems has the advantage that doesn't need to get consumers, since those were already attained by the DG operator and will have an added value by the improvement of the current micro-grid. A big threat however is the existence of subsidies for the price of kerosene and diesel, which lowers the operative costs of the DG and makes it harder to compete with from a financial point of view. Other substitute products include solar home systems and rechargeable lanterns that can be used for lighting during the evening.

6.3.3. Bargaining Power of Customers

Since the customer already has a source of electricity, his bargaining power is high. The DG operators are asked to make an upfront payment that can be seen as unnecessary if they already have a system and don't perceive the advantages of solar PV systems.

6.3.4. Bargaining Power of Suppliers

The market of solar PV systems is growing fast, having many suppliers entering the market. Therefore, the prices are decreasing and manufacturers and suppliers are competing hard to acquire bigger market shares. The solar PV system does not rely on specific suppliers, giving the flexibility to change from one supplier to another while the technical specifications are met; this reduces the bargaining power of suppliers.

6.3.5. Intensity of Competitive Rivalry

Since the market for rural electrification in India is big, the intensity of competitive rivalry is low. In contrast, rural electrification companies are working together and sharing learning experiences through programs like SPEED.

6.4. SWOT analysis

Figure 23. SWOT analysis (2014)

6.5. **Risk Analysis**

It is of upmost importance to acknowledge the risks that can be found during the establishment and running of the business. These were identified and are listed below. Each risk has been analyzed and ranked according to its probability of occurring and its consequence in case of happening. Table 38provides a clearer explanation of the ranking system.

Level of Risk calculator					
Likelihood [How likely is it that the risk will occur?]	**Consequence** [What will happen if the risk does occur?]				
	1 Insignificant	**2 Minor**	**3 Moderate**	**4 Major**	**5 Severe**
A Almost Certain	High	High	High	Extreme	Extreme
B Likely	Moderate	Moderate	High	High	Extreme
C Possible	Low	Moderate	Moderate	High	High
D Unlikely	Low	Low	Moderate	Moderate	High
E Rare	Low	Low	Low	Moderate	Moderate

Table 38. Risk ranking system [20]

Besides analyzing and ranking the risks, mitigation strategies for each risk consequence. Table 39 summarizes the risk assessment realized and the mitigation strategies proposed.

Description of risk	**Risk assessment**			**Impact or consequence**	**Mitigation strategy**
	Likelihood	**Consequence**	**Risk level**		
Low technical capability for installation of the system	B	5		**Loss of credibility**	· Skilled technicians will install the system and trained engineers will commission the plants. · Provide regular training to technical personnel.
Wrong operation of the system	C	5		**Loss of credibility**	· Trained technicians will visit the plants regularly and provide maintenance. · The operators will be trained on basic operation and troubleshooting.
Lack of access to finance	B	5		**Financial unfeasibility of the business model**	· Banks and financial institutions as key partners. · Franchiser has debt capability. · Franchiser is a well established company.

Description of risk	Risk assessment			Impact or consequence	Mitigation strategy
	Likelihood	Consequence	Risk level		
Electrification by the government	B	4		**Small market share**	· Provide a reliable service to the end consumer · Ensure supply hours to keep the trust of the end consumer
Subsidy and political framework changes	C	2		**Lost of liquidity**	· Make a financial plan that does not relies on subsidies · Procure a fast payback time
Government subsidies on fuel (kerosene or diesel)	C	4		**Financial unfeasibility of the business model**	· Strong value proposition · Awareness raising on the advantages of the technology · Remark the fact that after the owning the system, the expenses are lower than kerosene or diesel cost
Unwillingness of the DG operators to get debt	A	5		**Small market share**	· Remark the opportunity to acquire a valuable asset · Provide financial advisory so they can evaluate their ability to get debt
Inability of the operator to pay the replacement cost	C	3		**Small market share**	· Access to micro finance · Close relationship with manufacturers and providers to get lower prices
Inability to meet a fast demand increase	C	5		**Loss of credibility**	· Availability of technicians to increase the size of the system as required · Close relationship with manufacturers and providers to get fast the required components
Standardized system not meeting the specific requirements of certain sites	C	5		**Small market share / Financial unfeasibility of the business model**	· Availability of technicians to increase or decrease the size of the system as required · Having different standardized system sizes to meet different demands.

Table 39. Risk assessment and mitigation strategies (2014)

It can be seen that the most likely risks are related to the unknown willingness of conversion of the operator due the high upfront cost to be covered, the need to obtain debt, as well as the lack of awareness of the advantages of solar PV systems against DG. The DG operators interviewed showed to be entrepreneurs willing to invest. Nonetheless, some of them added that even if they are willing to invest, they currently don't have the capital to do it. This is why personal financial advisory is needed to help them evaluate their risks and their ability to incur debt. Awareness rising about the benefits of solar PV systems is also needed to encourage the DG operator to convert.

The lack of access to finance is another risk that should be considered. Access to funds is needed for feasibility of the financial model. Therefore, banks and financial institutions should be key partners and the franchiser has to be a well established company with debt capability.

Risks regarding governmental policies are also high. The Bihar government is setting up fast electrification infrastructure. Notwithstanding, the grid is not reliable, and so the trust of the consumer should be gained through a robust system and reliable service. The subsidies on diesel were just removed so prices are expected to hike. However, kerosene is still subsidized which lowers the operational costs of the DG operators and sustains the payment through kerosene. Awareness rising of the benefits of solar PV system and the opportunity of getting a valuable asset through this scheme is highly required to mitigate the latter risk. The change of policies can also affect the access to subsidies; thus the financial plan presented in the next chapter does not rely on the availability of subsidies.

Regarding technical risks, the over-sizing or sub-sizing of the system was identified. This is a possible risk with severe impact, principally for the financial analysis. Solar PV systems are modular as panels can be added or removed to meet the existing demand. Additionally, it is necessary to have a flexible financial plan and to evaluate before giving the franchisee to the operator, if the site demand can be supplied by the standardized system. Furthermore, it would be advantageous to have different standardized system sizes to meet different demands. Other technical risks are related to the wrong installation and operation of the solar PV plants. This can lead to the loss of credibility from the franchisee holder because the expected power would not be delivered. To reduce this risk, technicians and engineers will be hired and trained. As said before, engineers would be responsible for the commissioning of the power plants and solving major technical problems. Besides, one technician will be assigned to every 15 sites to provide maintenance. Furthermore, the operators will be trained on trouble shooting and operation of the system.

7. Financial Model

Apart from the technical feasibility of the project, the financial likelihood has also been evaluated. The components quantity and cost were input in the financial model to obtain the cash flows for the franchiser and the owner of the franchisee (operator). Additionally, a comparison between the conversion to solar and a business as usual case was realized.

7.1. The Model

Even though the prices for solar PV panels are decreasing and the operation and maintenance costs are low, the investment cost is still high when compared to a DG. Therefore, it is very unlikely that a small entrepreneur is willing to take such a risk and that a financial institution grants them the loan. This model presents a solution for the lack of capital of rural entrepreneurs, providing a financial plan to enable them to afford the system. This model supports the franchise model proposed in the previous chapter. The financial parameters to be included in the franchise agreement are listed below.

Financial parameters	
Percentage of CAPEX covered by operator	30%
Interest rate for operator	15%
Margin for franchiser	20%
Years to own the system	5

Table 40. Franchisee financial parameters (2014)

From Table 40 it can be understood that the DG operator should pay a 30% of the capital cost of the solar PV system in order to obtain the franchisee. The remaining 70% of the CAPEX turns into a debt that will be paid over a 5 year time frame, with a 15% interest rate and adding a 30% that is the margin for the franchiser. The total amount of the repayment of the debt, the interests and the margin for the franchiser conform the franchisee fee that gives to the operator the right to obtained free maintenance, technical problem solving and financing for the replacement of batteries while the debt is being repaid. After the debt is covered, the operator owns the system. The franchisee package is designed in a way that the operator will never pay more for the franchisee fee than what he would pay on diesel. Therefore, if the franchisee fee is higher than the diesel expenditure, he will disburse the same amount that he was supposed to pay for diesel, and the rest would be compensated at the end of the five years agreement.

Financial parameters	
Interest rate	15%
Leverage ratio	0.7
Years of loan	6
Years of moratorium	3
Number of franchisees	45

Table 41. Financial parameters for franchiser (2014)

To be able to afford the CAPEX of the solar PV systems, the franchiser has to obtain a loan for a timeframe of 6 years, with a 15% interest rate. It is assumed that the bank will provide 3 years of moratorium. The franchiser should be an institution with debt capacity and able to afford the 30% of the CAPEX of all the power plants to be built CAPEX. As a first tryout it was suggested to have 45 franchisees, a value that seems feasible and very conservative in a market of 140 000 un-electrified villages. It was assumed that one third of the solar PV systems will be commissioned during the first year and the rest during the second year.

7.2. Assumptions

To model the financial performance of the proposed solution, some general assumptions were made. The following tables present these assumptions; the support of each one can be found in the References section or the Appendix (11.3.1) section.

General assumptions	
Yearly diesel price increase	10%
Inflation rate [21]	9.62%
Maintenance cost of generator (Rs)	₹ 13,200.00[4]
Diesel price (INR/L)	₹ 61.55[5]
Daily diesel consumption for serving households (L/day)	**6.4**[6]
Daily diesel consumption for serving markets (L/day)	**9.7**[7]
LED bulbs per household	1
LED per shop	1
Price per LED bulb (INR) [22]	₹ 300

Table 42. General assumptions for the financial model (2014)

The previous table includes the inflation rate and the yearly diesel price increase, which is a basis for the future projections. The daily diesel consumption and its price is important to understand how much the DG operator is spending at the moment, and therefore how much it is able to save in case of conversion. It is important to remark that the diesel price is a conservative value. Usually the diesel price in villages is higher than in cities due to transportation and handling costs. Since energy efficiency is of upmost importance to reduce the size of the solar PV system and reduce the CAPEX, one LED is assumed to be purchased for each of the end consumers.

[4] Average maintenance expenditure of the DG operators interviewed.

[5] Average diesel price for June [25].

[6] Average diesel consumption of the DG operators serving households.

[7] See Appendix for calculations.

To model the franchiser cash flows the following assumptions regarding costs were made. They are presented as percentages of the revenue. Besides, as said before, it is expected that forming clusters will provide a reduced investment cost of components due economy of scale. This CAPEX discount, as well as the expected expenses, is shown in the following table.

Assumptions	Value
Miscellaneous expenses	2%
Travel costs	2%
CAPEX discount	5%

Table 43. Costs and discounts assumed for cluster (2014)

Human resources will also be required to run the business, design and commission the plants, provide maintenance and solve technical problems. It is assumed that the franchiser is a branch from a bigger company, not a nascent one; therefore, no administrative positions are considered. Further description of each of the positions can be found in the Business Model and Analysis

.

Man power	Salary (INR/Month)[8]	No. of Plants assigned	Man power required	INR/year
Technician	6,000.00 ₹	15	3	216,000.00 ₹
Engineer	30,000.00 ₹	45	1	360,000.00 ₹
Total man power expense				**576,000.00 ₹**

Table 44. Human resources required per cluster

[8] From conversations with one of the SPEED ESCO's.

7.3. **Households' System Package**

To model the households' system package cash flows the following assumption of demand served and charge per customer were made. It can be seen that for modelling the Business as Usual (BAU) case, it was assumed a higher load, as CFL of around 11 W to 15 W are being used at the moment. Besides, from the interviews performed it is known that DG operators provide the service for around 3.5 hours, while it is proposed to give 4 hours of electricity supply in order to offer an added value for the end-consumer.

Load variables	Solar	BAU
Number of households served	250	250
KW provided per household	0.01	0.02
Hours of electricity provided	4.00	3.50
Price per charging point (INR)	₹ 3.33	₹ 3.33

Table 45. Load and pricing variables for households' system package (2014)

7.3.1. Franchisee Business Case

Based on the previously mentioned assumptions, the calculations for revenues and expenses for each of the systems was performed and compared in order to demonstrate the franchisee holder's financial viability. The figure below shows the cash inflows and outflows for both cases. In the first year, the operator should cover the upfront investment for the solar PV system, while there are no outflows for the DG operator. In the following years the cash inflows are similar for both cases. The outflows are different since for the solar PV system the expenses are just the franchisee fee, land lease and a percentage of battery replacement in year 4, while for the BAU case the expenditure on diesel is increasing every year. After year 5, the outflows for the solar PV system are smaller because the system is already paid, thus increasing the cumulative cash flow value and reaching the one for the BAU case in year 7.

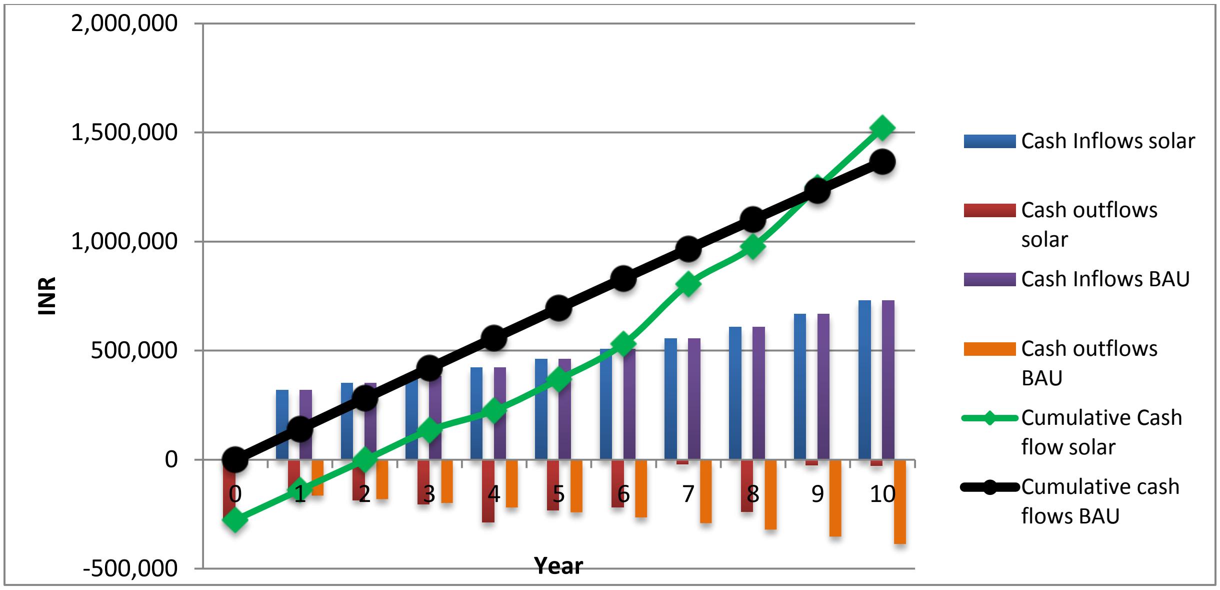

Figure 24. Cash flow comparison for the BAU and solar case for the households' package (2014)

The following table presents a comparison between the Net Present Value (NPV) for both cases in the fifth and tenth year, in order to realize how the NPV boosts after acquiring the ownership of the system. A comparison between the Levelized Electricity Cost (LEC) is also presented. The price per KWh for the solar PV system is very high since only the energy delivered was accounted and, as previously shown in the System Design chapter, a high amount of energy remains unused. Therefore, as said before, new customers that can make use of the surplus energy should be found. Even though the LEC for the solar PV system is higher than the one for the BAU case, the proposed system is competitive since it is energy efficient, providing less energy but generating the same revenue. Because the income for the solar PV system is so high after the complete payment of the system, the average monthly income after 10 years is 70% higher than the one for the BAU case.

Results	Solar PV	BAU
NPV 10 years	1,520,230.17 ₹	1,241,880.68 ₹
NPV 5 years	368,563.02 ₹	631,729.32 ₹
LEC (INR/KWh)	94.12 ₹	21.29 ₹
Average monthly income (INR)	31,194.12 ₹	18,045.40 ₹

Table 46. Financial results of the solar PV and BAU for the households' package (2014)

From the next table, Table 47, it can be seen that the Capital Expenditures (CAPEX) that should be affordable to the local entrepreneur seems relatively high. This can be a risk for the business, as discussed in the previous chapter, since the operator might not have the required amount of money available or not be willing to invest it. The high amount of debt that is needed is one of the reasons why local entrepreneurs need this type of franchisee in order to have access to credit. The expected monthly franchisee fee is around INR 19 000; nevertheless, as mentioned before, this value is not the one paid, since it is higher than the current expenses of the BAU case. The Internal Rate of Return (IRR) after 5 years is of 52% and the Return on Investment (ROI) after 5 years is 134%, demonstrating that the conversion from diesel to solar is profitable for the franchisee holder. These values were calculated after five years, as the financial indicators become more evident after that, because the franchisee fee is no longer being paid and most of the income turns into profit.

CAPEX	275,937.10 ₹
Debt	671,450.63 ₹
Franchisee fee (INR/month)	18,930.18 ₹
Balloon payment	211,631.17 ₹
IRR after 5 years	52%
ROI[9] after 5 years	134%

Table 47. Financial indicators for the households' package franchisee (2014)

The ten year cash flow for the proposed system is presented below. The values marked in yellow are just for comparisons and accounted for the cash flows. They show the assumed franchisee fee to be paid and the forecasted expenditure on diesel and maintenance of the DG, and the calculation of a viability gap, that is the difference between both. If the viability gap is negative the franchisee fee is higher than the expected expenditure on diesel and maintenance, therefore the amount paid to the franchiser would be equal to the diesel cost. If the value paid is less than the franchisee fee expected, the difference will be accounted and paid at the end of the 5 years period as a balloon payment. In this case, a balloon payment should be paid, which is even less than the monthly franchisee fee and the diesel and maintenance cost forecasted for that year.

[9] Calculated as NPV/ CAPEX

	0	1	2	3	4	5	6	7	8	9	10
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Operations											
Sales	0	319,725	350,483	384,199	421,159	461,674	506,087	554,773	608,142	666,646	730,777
Maintenance		0	0	0	0	0	-14,575	-15,977	-17,514	-19,199	-21,046
Land lease	0	-3,326	-3,646	-3,997	-4,382	-4,803	-5,265	-5,772	-6,327	-6,936	-7,603
Franchisee fee	0	-227,162	-227,162	-227,162	-227,162	-227,162	-211,631	0	0	0	0
Viability gap		-62,426	-46,003	-27,942	-8,080	13,762	53,313	291,359	320,408	352,354	387,484
Diesel and maintenance BAU	0	-164,736	-181,159	-199,220	-219,082	-240,924	-264,944	-291,359	-320,408	-352,354	-387,484
Franchisee fee paid		-164736	-181159	-199220	-219082	-227162	-211631	0	0	0	0
Earnings before interest and taxes (EBT)[7]	**0**	**151,663**	**165,677**	**180,981**	**197,695**	**229,709**	**289,191**	**533,024**	**584,301**	**640,510**	**702,128**
% over sales		*47%*	*47%*	*47%*	*47%*	*50%*	*57%*	*96%*	*96%*	*96%*	*96%*
EPC	-26,460										
CAPEX	-249,477	0	0	0	-64,320	0	0	0	-214,400	0	0
Earnings after taxes (EAT)	**-275,937**	**151,663**	**165,677**	**180,981**	**133,375**	**229,709**	**289,191**	**533,024**	**369,901**	**640,510**	**702,128**

Table 48. Households' package franchisee's cash flows (2014)

It is important to notice that no interest is consider, since the loan repayment and the interest associated is embedded in the franchisee fee. Furthermore, solar projects are not subject of taxation in India. [23]

7.3.2. Franchiser Business Case

CAPEX	2,459,696 ₹
Debt	18,447,720 ₹
IRR after 5 years	17%
ROI after 5 years	-109%
ROI after 10 years	53%

Table 49. Financial indicators for the households' package franchiser (2014)

The cash flows for the franchiser were also forecasted. The franchiser has to pay INR 2.5 million up front as a capital investment, and a debt of around INR 18 million should be acquired. The IRR is relatively high, indicating that the business is feasible. Regarding the return on investment, it can be seen that after 5 years the investment has not been recovered, but after this time frame, when the debt is paid and the balloon payment is received, the ROI increases fast to up to 53% after 7 years. As can be seen in the cash flow presented below, the franchiser doesn't have any more cash flows after year 7, since all the franchisees will have had paid their debt by that time and no more maintenance should be provided.

It can be seen in the cash flow how the ramp-up of the number of power plants is made, commissioning 14 during the first year and 31 the next one. The franchisee fee expected to be received per month is variable, since it is dependent on the operators forecasted diesel expenditure.

The maintenance cost is covered by the franchiser during the 5 years period of debt of the franchisee. Other expenses are related to travel, since the sites where the systems are located should be visited, and the salaries of the engineers and technicians. The loan is received in two instalments, linked to the number of systems commissioned each year. The financing institution is expected to provide a 3 years moratorium, after that the debt is covered in 4 more years. In this case, the franchiser provides finance for the replacement of batteries (70% of CAPEX); the money is equity since no other loan is requested. The total debt acquired by each franchisee considers this amount of money; therefore it is repaid during the five years loan.

As a next phase of the project, the possibility of setting up more plants to keep on running the business for longer, or to continue providing maintenance after the debt of the franchisee is paid in exchange of a franchisee fee, can be evaluated.

	0	1	2	3	4	5	6	7	8	9	10
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Operations											
Accumulate number of solar plants	14	45	45	45	45	45	45	31	0	0	0
Franchise fee	0	2,306,304	7,643,048	8,405,028	9,242,983	9,971,818	10,004,864	6,560,566	0	0	0
Maintenance	0	-128,913	-454,225	-497,922	-545,822	-598,330	-655,889	-718,986	0	0	0
Miscellaneous Expenses		-50,563	-183,686	-221,431	-266,932	-315,685	-347,200	-249,574	0	0	0
Travel Cost		-37,923	-137,765	-166,073	-200,199	-236,763	-260,400	-187,181	0	0	0
Salaries	0	-631,411	-692,153	-758,738	-831,729	-911,741	-999,450	-1,095,598	0	0	0
EBIT	**0**	**1,457,494**	**6,175,219**	**6,760,864**	**7,398,300**	**7,909,299**	**7,741,924**	**4,309,228**	**0**	**0**	**0**
% over sales		*63%*	*81%*	*80%*	*80%*	*79%*	*77%*	*66%*			
Interest expense	0	0	0	-2,075,369	-1,383,579	-691,790	0	0	0	0	0
Earnings before taxes (EBT)	**0**	**-17,504**	**1,434,154**	**-55,570**	**1,273,656**	**2,476,444**	**3,635,297**	**1,607,428**	**0**	**0**	**0**
Taxes paid	0	0	0	0	0	0	0	0	0	0	0
Income loan	5,739,291	12,708,429	0	0	0	0	0	0	0	0	0
Loan repayment	0	0	0	-4,611,930	-4,611,930	-4,611,930	-4,611,930	0	0	0	0
CAPEX	-8,198,987	-18,154,899	0	0	-2,101,120	-4,652,480	0	0	0	0	0
Earnings after taxes (EAT)	**-2,459,696**	**-3,988,976**	**6,175,219**	**73,565**	**-698,329**	**-2,046,901**	**3,129,994**	**4,309,228**	**0**	**0**	**0**

Table 50. Households' package franchiser's cash flows (2014)

7.3.3. Sensitivity Analysis

To verify how the financial model is affected by some of the assumptions made, a sensitivity analysis was carried out. The next graph, Figure 25, illustrates the variation of the IRR for the franchisee holder and for the franchiser with the number of households served, considering a solar PV system of the same specifications. The returns of the franchiser are diminishing with the increasing number of households. This is mainly because as more households are connected, therefore the CAPEX for the micro-grid is increased, and the franchisee fee is not getting higher than the expected expenditure on diesel. On the other hand, with more households served, the IRR for the franchisee is incremented, since more revenue is earned and the franchisee fee is not augmented. It has to be considered that the current PV system was designed to serve 250 households. More households can be connected and served during most of the months, but not during the months of low irradiation, like July and August.

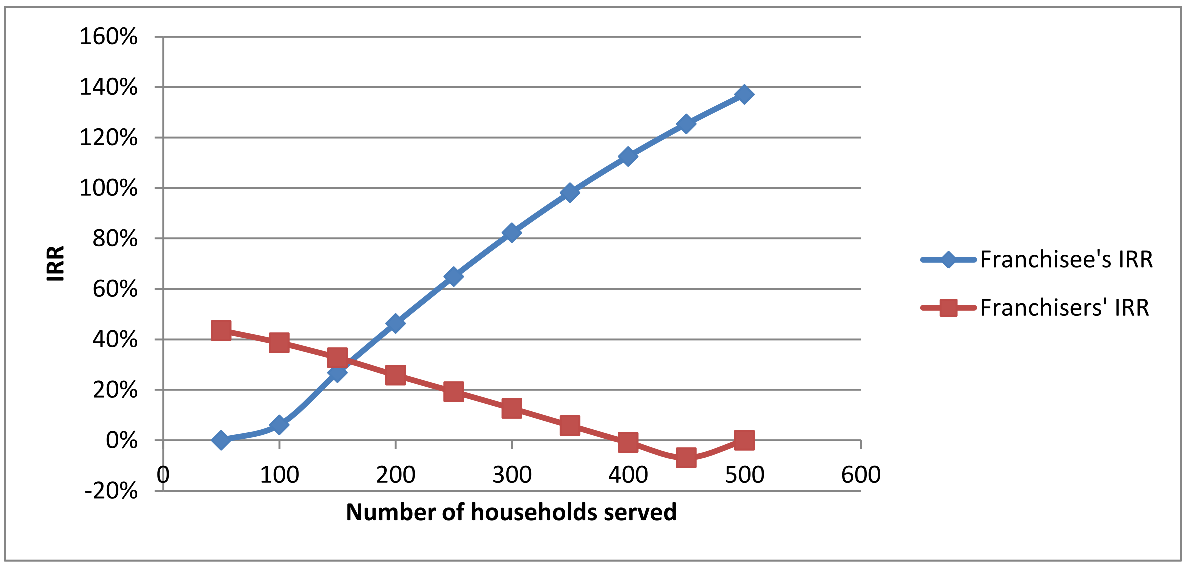

Figure 25. Franchisee's and franchiser's IRR for different number of households served (2014)

The daily diesel consumption of the operator was also varied to observe its effect on the IRR of both the franchiser and the franchisee holder. The IRR for the franchiser increases with increasing daily diesel consumption and is negative if the daily diesel consumption is less than 6 litres per day. For the franchisee holder is the opposite, while the daily diesel consumption augments, the IRR diminishes. This is because the franchisee fee to be paid is dependent on the diesel consumption – if it is low the franchiser will have less income and the franchisee will have higher earnings. Nevertheless, if the franchisee fee is lower, the franchisee holder will have to afford a higher balloon payment that was not considered in this analysis. It can be concluded that the franchiser should aim to convert DG operators that have a current diesel consumption of more than 6 litres per day in order to be profitable.

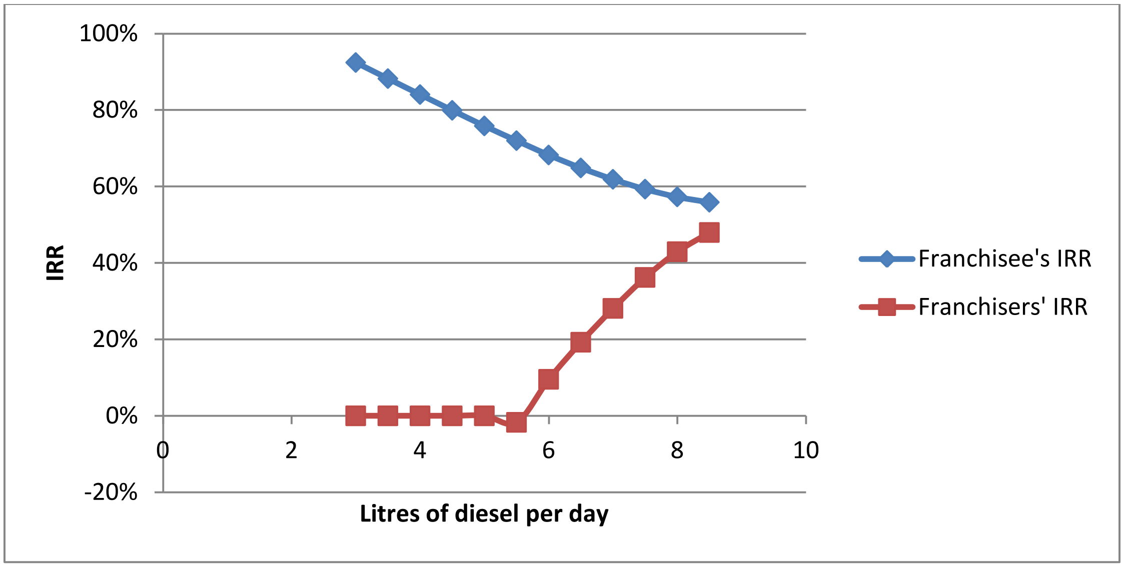

Figure 26. Franchisee's and franchiser's IRR for different daily diesel consumption for the households' package (2014)

The franchisers' IRR is also dependant on the number of franchisees served – with an increasing number of franchisees the IRR has a tendency to augment. Nevertheless, it fluctuates for certain values, since the number of employees required is dependent on the number of franchisees – every 15 franchisees require one technician and every 45 require one engineer. Therefore, when the number of franchisees is a multiple of 45 the IRR is higher, since the expenditure in human resources is better distributed among the customers.

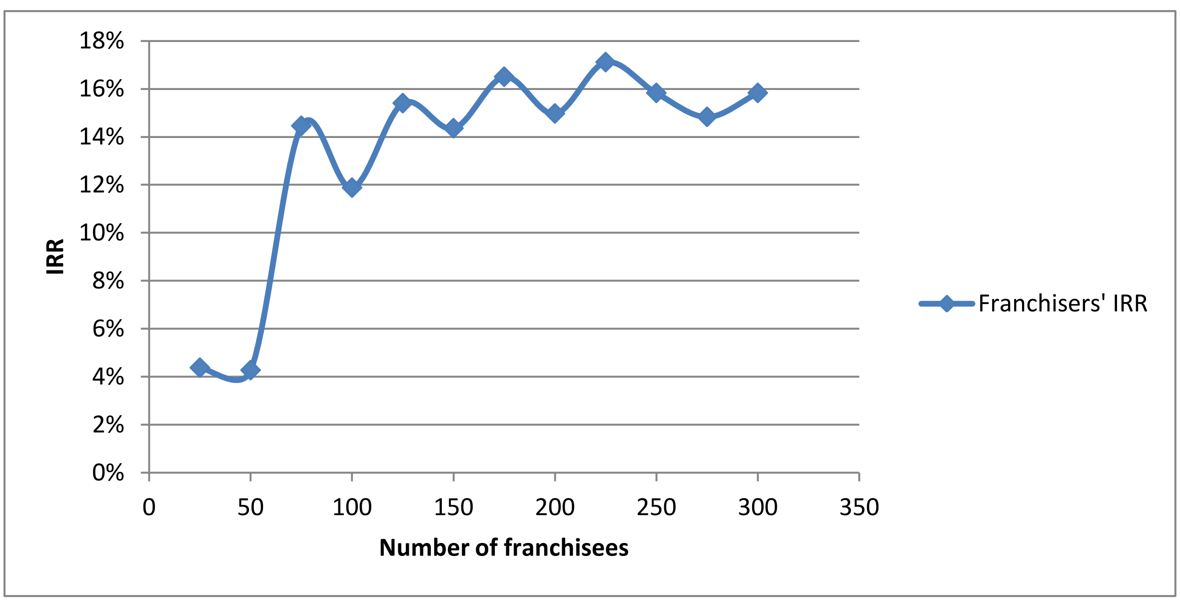

Figure 27. Franchiser's IRR for different number of franchisee for the households' package (2014)

7.4. Markets' System Package

In order to model the markets' system package, the demand to be served as well as the prices charged per customer per day was assumed as follows. As in the households' package case, a lower load for lighting was assumed compared to the BAU case, since LED lamps will be provided. The other loads and charges are alike for both cases.

Load variables	Solar	BAU
Shops	50	50
MEs	5	5
KW per shop	0.01	0.02
KW per ME	0.30	0.30
Hours of electricity for shop	4.00	4.00
Hours of electricity for ME	12.00	12.00
Price per charging point for shops (INR/day)	₹ 7.00	₹ 7.00
Price per charging point for MEs (INR/day)	₹ 100.00	₹ 100.00

Table 51. Load and pricing variables for the markets' system package (2014)

7.4.1. Franchisee Business Case

The following figure shows the yearly cash inflows and outflows, and the cumulative cash flows for each case. The inflows are similar for both cases at all time, but the outflows are smaller for the solar case, since it is not dependant on the fuel price. It is noticeable that in year 6 the cumulative cash flows are equal in both cases. After that the solar PV system is more profitable, since just maintenance and land lease cost should be afforded.

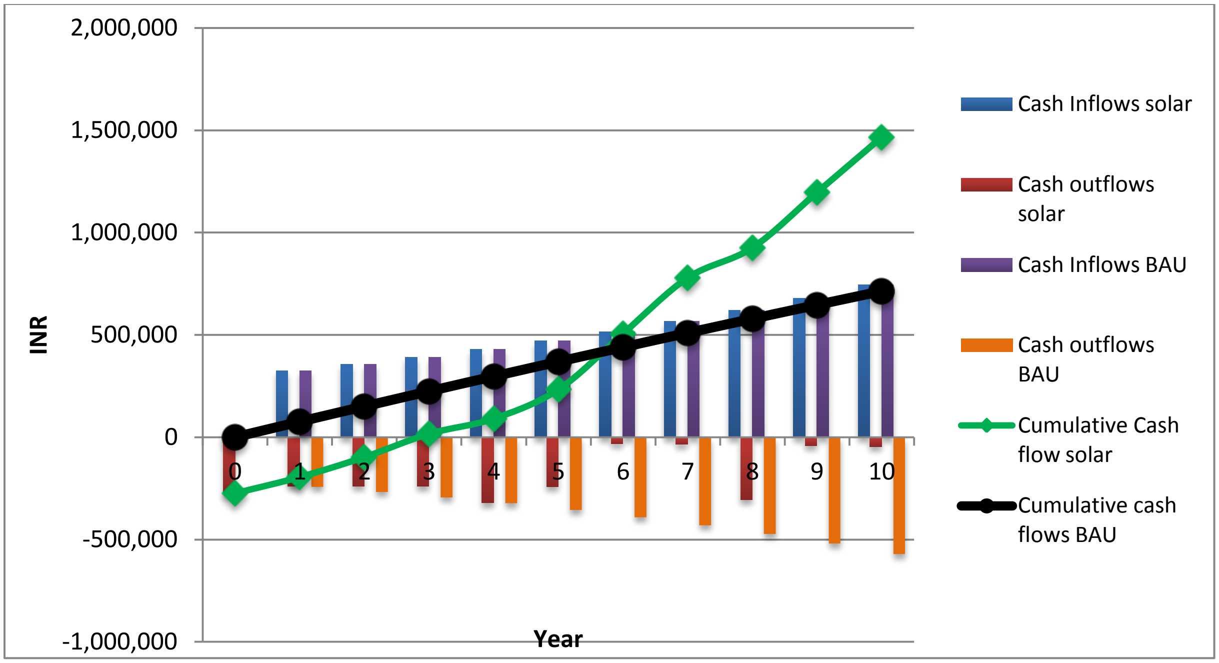

Figure 28. Cash flow comparison for the BAU and solar case for the markets' package (2014)

The next table presents the financial results for both cases. The trend is similar to the one of the households' package: The solar PV system has a lower NPV after 5 years, but after the payment of the system the profit boosts doubling the NPV of the BAU case. The LEC for solar PV in the markets' package is lower than the one for households' since less energy remains unused due to the existence of loads during the daylight hours. The average monthly income for the 10 years of analysis is more than 100% higher for the solar PV system than for the DG. These values demonstrate that the proposed solar PV system is competitive compared to the current DG.

Results	**Solar PV**	**BAU**
NPV 10 years	1,466,634.35 ₹	648,163.77 ₹
NPV 5 years	233,735.69 ₹	335,095.94 ₹
LEC (Rs/KWh)	52.80 ₹	24.98 ₹
Average monthly income	23,896.43 ₹	9,369.57 ₹

Table 52. Financial results of the solar PV and BAU for the markets' package (2014)

From the 10 years cash flows forecast various financial indicators were calculated. The CAPEX required for the markets' package is very similar to the one for the households' package; even if the solar PV system has a bigger capacity, the micro-grid has fewer connections and is therefore cheaper. Again, it is questionable if the local entrepreneurs will be capable and willing to afford the CAPEX and undertake the debt. The franchisee fee is around INR 19 500 per month and it is expected to be less than the current expenditure on diesel; therefore, it will be paid completely every month and no balloon payment will be required at the end of the 5 years period. From the ROI value it can be seen that the investment in CAPEX is almost doubled after five years. The high value of IRR demonstrates that the business is feasible and profitable.

CAPEX	273,271.70 ₹
Debt	691,009.87 ₹
Franchisee fee (INR/month)	19,481.62 ₹
Balloon payment	- ₹
IRR	35%
ROI after 5 years	86%

Table 53. Financial indicators for the markets' package franchisee (2014)

In the following table, the values marked in yellow are just for comparisons and not included in the cash flows. They show the assumed franchisee fee to be paid, the forecasted expenditure on diesel and maintenance of the DG, and the calculation of a viability gap, that is the difference between both. In this case, since the expenditure on fuel and maintenance is higher than the expected franchisee fee, no balloon payment is required at the end of the 5 year agreement. In year 4, a 30% of the batteries' replacement price should be afforded and after the repayment of the system, the operator should pay for the maintenance of the solar PV system and the replacement of batteries.

	0	1	2	3	4	5	6	7	8	9	10
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Operations											
Sales	0	326,120	357,492	391,883	429,582	470,908	516,209	565,869	620,305	679,978	745,392
Salaries	0	0	0	0	0	0	0	0	0	0	0
Maintenance		0	0	0	0	0	-23,321	-25,564	-28,023	-30,719	-33,674
Land lease	0	-5,322	-5,834	-6,395	-7,011	-7,685	-8,424	-9,235	-10,123	-11,097	-12,165
Franchisee fee	0	-233,779	-233,779	-233,779	-233,779	-233,779		0	0	0	0
Viability gap		9,092	33,329	59,985	89,301	121,543	390,783	429,782	472,673	519,845	571,724
Diesel + maintenance expenditure BAU	0	-242,872	-267,109	-293,765	-323,081	-355,323	-390,783	-429,782	-472,673	-519,845	-571,724
Franchisee fee paid		-233,779	-233,779	-233,779	-233,779	-233,779	0	0	0	0	0
Earnings before interests and taxes (EBIT)	**0**	**87,018**	**117,879**	**151,708**	**188,792**	**229,443**	**484,464**	**531,070**	**582,159**	**638,162**	**699,553**
% over sales		*27%*	*33%*	*39%*	*44%*	*49%*	*94%*	*94%*	*94%*	*94%*	*94%*
EPC	-42,336										
CAPEX	-230,936	0	0	0	-80,400	0	0	0	-268,000	0	0
Earnings after taxes (EAT)	**-273,272**	**87,018**	**117,879**	**151,708**	**108,392**	**229,443**	**484,464**	**531,070**	**314,159**	**638,162**	**699,553**

Table 54. Markets' package franchisee's cash flows (2014)

7.4.2. Franchiser Business Case

The cash flows for the franchiser of this type of package were also calculated. The franchiser has to afford around INR 2.5 million and acquire a debt of more than INR 18 million in exchange for an IRR of 35%, which is relatively high. In this case, since no balloon payment is perceived in year 6 and no maintenance should be provided after the finalization of the 5 year agreement, the franchiser doesn't have any cash flows after year 6; therefore, the ROI after 5 years and after 10 years is very similar.

CAPEX	2,451,746
Debt	18,388,092.43 ₹
IRR	35%
ROI after 5 years	46%
ROI after 10 years	50%

Table 55. Financial indicators for the markets' package franchiser (2014)

Table 40 presents the cash flows for the franchiser for a time period of 10 years. The income earned is due to the franchisee fee that is always lower than the expected expenditure on diesel and maintenance of the DG. The operative costs incurred are maintenance, travels to commission and maintain the solar PV plants, salaries of technicians and engineers, and other miscellaneous costs. The loan is perceived in two instalments, which value depends on the number of systems commissioned each year. The bank is expected to provide a moratorium of 3 years and a total timeframe of 6 years to pay the debt. The franchiser should provide financing for the replacement of batteries (70% of CAPEX); to afford this no other loan is requested. The total debt acquired by each franchisee includes this amount of money; therefore it is repaid during the five years loan.

As a next phase of the project, the possibility of setting up more plants to keep on running the business for longer, or to continue providing maintenance after the debt of the franchisee is paid in exchange of a franchisee fee can be evaluated.

When comparing the markets' package with the households' package it is noticed that the first one is more profitable for both the franchiser and the franchisee holder. Even if both require the same CAPEX, the current diesel consumption of DG operators serving households is lower and therefore the capability of paying the complete franchisee fee is affected.

	0	1	2	3	4	5	6	7	8	9	10
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Operations											
Accumulate number of solar plants	14	45	45	45	45	45	31	0	0	0	0
Franchise fee	0	3,272,911	10,520,072	10,520,072	10,520,072	10,520,072	7,247,161	0	0	0	0
Maintenance	0	-206,261	-726,761	-796,675	-873,315	-957,328	-1,049,423	0	0	0	0
Miscellaneous Expenses		-71,755	-252,830	-277,152	-303,814	-333,041	-251,499	0	0	0	0
Travel Cost		-53,816	-189,622	-207,864	-227,861	-249,781	-188,624	0	0	0	0
Salaries	0	-631,411	-692,153	-758,738	-831,729	-911,741	-999,450	0	0	0	0
EBIT	**0**	**2,309,667**	**8,658,707**	**8,479,643**	**8,283,354**	**8,068,182**	**4,758,164**	**0**	**0**	**0**	**0**
% over sales		*71%*	*82%*	*81%*	*79%*	*77%*	*66%*				
Interest expense	0	0	0	-2,068,660	-1,379,107	-689,553	0	0	0	0	0
Earnings before taxes (EBT)	**0**	**352,957**	**2,369,282**	**121,558**	**614,822**	**1,089,203**	**-565,191**	**0**	**0**	**0**	**0**
Taxes paid[8]	0	0	0	0	0	0	0	0	0	0	0
Income loan	5,720,740	12,667,353	0	0	0	0	0	0	0	0	0
Loan repayment	0	0	0	-4,597,023	-4,597,023	-4,597,023	-4,597,023	0	0	0	0
CAPEX	-8,172,486	-18,096,218	0	0	-2,626,400	-5,815,600	0	0	0	0	0
Earnings after taxes (EAT)	**-2,451,746**	**-3,119,198**	**8,658,707**	**1,813,960**	**-319,176**	**-3,033,995**	**161,141**	**0**	**0**	**0**	**0**

Table 56. Markets' package franchiser's cash flows (2014)

7.4.3. Sensitivity Analysis

Since some variables are just assumed values, a sensitivity analysis was performed to assess how a change in these parameters will affect the financial plan. For the franchisee it can be seen that the number of MEs served has a higher effect on the IRR than the number of shops served. This can be explained by the fact that MEs are served mostly during daylight hours, so no extra storage is required. Besides, they provide higher income to the franchisee holder with the same CAPEX on micro-grid construction – each ME provides INR 3 000 per month, while 10 shops provide INR 2 100. With the proposed size of the system more MEs could be served and use the extra energy at a certain extent during the daylight hours in order to don't increase the storage size; this would boost the IRR.

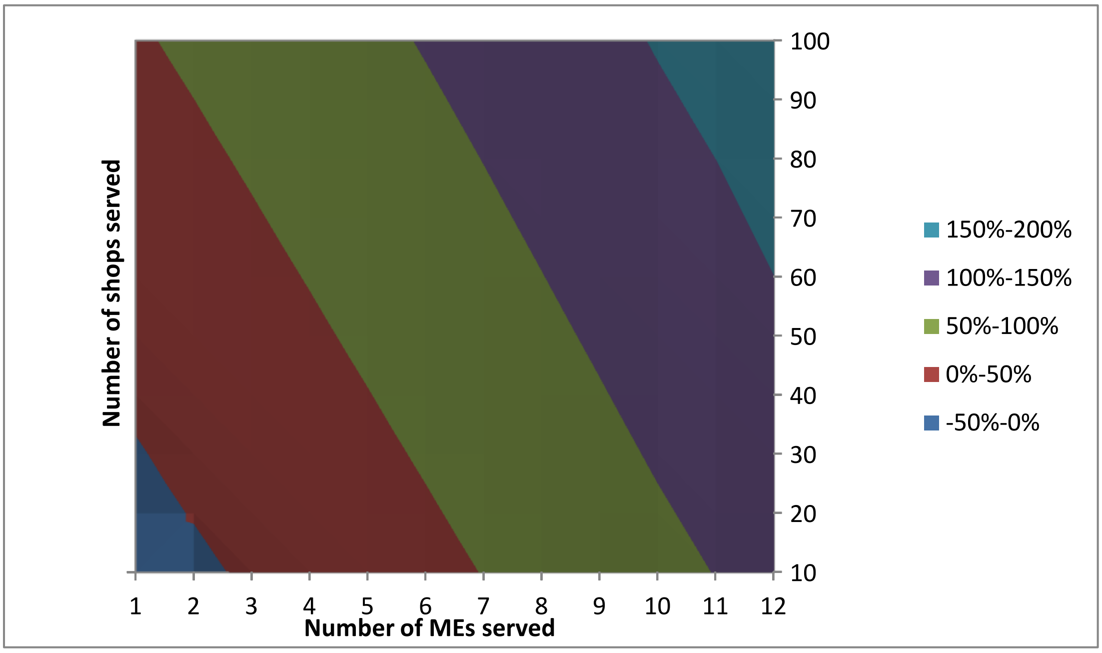

Figure 29. Franchisee's IRR for different number of shops and MEs served (2014)

For the franchiser the situation is different: The IRR is more dependent on the number of shops than in the number of MEs, this could be explained by the fact that the margin for the franchiser is accounted over the total debt. Therefore, a higher debt leads to a higher franchisee fee. In this case a higher number of shops require a higher CAPEX because of the augmented amount of connections required, and this increases the debt of the franchisee.

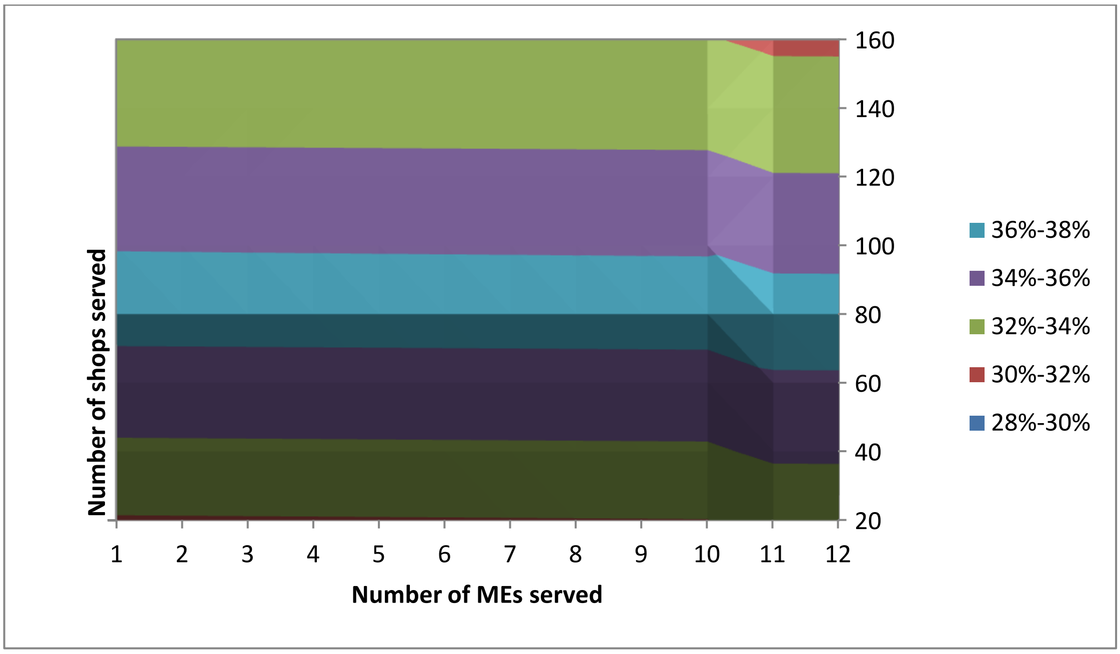

Figure 30. Franchiser's IRR for different number of shops and MEs served (2014)

Regarding the current daily diesel consumption of the DG operators, the trend is very similar to the one of the households' package. Higher diesel consumption leads to an increase of the franchiser's IRR and a decrease in the one of the franchiser. If the daily diesel consumption is below 8 litres per day, the IRR of the franchiser is too low and therefore the business is not feasible. It can be seen that both trends stabilize at a value of around 9 litres of diesel per day, meaning that at that point the franchisee can be fully covered by the expected diesel expenditure. Therefore, no viability gap is needed and the franchisee fee is fixed, maintaining the income for the franchiser and cost of the franchisee without change.

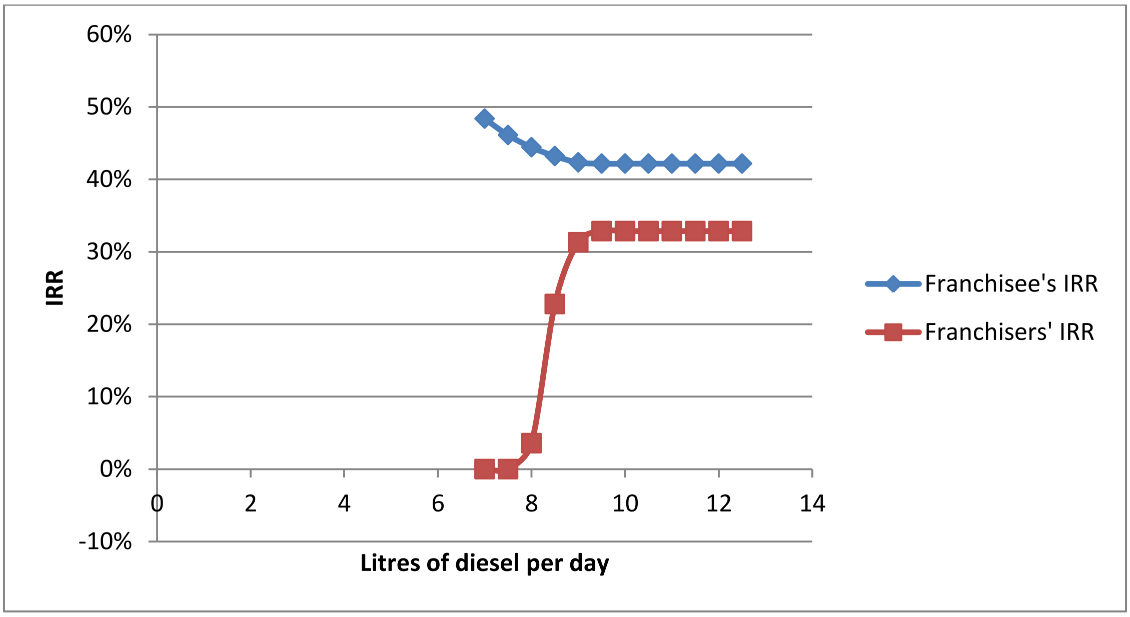

Figure 31. Franchisee’s and franchiser’s IRR for different daily diesel consumption for the markets' package (2014)

As in the households’ package, it can be seen that the IRR varies with the number of franchisees granted, presenting peaks when the number of franchisees is a multiple of 45, due to the expenses in human resources.

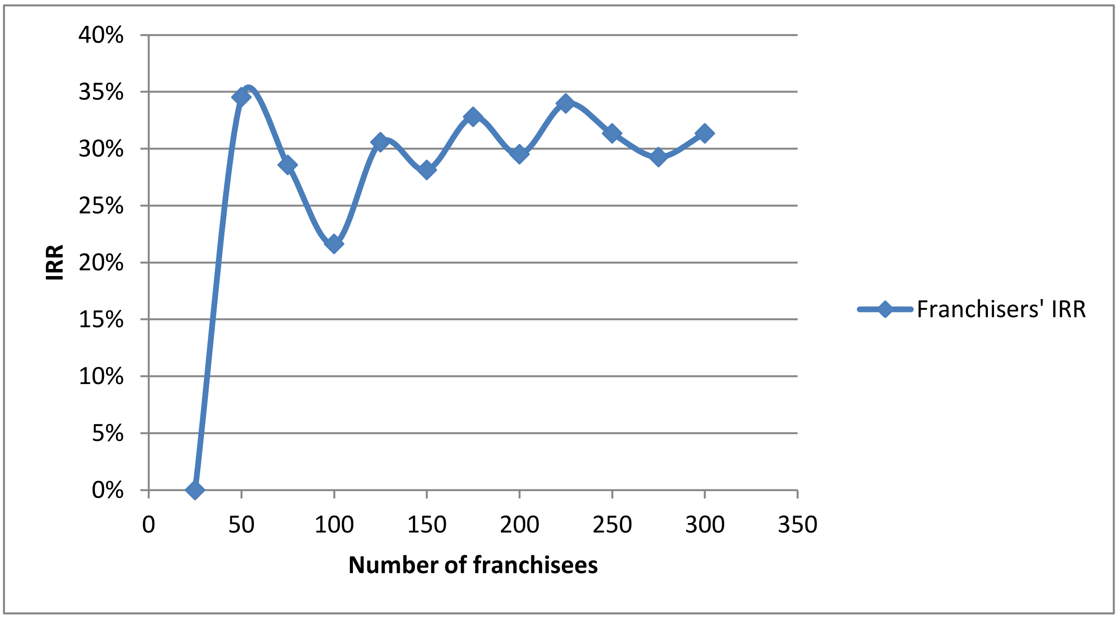

Figure 32. Franchiser’s IRR for different number of franchisee for the markets' package (2014)

8. Conclusions

This report presented the current rural electrification status in India. Even the grid seems to be extending fast, the quality and quantum of electricity that the villagers get is low. Besides, villages declared electrified don't necessarily have 100% of its households electrified. From these, DG operators exist.

DG operators are local entrepreneurs that provide electricity to households or market through micro-grids. They charge fixed tariffs to their customers irrespective of their electricity consumption, resulting in high tariffs.

Therefore, a franchise model to convert DG to solar PV system was proposed. Two standardized solar PV systems (one to serve households and one to serve markets) were designed attempting to minimize the loss of load probability and the cost. The standardization of the technical system and the operative model is a key factor to ensure the easy scalability of the system.

The franchise model proposes that the franchiser purchases the power plant and leases it to the franchisee, who can own it after 5 years. The financial model shows that the business is profitable if the DG operator has a current expenditure on fuel is higher than 6 litres per day for serving households or 9 litres for serving markets since the franchisee fee should not be higher than the current DG operator's expenditure on diesel. Furthermore, the revenue of the franchiser is highly dependent on the number of franchisees.

Various risks to the business were identified, including the unwillingness of the DG operator to get debt and the low technical capability for the installation, maintenance and operation of the system. Thus mitigation strategies, like training and hiring skilled manpower, were proposed.

As next steps, five pilot plants will be tested in Bihar. DG operators will be selected and trained in order to trial the model, refine it and scale it up.

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It is difficult to mention all the people that contributed, directly or indirectly, to the finalization of this Master's Thesis. For me, it was not just a six month project, but the achievement of a life goal.

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Thanks to my friends: Mariana and Wicho, who always believed in me and never let me feel alone; Judith, Simone, Iliana and Till, for sharing the dream with me; Caro and Arjun for their advice at all times of crisis; and my flatmates in India for accompanying me in this life changing experience, specially Mari and Blake for their help to write this report.

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11. Appendix

11.1. Diesel Generator Operators

11.1.1. Interview content

Date	
Person interviewed	
Village	
Is it grid connected?	
Average income	
Number of total HH	
Number of total shops	
Number of total ME (productive loads)	
Position (GPS)	

- How many years have you had this business?
- How many employees do you have?
- Do you have competitors? Which? How many?
- What is the greatest problem that your company faces?
    - From a technical perspective?
    - From a business perspective?
    - From a market perspective?
- How many of these systems do you operate? Just in this village?

Market related

1. What is the main interest of the people you are targeting?
    a. Lighting
    b. mobile phone charging
    c. TV
    d. Radio
    e. Productive loads
    f. Others

Connections

Type of load	Amount	Load (KW) or (A)	Hours of service	Payment
HH				
Shops				
Productive loads				
Other				

1. How do you collect the money?
2. How would you describe the growth of the business? How many connections did you have the first, second, third month?
3. How many new connections do you have per month?
4. How many disconnections do you have per month?
5. What happens if people do not pay?
6. Do you charge a connection fee?
7. Does the price of diesel affect their business?
8. Has he heard about solar? Biomass? Wind?

Technology related

1. How many diesel generators do you have? Size?
2. Where did he get it from? Is it new or refurbished?
3. How much do you know about diesel generators? Did you have any training?
4. How did they get into the business?
5. By which means are you proving it?
    a. AC/DC?
    b. One phase/three phase?
6. How long does it take you to build a system?
7. How do you build your micro grid? Expenses?
8. Is there inside wiring? Who does it?
9. How do you measure consumption?
    a. Meter?
    b. Fixed load?
10. How do you manage technical problems?

11. How does maintenance work?
12. Do they measure current or power? How?
13. How do they size the system? How do they know how many loads they can connect?
14. How do they measure drops?

Business case related

Expenses on diesel INR/month	
Cost of diesel INR/ L	
Maintenance costs (INR/year)	
Litres of oil per year	
How much do they want to earn per month?	
CAPEX spent on diesel generator	
How many years have the DG been running	
Operative hours per week	
Expected lifetime	
Would he be willing to convert to solar?	
Would he be willing to operate or to hire to purchase?	
In the case of hire to purchase, would he be willing to pay 30% of investment cost?	

11.2. **Proposed Systems’ design**

11.2.1. Voltage drops in micro-grid

The voltage drops for 25 mm^2 aluminium conductor, XPLE insulated cable are 2.40 mV/Amp/m [24].

For the households’ system, it is assumed that the micro-grid will have a maximum radius of 250 meters. From the inverter characteristics, the maximum amperage per phase is 4.3 A. Therefore the maximum voltage drop is:

$$\frac{0.0024\frac{V}{A}}{m} * 250\ m * 4.3\ A = 2.6\ V$$

That is equal to 1.1% voltage drop for a 230 V grid.

The same way, for the markets’ system, it is assumed that the micro-grid will have a maximum radius of 150 meters. From the inverter characteristics, the maximum amperage per phase is 1o A. Therefore the maximum voltage drop is:

$$\frac{0.0024\frac{V}{A}}{m} * 150\ m * 10\ A = 3.6\ V$$

That is equal to 1.5% voltage drop for a 230 V grid.

11.2.2. Solar PV system components' data sheets

Electrical data - All data refers to STC (AM 1.5, 1000W/m², 25°C)

Type	ELV 275	ELV 280	ELV 285	ELV 290	ELV 295	ELV 300
Nominal power Pmpp (0~+4.99Wp)	275	280	285	290	295	300
Nominal voltage Vmpp (V)	35.80	36.00	36.20	36.40	36.60	36.80
Nominal current Impp (A)	7.70	7.80	7.90	8.00	8.10	8.20
Open circuit voltage Voc (V)	44.60	44.80	45.00	45.20	45.40	45.60
Short circuit current Isc (A)	8.35	8.45	8.50	8.60	8.70	8.80
Module efficiency (V)	14.32	14.58	14.84	15.10	15.36	15.62

* Electrical Parameters tolerance ± 3% except Pmpp

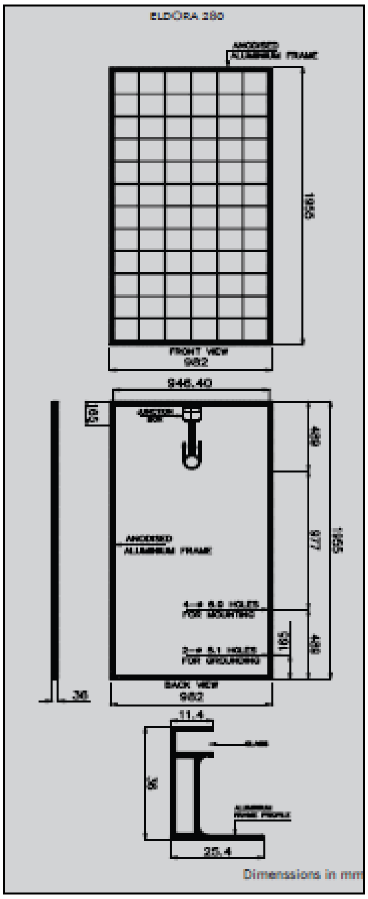
Temperature coefficients (Tc) and permissible operating conditions

Tc of Open circuit voltage (β)	-0.32 % /°C
Tc of short circuit current (α)	0.04 % /°C
Tc of Power (γ)	-0.45 % /°C
Maximum system voltage	1000 V(TUV), 600V(UL)
NOCT	45°C ± 2°C
Temperature range	-40°C to + 85°C

* NOCT irridance 800 w/m², ambient temperature 20° C, wind speed 1 m/sec

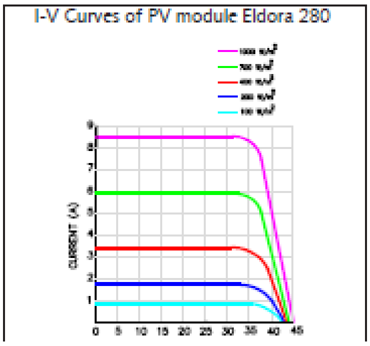
Mechanical specification

Length	1955 ± 1.5mm
Width	982 ± 1.5mm
Height	36mm (Optional 42mm)
Weight	20.50 Kgs
Junction Box	IP65, sunbolts / Tyco with 3 bypass diodes
Cable & Connectors	4mm², TUV & UL Certified, 1000 mm
Application class	CLASS A (Safety Class II)
Front cover	High Transmission, Low Iron, Tempered Glass
Cells	72 pcs poly-crystaline solar cells (156 X 156mm), 2BB & 3BB
Cell encapsulation	EVA (Ethylene Vinyl Acetate)
Back cover	Composite film
Frame	Anodized aluminium frame with twin wall profile
Maximum surface load capacity	According to IEC 61215, 5400 Pa



Guarantees and Certifications

Product Warranty**	5 Years
Performance Guarantee**	Guaranteed Power Output of 90% for 10 Years and 80% for 25 Years
Approvals and Certificates	TUV: IEC 61215 Ed.2, IEC 61730, IEC 61701, UL1703, MCS, CEC Listed



Packing Information

Quantity/Pallet: 28
Pallets/Container (40'HC): 24
Quantity/Container (40'): 672

Your specialty retailer:

Figure 33. Technical specifications of VikramSolar ELV 280

		FLEXmax 80 - FM80-150VDC	FLEXmax 60 - FM60-150VDC
Nominal Battery Voltages		12, 24, 36, 48, or 60 VDC (Single model - selectable via field programming at start-up)	
Maximum Output Current		80A @ 104°F (40°C) with adjustable current limit	60A @ 104°F (40°C) with adjustable current limit
NEC Recommended Solar Maximum Array STC Nameplate		12 VDC systems 1000 Watts / 24 VDC Systems 2000 Watts 48 VDC systems 4000 Watts / 60 VDC Systems 5000 Watts	12 VDC systems 750 Watts / 24 VDC Systems 1500 Watts 48 VDC systems 3000 Watts / 60 VDC Systems 3750 Watts
PV Open Circuit Voltage (VOC)		150 VDC absolute maximum coldest conditions / 145 VDC start-up and operating maximum	
Standby Power Consumption		Less than 1 Watt typical	
Power Conversion Efficiency		97.5% @ 80 Amps DC in a 48 VDC System - Typical	98.1% @ 60 Amps DC in a 48 VDC System - Typical
Charging Regulation		Five Stages: Bulk, Absorption, Float, Silent and Equalization	
Voltage Regulation Set points		13 to 80 VDC user adjustable with password protection	
Equalization Charging		Programmable voltage setpoint and duration - automatic termination when completed	
Battery Temperature Compensation		Automatic with optional RTS installed / 5.0 mV per °C per 2V battery cell	
Voltage Step-Down Capability		Down convert from any acceptable array voltage to any battery voltage. Example: 72 VDC array to 24 VDC battery; 60 VDC array to 48 VDC battery	
Programmable Auxiliary Control Output		12 VDC output signal which can be programmed for different control applications (maximum of 0.2 Amps DC)	
Status Display		3.1" (8 cm) backlit LCD screen - 4 lines with 80 alphanumeric characters total	
Remote Display and Controller		Optional MATE3, MATE or MATE2 with RS232 Serial Communications Port	
Network Cabling		Proprietary network system using RJ-45 Modular Connectors with CAT5 Cable (8 wires)	
Data Logging		Last 128 days of operation: Amp Hours, Watt Hours, Time in Float, Peak Watts, Amps, Solar Array Voltage, Max. Battery Voltage, Min Battery Voltage and Absorb, Accumulated Amp Hours, and kW Hours of production	
Operating Temperature Range		-40 to 60°C (power automatically derated above 40°C)	
Environmental Rating		Indoor Type 1	
Conduit Knockouts		One 1" (35 mm) on the back; One 1" (35 mm) on the left side; Two 1" (35 mm) on the bottom	
Warranty		Standard 5 year / Available 10 Year	
Weight	**Unit**	12.20 lbs (5.56 kg)	11.65 lbs (5.3 kg)
	Shipping	15.5 lbs (7.3 kg)	14.90 lbs (6.7 kg)
Dimensions (H x W x D)	**Unit**	16.25 x 5.75 x 4.5" (41.3 x 14.6 x 11.4 cm)	13.75 x 5.75 x 4.5" (35 x 14.6 x 11.4 cm)
	Shipping	19 x 9.5 x 8.5" (48.3 x 24.1 x 21.6 cm)	17 x 9.5 x 8.5" (43.2 x 24.1 x 21.6 cm)
Options		Remote Temperature Sensor (RTS), HUB4, HUB10, MATE, MATE2, MATE3	
Menu Languages		English & Spanish	
Certifications		ETL Listed to UL1741, CSA C22.2 No. 107.1	

Figure 34. Technical specifications for charge controllers FleMax 60 and 80

		FX2012ET	FX2024ET	FX2348ET	VFX2612E	VFX3024E	VFX3048E
Nominal DC Input Voltage		12 VDC	24 VDC	48 VDC	12 VDC	24 VDC	48 VDC
Continuous Power Rating at 25°C (77°F)		2000 VA	2000 VA	2300 VA	2600 VA	3000 VA	3000 VA
AC Voltage/Frequency		230 VAC/ 50 Hz	230 VAC / 50 Hz	230 VAC / 50 Hz	230 VAC / 50 Hz	230 VAC / 50 Hz	230 VAC / 50 Hz
Continuous AC RMS Output at 25°C (77°F)		8.7 Amps AC	8.7 Amps AC	10 Amps AC	11.3 Amps AC	13 Amps AC	13 Amps AC
Idle Power	**Full**	~ 20 Watts	~ 20 Watts	~ 23 Watts	~ 20 Watts	~ 20 Watts	~ 23 Watts
	Search	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts	~ 6 Watts
Typical Efficiency		90%	92%	93%	90%	92%	93%
Total Harmonic Distortion	**Typical**	2%	2%	2%	2%	2%	2%
	Maximum	5%	5%	5%	5%	5%	5%
Output Voltage Regulation		± 2%	± 2%	± 2%	± 2%	± 2%	± 2%
Maximum Output Current	**Peak**	28 Amps AC	35 Amps AC	35 Amps AC	28 Amps AC	35 Amps AC	35 Amps AC
	RMS	20 Amps AC	25 Amps AC	25 Amps AC	20 Amps AC	25 Amps AC	25 Amps AC
AC Overload Capability	**Surge**	4600 VA	5750 VA	5750 VA	4600 VA	5750 VA	5750 VA
	5 Seconds	4000 VA	4800 VA	4800 VA	4000 VA	4800 VA	4800 VA
	30 Minutes	2500 VA	3100 VA	3100 VA	3100 VA	3300 VA	3300 VA
AC Input Current Maximum		30 Amps AC	30 Amps AC	30 Amps AC	30 Amps AC	30 Amps AC	30 Amps AC
AC Input Voltage Range (MATE Adjustable)		160 to 300 VAC	160 to 300 VAC	160 to 300 VAC	160 to 300 VAC	160 to 300 VAC	160 to 300 VAC
AC Input Frequency Range		44 to 56 Hz	44 to 56 Hz	44 to 56 Hz	44 to 56 Hz	44 to 56 Hz	44 to 56 Hz
DC Input Voltage Range		10.5 to 17 VDC	21 to 34 VDC	42 to 68 VDC	10.5 to 17 VDC	21 to 34 VDC	42 to 68 VDC
Continous Battery Charge Output		100 Amps DC	55 Amps DC	35 Amps DC	120 Amps DC	85 Amps DC	45 Amps DC
Temperature Range	**Rated**	0 to 50°C (power derated above 25°C)			0 to 50°C (power derated above 25°C)		
	Maximum	-25 to 60°C (Functions, but does not necessarily meet all component specifications)			-25 to 60°C (Functions, but does not necessarily meet all component specifications)		
Warranty		Standard 5 year Warranty			Standard 5 year Warranty		
Weight	**Unit**	29 kg (62 lbs)			28 kg (61 lbs)		
	Shipping	31 kg (67 lbs)			31 kg (67 lbs)		
Dimensions (H x W x L)	**Unit**	33 x 21 x 41 cm (13 x 8.24 x 16.25")			30 x 21 x 41 cm (12 x 8.25 x 16.25")		
	Shipping	55 x 33 x 56 cm (21.75 x 13 x 22")			55 x 33 x 56 cm (21.75 x 13 x 22")		

Figure 35. Technical specifications of Outback 3.5 kW inverter (VFX3048E)

		GS7048E
Nominal DC Input Voltage		48 VDC
Continuous Output Power at 25°C		7000 VA
AC Output Voltage (selectable)		230 VAC (210 - 250 VAC)
AC Output Frequency (selectable)		50 or 60 Hz
Continuous AC RMS Output Current at 25°C		30 AAC
Idle Power	**Full**	34 W
	Search	10 W
Typical Efficiency		92%
Total Harmonic Distortion	**Total harmonic current**	<5%
	Maximum single voltage harmonic	<2%
Output Voltage Regulation		± 2%
Maximum Output Current	**1 ms peak**	100 AAC
	100 ms RMS	70.7 AAC
AC Overload Capability	**100 ms surge**	16.3 kVA
	5 seconds	11.5 kVA
	30 minute	7.9 kVA
Maximum AC Input Current		50 AAC
AC Input Voltage Range (adjustable)		170 to 290 VAC
AC Input Frequency Range		45 to 65 Hz
DC Input Voltage Range		40 to 68 VDC
Continuous Battery Charge Output		100 ADC
Temperature Range	**Rated**	-20 to 50°C (power derated above 25°C)
	Maximum*	-40 to 60°C
Warranty		Standard 5 year Warranty
Weight	**Unit**	125 lbs / 56.7 kg
	Shipping	140 lbs / 63.5 kg
Dimensions H x W x D	**Unit**	28 x 16 x 8.7" / 71.1 x 40.6 x 22.1 cm
	Shipping	14.5 x 34.5 x 21" / 36.8 x 87.6 x 53.3 cm
Accessory Ports		Remote Temperature Sensor and MATE3/HUB Communications
Non-volatile Memory		Yes
Field Upgradable Firmware		Yes
Chassis Type		Vented
Certifications		IEC 62477-1 AS4777.2 and AS4777.3, EN 61000-6-1, EN 61000-6-3, EN 61000-3-3, CE, RoHS compliant per directive 2011/65/EU

Figure 36. Technical specifications of Outback 7 kW inverter

11.2.3.Micro-grid components quotation

TARA
Society for Technology and Action for Rural Advancement
B-32, TARA Crescent, Qutub Institutional Area
New Delhi - 110016, INDIA
Tel: 91 (11) 2654 4255, 2654 4100, Fax: 91 (11) 2685 1158
e-mail: taratech@devalt.org, Web: www.tara.in

To,

Rakman Industries Ltd.
E-2, Sector - VII, Noida - 201 301 (U.P)
PH:- 0120-2423262/4262667
Dated: 24.06.2014

Purchase Order

Dear Sir,

1. **Ref:** Your Quotation W.E.F.11th June, 2014; we are pleased to place a confirmed order for AB cable accessories, Unarmored cables set as mentioned in the enclosed Quotation.

S.no	Item	Quantity	Rate(in Rs./unit)	Tax(%)	Amount (in Rs.)
1	3C x 25sq.mm + 25 sq.mm bare messenger,XLPE Insulated AB Cable	8000 m	75	5	6,30,000.00
2	Dead End Clamp	100 pcs	70	14	7,980.00
3	Piercing Connector	500 pcs	54	14	30,780.00
4	Suspension Clamp	500 pcs	60	14	34,200.00
5	I-Bolt	500 pcs	42	14	23,940.00
6	Stay Wire	250 kgs	63	5	16,537.50
7	Stay Set (14mm)	20 pcs	450	14	10,260.00
8	Flat Al. 2 x 2.5 Core Unarmored PVC cable	10000 m	9	5	94,500.00
			Grand Total - (Inclusive of Taxes)	Rs.	8,48,197.50

Terms and Conditions:

1. Kindly raise the invoice in the name of Society for Technology and Action for Rural Advancement , New Delhi
2. The cables shall be delivered to – Gopalganj District , Bihar
3. Rakman Industries Ltd. will deliver the material within seven days from receipt of payment.
4. Any other taxes, duties, levies, entry tax/local govt. taxes, octroi charges which ever are applicable during the time of dispatch will be paid by TARA
5. 50 % of total amount will be paid as advance.Balance will be paid when material is ready for dispatch.
6. Quality of material will be according to TARA's quality plan

E & OE for TARA

Society For Technology & Action For Rural Advancement

Authorized Signatory

Gp. Capt. Deepak Verma (Retd.)
Head-Administration

The cost in this quotation are updated to June 2014, the ones used were the values available during the realization of the financial model. Nevertheless, the costs are very similar.

Figure 37. Quotation for micro-grid components provided by TARA

11.3. **Financial Model**

11.3.1. Yearly diesel price increase calculation

The following table shows the monthly prices for diesel in major cities of India 2013 and 2014.

Month	Delhi (INR/L)	Kolkata (INR/L)	Mumbai (INR/L)	Chennai (INR/L)	Average (INR/L)
1-June-14	57.28	61.97	65.84	61.12	61.55
13-May-14	56.71	61.38	65.21	60.5	60.95
1-Apr-14	55.49	60.11	63.86	59.18	59.66
1-Mar-14	55.48	60.09	63.86	59.17	59.65
1-Feb-14	54.91	59.5	63.23	58.56	59.05
4-Jan-14	54.34	58.91	62.6	57.95	58.45
21-Dec-13	53.78	58.18	60.8	57.32	57.52
1-Dec-13	53.67	58.08	60.7	57.23	57.42
1-Nov-13	53.1	57.49	60.08	56.61	56.82
1-Oct-13	52.54	56.9	59.46	56.01	56.23
1-Sep-13	51.97	56.33	58.86	55.37	55.63
1-Aug-13	51.4	55.74	58.23	54.76	55.03
2-Jul-13	50.84	55.16	57.61	54.15	54.44
1-Jul-13	50.26	54.57	56.99	53.54	53.84
1-Jun-13	50.25	54.56	57.79	53.53	54.03
23-May-13	49.69	53.97	57.17	52.92	53.44
11-May-13	49.69	53.97	56.04	52.92	53.16
16-Apr-13	48.67	52.91	54.92	51.82	52.08
1-Apr-13	**48.63**	**52.86**	**54.87**	**51.78**	**52.04**
22-Mar-13	48.67	52.57	54.83	51.78	51.96
16-Feb-13	48.16	52.04	54.26	51.23	51.42
17-Jan-13	47.65	51.51	53.71	50.68	50.89

Table 57. Diesel prices in major cities of India during 2013 and 2014 (2014) [25]

From these data, the yearly diesel price increase was calculated, being 14% for 2013 and 5% during half a year of 2014. These values were averaged, obtaining the 10% yearly increase that was used in the financial model.

11.3.2. LED specifications

The prices and specifications of different LED's were provided by HAVELLS through an email conversation.

TECHINCAL SPECIFICATION												
	Electric											
Description	Power (W)	PF	Ra	CCT/K	Total Flux(lm)	Total Eff. (lm/W)	RATED FREQUENCY	LAMP VOLTAGE	OPERATING TEMP	LENGTH	MAXIMUM DIA
A60 5W 200-240V 6500K B22D	5.00	0.97	76	6500	400.0	80.0	50-60HZ	220-240V	"=-15 C-+ 50 C"	104 MM	60 MM
A60 5W 200-240V 3000K B22D	5.00	0.97	71	3000	380.0	76.0	50-60HZ	220-240V	"=-15 C-+ 50 C"	104 MM	60 MM
A60 7W 200-240V 6500K B22D	7.00	0.97	75	6500	500.0	71.4	50-60HZ	220-240V	"=-15 C-+ 50 C"	117 MM	60 MM
A60 7W 200-240V 3000K B22D	7.00	0.97	70	3000	480.0	68.6	50-60HZ	220-240V	"=-15 C-+ 50 C"	117 MM	60 MM
LED CANDLE 3W 6500K B22D	3.00	0.50	70	6500	200.0	66.7	50-60HZ	220-240V	"=-15 C-+ 50 C"	105 MM	37 MM
LED CANDLE 3W 3000K B22D	3.00	0.50	70	3000	170.0	56.7	50-60HZ	220-240V	"=-15 C-+ 50 C"	105 MM	37 MM

Figure 38. Technical specification for HAVELLS LED [22]

11.3.3. Diesel consumption for serving markets

Since no DG operator that serves the exact load proposed for the markets' package was interviewed, the daily diesel consumption was calculated as using the specific diesel consumption for a 5 KVA generator and the energy to be supplied to the market per day.

Parameters	Values	Units
Diesel density	832	g/L
Specific diesel consumption for a 5 KVA generator [26]	275	g/KWh
Diesel consumption per KWh	0.331	L/kWh
Energy supplied to the market per day	22	KWh/day
Efficiency at part load	75%	
Diesel consumption per day	**9.7**	**L/day**

Table 58. Values for the calculation of daily diesel consumption (2014)