Names of different land areas:

<table>
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<tr>
<th></th>
<th>Square Meter</th>
<th>Hectare (Ha)</th>
<th>Acre</th>
<th>Bigha (Gujarat)</th>
<th>Bigha (Bihar)</th>
<th>Katha (Bihar)</th>
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<td>0.000247</td>
<td>0.00062</td>
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<td>Hectare (Ha)</td>
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<tr>
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<td>Katha (Bihar)</td>
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<td>0.031</td>
<td>0.079</td>
<td>0.05</td>
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1 Lakh = 100,000 (English numbering) = 1,00,000 (Indian numbering system)
1 Crore = 10,000,000 (English numbering) = 1,00,00,000 (Indian numbering system)
Approximately 70 Indian Rupees (Rs) = 1 Euro (XE, 2015)
Approximately 64 Indian Rupees (Rs) = 1 Dollar (XE, 2015)
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternative current</td>
</tr>
<tr>
<td>CCGT</td>
<td>Combined-cycle gas turbines</td>
</tr>
<tr>
<td>CGIAR</td>
<td>Consortium group of International agricultural research</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CSP</td>
<td>Concentrated solar power</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DSM</td>
<td>Demand-side management</td>
</tr>
<tr>
<td>GW(h)</td>
<td>Gigawatt(-hour) (10^9 Watt(-hour))</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>hp</td>
<td>Horse power</td>
</tr>
<tr>
<td>IRMA</td>
<td>Institute of Rural Management Anand</td>
</tr>
<tr>
<td>IWMI</td>
<td>International Water Management Institute</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt (10^3 Watt)</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt-hour, locally know as a “Unit”</td>
</tr>
<tr>
<td>MW(h)</td>
<td>Megawatt(-hour) (10^6 Watt(-hour))</td>
</tr>
<tr>
<td>NABARD</td>
<td>National Bank for Agriculture and Rural development</td>
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<tr>
<td>PV</td>
<td>Photo voltaic</td>
</tr>
<tr>
<td>SLDC</td>
<td>State Load Despatch Centre</td>
</tr>
<tr>
<td>SIPs</td>
<td>Solar Irrigation Pumps</td>
</tr>
<tr>
<td>TW(h)</td>
<td>Terawatt(-hour) (10^12 Watt(-hour))</td>
</tr>
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</table>
SOLARIZING INDIAN AGRICULTURE BY DEPLOYING SOLAR IRRIGATION PUMPS
Solarizing Indian agriculture by deploying solar irrigation pumps

<table>
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<th>Report Title</th>
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<tr>
<td>Placement title</td>
<td>Intern</td>
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<tr>
<td>Internship duration</td>
<td>February, 2015 - July, 2015</td>
</tr>
<tr>
<td>Author</td>
<td>Dekker, Tobias Dylan</td>
</tr>
<tr>
<td>Company</td>
<td>International Water Management Institute (IWMI)</td>
</tr>
</tbody>
</table>
| Number of employees | Anand: 6  
|                  | Total: 300 |
| Address      | Anand: IWMI-India Water Policy Program "Jal Tarang", Near Smruti Apartment, Behind IRMA, Mangalpura, Anand, Gujarat, India  
|              | Head office: 127, Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka |
| Company tutor | Tushaar Shah |
| Function/Institution | Senior Fellow, International Water Management Institute |
| Academic tutor | Mark Howells & Dimitris Mentis |
| Function/Institution | Professor & Researcher in Energy Systems Analysis / KTH Royal Institute of Technology |

Summary

Solar irrigation pumps (SIPs) will bring a big change in India. Farmers with SIPs will be able to pump for almost zero marginal cost and can so irrigate at a very low cost. Lessons learned from SIPs already in place in the pioneer state Rajasthan in India will be discussed. As well as the possible advantages of a loan product to finance SIPs. The last part will be about the research that was done about how the grid would be able to function stable with solar being (a big) part of the generation techniques.
1 Abstract

Solar Irrigation Pumps (SIPs) are used to pump (ground and surface) water to irrigate farm lands. In a country with a historical mismatch of energy supply and demand, and almost 120 million families dependent on earnings from agriculture (Prachi Salve, 2014), SIPs offer great prospects. Unlike electric and diesel pumps – dominating the market till today – SIPs have almost zero marginal costs. This leads to extra crop production at negligible costs and also generation of electricity when not being used for pumping. Due to almost zero emissions, it simultaneously addresses the issue of climate change hence bringing prosperity to the population at all levels.

SIPs are a new phenomenon in India and due to the comparatively\(^1\) high capital costs, SIPs require subsidies to make them affordable for a farmer. Support in the form of subsidies has been given to around 15,000 farms in the whole country. By introducing solar pumps on a subsidy scheme in 2009-2010, Rajasthan has become the pioneer state of India. Since then numerous solar pumps have been deployed and farmers have gained experience with their usage. These farmers appear to be happy with the functioning of the pumps; 95% of the farmers, who gained enough knowledge to answer the question, say that the pump works better than their diesel or electric pump. A surprising finding is that the project cost per pump is getting higher while the pumps are getting cheaper. This means that the government is using more money to run the project. To find the reasons for the rising project costs and to find a way to decrease them, further research is needed. If the project cost could be decreased more pumps could be supplied with the same amount of subsidy.

It was also found that the SIPs were not successful in replacing the electric and diesel pumps. The diesel and electric pumps had more horse power (hp) so were able to pump more water resulting in irrigation of more land in the same amount of time. Farmers expressed they could fully switch to SIPs when more powerful pumps were supplied.

Because the present SIPs are off grid systems, it is not possible to sell the excess electricity that is not needed for pumping water. Because there are no marginal costs, there is no incentive for switching off the machines either. The consequence is excessive pumping of water leading to groundwater depletion. An important improvement would be to connect these pumps to the electricity grid. The possibility to earn some money with delivering energy would probably be a good reason to stop needless pumping.

The subsidy program that was in place in Rajasthan had an 86% capital subsidy (the farmer had to pay only 14% of the price of SIP). With the available money only 10,000 pumps per year could be supplied (Dr. Dinesh Kumar Goyal, 2013). When the subsidy per pump is decreased more pumps could be deployed and it was shown that even with a lower subsidy getting a SIP will still be attractive.

One of the points of improvement for a quick roll out of SIPs might be found in the way these pumps are financed. Pumps have a high capital cost and are currently financed by 70-90% capital subsidies of the government. The amount of total subsidy is limited and so with a high percentage of subsidy a small amount of pumps are deployed by this subsidy. These subsidies could be dramatically reduced when a loan/lease product would be put in place. Without a bank loan farmers are unable to pay the major part of the capital cost of the pump. Offering a bank loan is a win-win situation for the farmers and the people of India, represented by the government. With these pumps farmers are able to sell electricity to the grid and earn extra income or they can sell water to other farmers for a price below the price of current diesel pumping. With this income they could pay off the loan in 7 years and earn a reasonable income. The people of India will not only benefit by having to pay less for subsidies, they will also benefit from less greenhouse gas emissions as solar has almost zero emissions compared to mainly coal based electricity pumps and diesel pumps.

SIPs supplying electricity can have a big effect on grid stability. Hence, in chapter 6 the question of grid stability was raised. Under what conditions can the Indian grid deal with a large amount of electricity injected from SIPs. India currently has 70% of the electricity produced from coal power plants while 3% comes from Nuclear power plants (Trading Economics, 2011a). These sources have a response time of several hours which is not quick enough to respond to fluctuations in the demand of energy by for example households, or

\(^{1}\) The cost is 10-30 times higher than a diesel or electric pump depending on the size of the pump and the amount of solar panels.
a change in production by other sources, for example solar. The present sources should be partly replaced by quick response sources like the renewable sources and gas turbines. Currently 6% of the installed capacity is a gas power plant (Central Electricity Authority, 2015) but this percentage should be increased. Also other solutions should be implemented, such as developing storage of energy and more interconnections between grids of states and other countries.

Since the idea is that SIPs would not use electricity from the grid anymore unlike electric pumps, 25% of electricity currently used from the grid by agriculture will be less. The current electric pumps only get electricity for certain hours a day and are used to balance the grid, only at times of low electricity use of other users, farmers will get electricity. When the electric pumps are replaced by SIPs that do not use electricity from the grid the balancing function that the electric pumps currently fulfil will no longer be present. Having no experience with SIPs connected to the grid so far, it will be difficult for the state load dispatch centres, which manage the grid, to schedule the expected load. Hence, pilots should be set up to find out how these pumps are used throughout the day so that in the future these loads can be predicted. In Gujarat the solar installed capacity could easily be a fivefold without having to invest in extra capacity of quick responsive sources, since enough installed capacity of gas turbines is already in place but currently not used. Extra investment would be needed in the grid in order to be able to transmit so much electricity over the grid from the (distributed) solar plants.

Solar irrigation pumps, when implemented correctly, can not only lead to much cheaper irrigation for farmers but also less groundwater depletion and a source of extra income. Solar pumps can lead the way to more prosperity for the Indian people, but new guidelines and plans have to be made by the government to realise this potential. Without policy changes as described in this thesis SIPs benefit a small number of lucky farmers at the expense of the larger whole (wasting public money and groundwater).
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2 Acknowledgement

A big acknowledgment goes to Dimitris Mentis for the helpful feedback he gave and the speed at which these responses were given. Without his help this thesis would have been far less structured and useful. I would also like to thank Mark Howells and Shahid Hussain Siyal from KTH for their feedback and help. I would also like to thank the KTH as a whole because without the scholarship I received I would not have been able to pursue this experience in India.

In India a lot of valuable feedback and insights were given by my supervisor Tushaar Shah. I would also like to thank Neha Durga and Shilp Verma for teaching me what the important aspects are of agriculture in India. Amit Patel was a valuable companion for the field work. The administrative work was made easy with the help of Poozhiyil Reghu. Last but not Jagdish Yadav was a source of happiness that he managed to spread around the office and the teas he brought were delicious.

The whole adventure of the ME3 program wouldn’t have been such a positive experience without my fellow classmates, called the ME3 family. Every semester we grew more closely together and I managed to learn a lot from all of them. I would especially like to thank Sindhu Mamillapalli for her support and valuable proofreading.
3 Introduction
The thesis will look into the current usage and the possible improvements that can be made in the policies for deploying the use of Solar Irrigation Pumps (SIPs). An introduction to the background of the organisation in which this research was done (the International Water Management Institute (IWMI)), solar irrigation pumps its advantages and disadvantages as well as a small section on the limitations of this study and a section on theory versus reality is given in this chapter.

In chapter 4, the current status and lessons learned about the current deployment of Solar Irrigation Pumps in the state of Rajasthan in India can be found. In the following chapter, a financial model will be discussed that looks into the possibility of maximizing the usage of solar pumps by using the opportunities of selling water or electricity while taking care of other current problems related to solar pumps. Another important part of solar irrigation pumps and solar energy in general is the ability of the electricity grid to deal with these changing loads. This was studied and the results can be found in chapter 6.

Chapter 4, 5 and 6 can be read as separate papers since they have their own background and objective section. The only information needed to read either of these three chapters is a basic knowledge about farming in India and solar irrigation pumps.

3.1 The International Water Management Institute (IWMI)
IWMI is a non-profit, scientific research organization focusing on the sustainable use of water and land resources in developing countries. It is headquartered in Colombo, Sri Lanka, with regional offices across Asia and Africa. IWMI works in partnership with governments, civil society and the private sector to develop scalable agricultural water management solutions that have a real impact on poverty reduction, food security and ecosystem health. IWMI is a member of Consortium group of International agricultural research (CGIAR), a global research partnership for a food-secure future. This paragraph was quoted from (“Who we are: IWMI,” n.d.)

3.1.1 Anand field office
This research took place in the regional office of IWMI in Anand, a city in Gujarat. This research was done as part of the Energy-Irrigation nexus as a continuation of the research done by employees of IWMI. In the past, two papers were published about Solar Irrigation Pumps, which will be discussed in literature review, and in December 2014 interns did research about the current state of Solar Irrigation Pumps in Rajasthan, since farmers had gained more knowledge about the solar pumps since the research had been done for the last paper. This research was used to draw conclusions and insights presented in chapter 3.
3.1.2 Literature review

At two instances before IWMI has published about the experiences in solar pumps in Rajasthan. The first time was in 2012 (Nidhi Prabha Tewari, 2012), when the solar pumps had just been used for a time between 1 and 6 months. That paper explains the subsidy in place and the farmers experiences from which it concludes that solar pumps have a bright future. Two years later the farmers were more experienced and a more in depth study was done with 107 farmers (Kishore et al., 2014). It revealed the kind of subsidy scheme that is deployed in Rajasthan and how it works. The paper concludes that entry barriers for participating suppliers should be lowered in order to increase competition and that the subsidies should be much lower than the 86% that was then given and the subsidy should be given on a lump sum basis (an fixed amount per horse power (hp) of the pump) instead of a pro rate (the 86% of whatever configuration is chosen).

IWMI has not done any prior research on the topics of a financial model, which is a model that simulates how to best financially deploy solar irrigation pumps in order for the most people to benefit, or how to integrate solar into the grid.

3.1.3 Objectives

Goal of the research is to make impact by publishing the results in papers which are read by policy makers who can implement it. The papers should detail the current state, the problems and the possible improvements explaining the advantages and disadvantages of these improvements so that the policy makers make a well-balanced decision. The past has shown that these papers do have such an effect. The improvements that have been discussed in papers such as reduced subsidy in Rajasthan and a lump sum amount of subsidy are now incorporated into the new subsidy schemes.
3.2 Introduction to solar pumping

Solar energy in India has a huge potential. An installed capacity of 1000 GW of solar could generate 1500 TWh, which is 1.5 times India’s current electricity demand. This 1000 GW can be installed on 16,000 km², only 0.5% of India’s landmass (Tobias Engelmeier et al., 2014). In 2013, almost 18% of India’s total electricity was used for agriculture (EMIS, 2014). Furthermore 55, almost 263 million, of the working population works on agriculture & allied activities, the last time when it was counted in 2011 (Jyotika Sood, 2013). Hence proper and low cost irrigation can have a big impact in India. Solar irrigation pumps will play a definite part of changing India’s energy landscape into the use of solar energy.

Solar pumps are viable in countries with adequate solar radiation and a significant need of pumping water for irrigation or other purposes, when the grid connection is unavailable or not strong enough. Other countries that are dominantly using solar irrigation pumps are Pakistan, Bangladesh, Nepal and Kenya. Exact numbers of the amount of solar irrigation pumps in other countries are unknown but according to SunEdison (“SunEdison: The Global Market For Solar Irrigation Is Almost Limitless,” 2014) India is currently the largest user of solar irrigation pumps. In Nepal an earthquake happened on the 25th of April 2015 leaving people without electricity and water (“Earthquake rocks Nepal - as it happened - BBC News,” 2015). Solar irrigation pumps could quickly bring electricity and water in those cases while not having to wait for the reparations of the electricity cables and water pipes. A charity organisation is now offering Solar irrigation pumps in order to help people. (“Energy-Poor Nepal Looks to Solar for Post-Quake Power,” 2015)

3.3 What is a solar irrigation pump?

A solar irrigation pump is a water pump that uses electricity produced from solar panels to pump the water (Kishore et al., 2014).

When going through Figure 2 from left to right the first part is the solar Photo voltaic (PV) panels. There are different technologies and configurations of panels. The number of solar panels needed will be decided on basis of the pump size. Solar PV manufacturing industry in India has many players who provide more or less the similar quality and efficiency of the panels. Another difference except for the number of solar panels is if
they have an (auto) tracker. An (auto) tracker is made so that the solar panels are moveable and will be in the right position to capture the full amount of sun rays.

The next part of the schematic is the water pump. The amount of water that can be pumped depends on the amount of input fuel (diesel or electricity), the efficiency of the pump and also the head. The head is the difference between the level of the tank and the groundwater level, so if the water is deeper lesser output is expected.

There are two different types of pumps depending on what type of input the pump needs: alternative current (AC) pumps and direct current (DC) pumps. AC is what comes out of the electricity socket in a normal house and DC is what comes out of a normal battery. An alternative current (AC) pump will only work if the energy level is above a certain level, so at the first rays of sun the AC pump will not start. The solar panels will give out electricity in a DC form so this has to be transformed to AC when an AC pump is used, that is done by the inverter. A direct current (DC) pump will not need this inverter and can start at any level but will not be very effective at those low levels of radiation. DC pumps are more effective at low levels of radiation than AC pumps but are also more costly in general.

Storage tanks in different sizes are used to store the water that is pumped. Some storage tanks are closed in order to have a little pressure difference so that the water can be distributed better. In most cases storage tanks are placed higher above the ground to compensate for the head that the water needs in order to be distributed. With both methods, when built correctly, water distribution can happen at a later point when the pump is not running anymore. The water that is stored in the tank can be used for irrigation when needed.

There are different types of agricultural irrigation (which are illustrated in Figure 3).

- **Flooding**: Irrigation by flooding the land with water. This has an efficiency of 40-50% (Dr. Dinesh Kumar Goyal, 2013) because the majority of the water will go into the earth while not being in contact with the seeds. So that part of the water will not help the crops grow but will just refill the groundwater table or vaporize. Since the water is not only supplied to the seeds it will also increase the amount of weeds grown, which need to be removed later. The advantage of this technique is that it is cheap. Some crops like rice can only be irrigated through this technique (see Table 1 below).
- **Open channels**: Channels made out of concrete, asphalt, clay or rubber to distribute the water while using gravitational force. (“Sourcebook of Alternative Technologies for Freshwater Augmentation in West Asia,” n.d.). Open channels are easy to construct and relatively inexpensive compared to sprinklers and drip. They can be used for any crop but are not very efficient. The efficiency is 50-60% (Dr. Dinesh Kumar Goyal, 2013)
- **Sprinklers**: Irrigation method that distributes water similar to how rainfall would have given the water, water is sprayed to the air. Sprinklers will distribute the water in a circle around the sprinkler. Sprinklers are mainly installed for high value crops. Compared to drip they are easier to install and less costly in investment cost, but also less efficient 50-70% compared to more than 90% (Wilson and Bauer, 2014)
- **Drip**: The most efficient technique with an efficiency of more than 90% (Wilson and Bauer, 2014). Drip lines are lines made out of rubber with small holes at a given distance (for example every 5 cm or every 10 cm). Water is sprinkled at a specified constant rate, for example every second, so there won’t be a continuous flow. The drip lines are engineered in a way that the drip outlet nearest to the water outlet is giving as much water as at the end of the drip line. In reality it is seen that the difference is not zero but minimal: the outlet at the furthest point from the distribution is showing 85% less output than nearest to the water distribution point (Bob Yoder, 2015)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Flood</td>
<td>Wheat, Rice, tomato, cotton</td>
</tr>
<tr>
<td>Open canal</td>
<td>All crops</td>
</tr>
<tr>
<td>Sprinklers</td>
<td>Aloe, capsicum, vegetables, cotton, soya bean, tea and coffee (high value crops)</td>
</tr>
<tr>
<td>Drip</td>
<td>All kinds of high value crops: tomato, cotton, banana, capsicum</td>
</tr>
</tbody>
</table>

Table 1 the possible crops that could be grown while using a specific irrigation technique
In Figure 2 no connection is made to the grid so this would be a stand-alone pump. As will be explained in more detail with an example in theory vs reality there are also configurations in which solar power are connected to the grid so that power can be either sold to the grid or used for pumping. Connecting a system to the grid will be more expensive since extra grid tie inverters are needed.

Figure 3 Different irrigation methods. Top left: Flood ("LevelBasinFloodIrrigation.JPG (2100×1500)," n.d.), Top right: Open channel ("waterproblem3.jpg (500×333)," n.d.), down left: Sprinkler ("irrigation-moveable-sprinkler.jpg (400×317)," n.d.), down right: Drip ("drip-irrigation-systems-1108018.jpg (650×520)," n.d.)

Figure 4 Solar irrigation pump ("maxresdefault.jpg (1920×1080)," n.d.)
3.4 Why solar irrigation pumps?
India uses more than 4 billion litres of diesel and around 85 million tons of coal per annum to support water pumping for irrigation (KPMG, Shakti Foundation, 2014). Replacement of 1 million diesel pumps with solar pumps would result in diesel use mitigation of 9.4 billion litres over the life cycle of solar pumps which translates into a CO2 emission abatement of 25.3 M Tonnes (KPMG, Shakti Foundation, 2014)

Table 2 Differences between Diesel, Electric and Solar Pumps

<table>
<thead>
<tr>
<th></th>
<th>Diesel Pump</th>
<th>Electric Pump</th>
<th>Solar Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less CO2 emissions</td>
<td>-</td>
<td>- (electricity generated with coal) (Trading Economics, 2011b)</td>
<td>+</td>
</tr>
<tr>
<td>Less Running cost</td>
<td>- (cost of diesel is around Rs 60/liter)</td>
<td>- (electricity for farmers is highly subsidized but is not free, it is around Rs 0.60 per kWh)</td>
<td>++ (almost no running cost except for some water to clean the panels and minor maintenance)</td>
</tr>
<tr>
<td>Fuel easily available</td>
<td>+/- (available in the nearby village mostly but a hassle to get)</td>
<td>- (in a lot of states farmers have a quota of usage and electricity is not always there)</td>
<td>+ (the sun is almost always available in India during daytime, in the rainy season, but then there is no need for it)</td>
</tr>
<tr>
<td>Subsidy</td>
<td>+ (In almost all states there are diesel subsidies for farmers)</td>
<td>++ (Electricity is sold to farmers at 10% of the cost of generation)</td>
<td>++ (in some states current subsidies are 70% of total capital cost)</td>
</tr>
<tr>
<td>Proven technology</td>
<td>++</td>
<td>++</td>
<td>- (has been only around for a few years)</td>
</tr>
<tr>
<td>Spread cost</td>
<td>++ (can buy diesel whenever the farmer wants, minor investment in the beginning for pump)</td>
<td>+/- (electricity bill comes every two months, investment in the beginning needed for pump and connection)</td>
<td>- - (high capital cost need to be paid upfront)</td>
</tr>
<tr>
<td>Land footprint of pump</td>
<td>++</td>
<td>++</td>
<td>+ (solar panels use a little bit extra land but space under solar panels can be used for high value crops)</td>
</tr>
</tbody>
</table>

There is also the possibility of manual pumps. Manual pumps are very rarely used for irrigation purposes since a large amount of water is needed for irrigation, so this will cost a lot of manual force to pump up this amount of water. The number of solar irrigation pumps are quickly increasing, the government plans to install 100,000 (1 lakh) solar pumps before 2020. There were 11,626 solar pumps in India on 31 March 2014 (Press Trust of India, 2014). Most of these pumps have been employed in the last few years.

Except from the above stated advantages and disadvantages there is one more major advantage:

- Perfect match between solar hours and usage: normally farmers use the pumps during the day when the sun is shining. In the Monsoon season, there is less possibility and need of using SIP due to heavy rains.

There is also an additional disadvantage:

- Over extraction of ground water leading to water table depletion: Low or almost no cost of pumping is an opportunity for many to pump water more than needed. This could be prevented by offering incentives to farmers to not pump the water above their need, which is not implemented in many states.

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2 ++ : very positive, - - : very negative, + : positive, - : negative
3.5 Limitations of this study
Data gathering and working efficiency are not the same in India as in developed countries. In the developed countries a lot of data is already gathered and publicly available for example on government sites, which is not the case in India. Because already a lot of research is done in developed countries data from these researches can be taken. In India, on the other hand, most techniques talked about in this thesis are just rolled out in the last few years and no data has been gathered so far because the focus is currently on rolling it out quicker. For this study only 26 weeks were available and, as can be understood, the speed at which data can be gathered has an effect on the quantity and the quality of the outcomes. The availability of electricity as well as (high speed) internet is another variable that decreases the working efficiency. There were numerous days at which no internet was available and so no papers or data could be sought.

Furthermore numerous days were spent in government offices for getting simple things done. For example in total 4 months were needed with weekly trips to government offices in order to get the pilot (see Reality vs theory) connected to the grid. Another limitation is the language barrier. In Gujarat, Hindi and Gujarati are widely spoken but English is spoken by a far lesser number of people. That resulted in not having the possibility of doing fieldwork alone.

3.6 Reality vs theory
In December 2014, IWMI Anand gave the assignment to start building a pilot project in a village called Thamna. The installation of the solar panels was finished in January 2015. The project is a solar irrigation pump for 1 farmer having a 7.5 hp pump, 8.5 kW solar panels and the possibility to sell power to grid with 8 kW capacity. This means that the farmer can choose to pump up water or sell electricity. A lot of data was gathered from this place also by the author. With this data it was easier to see how the theory worked in reality.

In theory, a solar system of 8 kWp should be able to produce 8 kW during peak time. But in reality it is seen that only 5.5 kW can be reached during peak times. The problems for not achieving the peak power were observed to be due to dirty solar panels (dust on top) decreasing the efficiency by 15-25% (Mathias Aarre Maehlum, 2013), no auto tracker and system set to 30 degree, instead of 22 degrees which is the latitude angle with the direction pure south. As shown by studies considerable extra output (10-40%) can be achieved when a tracker system is installed (Mehrtash et al., 2013). High temperatures might also decrease the output as shown by ("Effect of Temperature on Solar Panels - Solar," 2014). The temperature on the solar panels was measured to be 65˚C this would mean a decrease of 25%. These together might be the cause of the decreased efficiency. Another influence could be the shade on the solar panels due to the banana plants (see the start and end of the day. on the left side), but this only has an influence at the start and end of the day.

Figure 5 Left: shade on the solar panels in the left bottom corner. Right: Dust on the solar panel (right) vs cleaned (left)
While the land space under the solar panels should be able to be used for crops that do not need sun it is used at the pilot site for Eggplant. According to the farmer’s experience the crop output of the crops under the solar panel is only 30% of the same crop outside the solar panels. (Ramankaka, 2015)

Data was gathered on the site (Thamna) by checking the output of the different inverters and the export meter. This was gathered on a 30 min basis from sunrise at 6:15 AM till sunset at 6:30 PM when the inverters were switching off because of too less generation. A comparison was made with a solar park of 345 MW installed capacity in a region in the North West of Gujarat called Charanka. Both sources of data were plotted. As can be seen (in Figure 6) at the site where the author gathered the data there was a dip at 13:00 because the 3kW inverter stopped working. When compensated for that the difference of total generation is 30%, this can be due to shade, tilt angle and dust as explained above.

The big lesson learned is that when expecting an outcome of at least 7 kW in order to run the pump effectively more solar panels have to be installed and a tracking system has to be considered because the problem with temperature is inevitable.

![Figure 6 Comparison for 29th May of Charanka solar park (State Load Despatch Centre (SLDC), 2015) vs pilot site at Thamna](image)

4 Experience in Solar Irrigation pumps from Rajasthan

4.1 Introduction

Rajasthan is the pioneer state of installing solar irrigation pumps in India. Rajasthan is the state with the highest solar irradiance of India 6-7 kWh/m²/day (Dr. Dinesh Kumar Goyal, 2013) and approximately twice as much yearly radiation per square meter than in Germany (SolarGIS, 2015). Approximately 15,000 pumps have been installed till now as part of the subsidy scheme managed by the horticulture department. Farmers were very interested in this scheme since only 14% of the capital cost had to be paid by them of the total cost of 5 lakhs³ (Dr. Dinesh Kumar Goyal, 2013), approximately $7800 (XE, 2015).

For the year 2014-2015, the subsidy scheme has been changed to allow pumps of 5 hp instead of just 2.2 and 3 hp pumps. The subsidy has also decreased from 86% to 70%.

³ Lakh= 100,000
4.2 Objectives
The objective of this study was to better understand how the farmers were using the SIPs and what their opinion was on how well the SIPs worked. Since Rajasthan is the pioneer state and this is the first large scale implementation of a subsidized solar irrigation pump scheme valuable lessons can be learned that are applicable for other parts of India and the world.

4.3 Background
At two instances before IWMI has published about the experiences in Solar Pumps in Rajasthan. The first time was in 2012 (Nidhi Prabha Tewari, 2012), when the solar pumps had just been used for a time between 1 and 6 months. That paper explains the subsidy in place and the farmers experiences from which it concludes that solar pumps have a bright future. Two years later the farmers were more experienced and a more in depth study could be done with 107 farmers (Kishore et al., 2014). It shows what kind of subsidy scheme is deployed in Rajasthan and how it works. The paper concludes that entry barriers for participating suppliers should be lowered in order to increase competition and that the subsidies should be much lower than the 86% that was then given and the subsidy should be given on a lump sum basis (a fixed amount per hp of the pump) instead of a pro rate (the 86% of whatever configuration is chosen).

The Field research for this paper was done in December 2014 by two students of the Institute of Rural Management Anand (IRMA). The analyses that were done by the author complemented the analysis already done by the IRMA students. It included data from the hard copies of the surveys for which the IRMA students didn’t have time to include it in their analysis. The most useful analysis done by the author are included in this paper.

4.4 Methodology
The state of Rajasthan is divided into 33 districts. Of these districts the six districts with the largest amount of solar irrigation pumps installed are Ganganagar, Bikaner, Hanumangarh, Sikar, Jaipur and Bhilwara which in total have 68% of the installed pumps. Ganganagar, Bikaner and Hanumangarh are canal irrigated areas and the other three are solely dependent on groundwater for meeting their irrigation needs. A survey was conducted on 96 farmers, belonging to Ganganagar, Bikaner, Jaipur and Bhilwara. 23 of those farmers live in Sri Ganganagar, 20 come from Bhilwara, 29 come from Bikaner and 24 from Jaipur.

Of the farmers in the sample 44% has one year experience with the SIP, while 34% has two years of experience and the last 22% has three years of experience.

4.5 Results
4.5.1 Beneficiary
Sample clearly shows that most of the farmers with large landholdings have managed to get solar pumps. The average landholding was found to be 7.9 hectare (Ha.) while the average of land size for all farmers in Rajasthan is 3.65 Ha. 73 farmers from the sample also had an additional pump (electric, diesel or both) apart from the solar pump. 15 farmers even had multiple solar pumps, with one farmer having 4 solar pumps. In the sample there were no farmers that bought a SIP without making use of the subsidy scheme this means that all the solar pumps are bought by farmers under the solar pumping program run by the department of horticulture of the government of Rajasthan.

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Table 3 Amount of pumps deployed with the Rajasthan Solar Pumping program (Dr. Dinesh Kumar Goyal, 2013)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Pumps</th>
<th>Number of Districts</th>
<th>Capacity (kWp)</th>
<th>Total Cost (Rs. Cr)(^4)</th>
<th>Total Cost (Million $)</th>
<th>Subsidy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-11</td>
<td>34</td>
<td>6</td>
<td>97</td>
<td>1.8</td>
<td>0.28</td>
<td>100</td>
</tr>
<tr>
<td>2011-12</td>
<td>1,675</td>
<td>14</td>
<td>4,967</td>
<td>95.9</td>
<td>15</td>
<td>86</td>
</tr>
<tr>
<td>2012-13</td>
<td>4,000</td>
<td>33</td>
<td>13,340</td>
<td>258.3</td>
<td>40</td>
<td>86</td>
</tr>
<tr>
<td>2013-14</td>
<td>10,000</td>
<td>33</td>
<td>30,000</td>
<td>584.7</td>
<td>91</td>
<td>86</td>
</tr>
</tbody>
</table>

\(^4\) Cr=Crore=10 million
4.5.2 Utilization of Solar Pumps

It was found that on a summer day the solar pump delivers its peak output for about 7.5 hours and in winters it reduces to 5.5 hours. In monsoon season, which lasts for not more than a month in Rajasthan, a solar pump delivers its peak output only for 0:30 hours. As per the data, a solar pump delivers its peak discharge for about 2000 hours in a year. Farmers use around 1500 hours from these and the rest is surplus power which gets wasted. Therefore the current utilization of the pump is about 70%. The range of utilization of pumps across the farmers ranges from 100% to 26%. The solar pumps used to distribute stored water in the canal command area have a better utilization (75%) compared to the solar pumps which are used for pumping groundwater (67%). Since water availability is a bigger constraint in Rajasthan, the utilization of pumping tools is affected by water availability more than that of energy availability. The utilization of solar pumps was highest in Sri Ganganagar district with 79%. This can be attributed to the presence of large number of diesel pumps in the region, since diesel is an expensive source compared to electricity.

4.5.3 Local Market Dynamics

Most of the farmers know only one SIP manufacturer brand, out of the total 15 brands that are applicable for this subsidy scheme. This and further questions about why farmers choose this brand indicate that farmers choose the brand because they only knew one brand, the only dealer in their village was of that brand and/or their relatives use that brand. A further increase of brand awareness and a dealer network can increase competition and so increase the quality delivered.

4.5.4 Cropping patterns

In Monsoon the majority of the land is rain fed after that the solar pump is most popular way of irrigation. Cluster bean, locally known as Guwar, is mostly grown crop while being rain fed, while using the solar pump cotton is the most grown crop. In winter the solar pump is used as the main irrigation source, it irrigates the most land when compared to diesel or electric pumps. In winter mostly wheat is grown. In summer the amount of crops grown is really low because of the shortage of water but the crops that are grown are again grown mostly by the solar pumps. Especially Jaipur is active in summer where they grow mostly vegetables and chickpea (Chana). The annual crops are mostly horticultural crops grown with the help of solar pump.

Overall it can be seen that the solar pump is used for the biggest area of land. It is used for both high value and non-high value crops. Solar pumps also helped to irrigated 39 hectare of land that were not irrigated before.

4.5.5 Farmers Satisfaction and opinion

Most farmers are very satisfied with the pump, they say the pump operates better than a diesel or electric pump. Most farmers don’t perform any maintenance except for cleaning the pump. 20% of the farmers had to let their system be repaired but that was mostly due to the auto tracker5.

It’s observed that almost half of the farmers would buy a pump if they would get only 50% subsidy and no one would if they would not get any subsidy at all. Two third of the farmers would give up their grid connection if they had to in order to get a solar pump. 95% of the farmers, who gained enough knowledge to answer the question, say that the pump works better than their diesel or electric pump.

4.6 Discussion

4.6.1 Over the years: government gets more money per pump and manufacturer less

A very interesting observation arises when looking at the capital cost of the pump. As shown before in the state of Rajasthan more and more pumps have been deployed over the last year and also the amount of districts have increased till 33, including districts that just get 11 pumps compared to the 1300 of the biggest district. This table shows how the prices have changed over the years:

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5 a device that turns the solar panels automatically towards the sun so that more sunlight can be captured
Table 4 Cost of the Rajasthan SIP programme in price/Wp meaning a 3 hp pump has 3000 Wp (source own analysis based on (Dr. Dinesh Kumar Goyal, 2013))

<table>
<thead>
<tr>
<th>Price/Wp</th>
<th>Project cost</th>
<th>Money to manufacturer</th>
<th>Money to government</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-11</td>
<td>Rs 300</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td></td>
<td>$4.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011-12</td>
<td>Rs. 189</td>
<td>Rs. 185</td>
<td>Rs. 4</td>
</tr>
<tr>
<td></td>
<td>$2.95</td>
<td>$2.89</td>
<td>$0.06</td>
</tr>
<tr>
<td>2012-13</td>
<td>Rs. 193</td>
<td>Rs. 150</td>
<td>Rs. 43</td>
</tr>
<tr>
<td></td>
<td>$3.02</td>
<td>$2.34</td>
<td>$0.67</td>
</tr>
<tr>
<td>2013-14</td>
<td>Rs. 194</td>
<td>Rs. 143</td>
<td>Rs. 51</td>
</tr>
<tr>
<td></td>
<td>$3.03</td>
<td>$2.23</td>
<td>$0.80</td>
</tr>
</tbody>
</table>

The price of the manufactures went down over the years, this makes sense since the price of solar panels went down as well. The price the manufacturers got went down although they had to supply more districts. It is interesting to see that the price for the total project went up. This can only be due that the cost that the government needs to run the program went up drastically. Normally you would expect the price that the government needs in total to go up with the increase of pumps but per pump (or per Wp) the price should go down due to economies of scale. The only reason for the increase in cost is because more districts were supplied, but it is questionable if such a high increase of the price is justified. Unfortunately the horticulture department of Rajasthan was unavailable for comments on the reasons why this cost had increased.

Furthermore the cost that go to the manufacturer are approximately 30% higher than a local contractor is asking for the same pump. The difference can be partly explained because these manufacturers need extra certifications, need to supply 5 years of free maintenance and will get part of their money only after 5 years. The question is if this is worth a 30% increase or if the prices are increased by the manufacturers just for their own benefit.

Looking at the prices of the local contractor we can see that there is a fitting equation to calculate the price: 45,000 fixed cost and 60,000 per hp. Now that the state of Rajasthan decided to supply more powerful pumps, more hp per pump, they can expect a decrease in Rs/Wp.

4.6.2 Prerequisites needed for the subsidy
There are three prerequisites to be able to get the subsidy: (i) he should own at least 0.5 hectares (ha) of land; (ii) his land should have a diggi (a farm pond) or other water storage structure; and (iii) he should have installed a drip irrigation system in his farm (Kishore et al., 2014). From the sample taken in the field study it can be seen that the average size of the farms is 7.9 hectares while the average farm size in Rajasthan is 3.65 Ha. So currently the farmers with a bigger land size are getting most of the pumps. The farmers with larger land sizes are richer and so have the ability to invest in a diggi and drip irrigation. The question is if subsidy should instead supply the poorer farmers who will benefit more from a pump that costs a lot less in operation & maintenance then their current pump.

4.6.3 Groundwater depletion
The horticulture department of Rajasthan has shown that in 200 out of 249 are in the “high critical” zone when looking at ground water. Currently the solar irrigation pumps are deployed only with the incentive that a drip system needs to be present in order to apply for the pump. A drip system is twice as efficient with the water as a flood system (Dr. Dinesh Kumar Goyal, 2013) but it was also seen in this survey that not all the farmers are actually using the drip system. So there is no continuous incentive to pump less. Since solar irrigation pumps have almost zero marginal cost for pumping water, the deployment of SIP without a continuous incentive will most likely lead to even more groundwater depletion. A subsidy model should be implemented that not just incentives farmers to switch to SIP and buy drip but also to use the drip and other water saving techniques to stop the over exploitation of groundwater.

4.7 Conclusion
The solar irrigation pump programme in Rajasthan can be called a success. The farmers are happy with the pump. Still farmers are using their electric and diesel pumps as well. In an ideal situation the SIP would replace the other pumps fully. One of the reasons why the SIPs didn’t fully replace the other pumps is that
the SIPs were only 3 hp each while the diesel and electric pumps were more powerful. Farmers were asking for bigger pumps and now that the policy has allowed 5 hp pumps it will be interesting to see if they will replace the usage of electric and diesel pumps even more.

The study has shown that farmers are using their solar pumps for a large part of the year and that it is actually used for the biggest amount of irrigation, although some farmers had electric and diesel pumps too.

This scheme is successful and can be rolled out in other states too but with some improvements. The amount of money the government needs to run the program has skyrocketed for unknown reasons. Most probably the total subsidy per pump can be even further decreased as a majority of the farmers would still take a pump if only 50% subsidy was given. The government should make up their minds if they want to supply this scheme mostly to rich farmers, which is the case with the current prerequisites or if they want to supply it to poor farmers. Currently there is no real incentive to stop excessive pumping of groundwater. This could be improved by offering the farmers a (financial) incentive to not pump too much water.

4.8 Future work
This study is still work in progress, this analysis combined with other analysis done by the author as well as analysis done by the initial students might be enough to write an appropriate paper about it but most probably more analysis need to be done. This paper will probably be published in December 2015 in Environmental and Political Weekly.

5 A financial product in Solar Irrigation Pumps to speed up deployment

5.1 Introduction
While Solar Irrigation Pumps (SIPs) have seen the largest increase in deployment over the last year, there are only 12 thousand pumps installed to date (Press Trust of India, 2014). Compared to 7 million diesel and 18 million electric pumps (KPMG, Shakti Foundation, 2014), there is still a long way to go to replace all of these with solar pumps. The price of solar pump sets dropped by 24% since 2011-12 (Dr. Dinesh Kumar Goyal, 2013). Even with the decreasing prices, solar pump sets are deployed with a subsidy scheme allowing limited number of farmers to avail the opportunity. This paper will show the possibility of supplying SIPs with a bank loan so that the subsidy per pump set can be decreased and with the same total amount of subsidy more pumps can be provided.

Solar irrigation pumps are currently deployed with the farmers contributing just 10-30 percent of the cost while the rest comes from subsidies of the Government. There is a difference per state in the amount of subsidy given, for example, Rajasthan is giving 70% (RHDS, 2015) while 80% is given in Tamil Nadu, a state in the South of India (PowerToday, 2013). The low percentage of the total cost invested by the farmer leads to investments in unnecessary design features for their pumps since only a small percentage of these extra features had to be paid by themselves (Kishore et al., 2014).

The high subsidies leads to lack of competition on pricing by the manufacturers of the SIPs. Which demotivates the private sector to buy solar pumps which in turn leads to the necessity of subsidies. This viscous circle needs to be broken and can be done by implementing a loan or lease scheme for SIPs in which farmers will pay for the majority of the pump themselves so that they are more concerned about the price.

5.2 Objectives
The objective of this study is to look at the attractiveness of a quicker deployment of solar irrigation pumps. A quicker deployment of solar irrigation pumps could happen with the same total amount of subsidy when the subsidy per pump is decreased. This alternative needs to be attractive for two groups: farmers and the government, which represent these farmers and the Indian population.

The solution will be attractive for farmers when the pump is more reliable, has a lesser amount of total lifetime cost and when it is easier to get the fuel compared to the current pump. This might be attractive not only for the owner of the pump but also for the other farmers situated around the area where the pump is installed since in some parts of the country water is sold by pump owners to other people.
For the people of India the benefit would lay in having to pay less in subsidies to the farmers, which would mean that they have to pay less taxes. Another benefit lays in the reduction of the produced greenhouse gas emissions when a SIP is used instead of diesel or electric pump.

5.3 Background
Solar irrigation pumps have been around for several years. The advantages of SIPs compared to diesel and electric pumps include almost zero cost for pumping since no diesel or electricity has to be bought and a lesser amount of CO₂ being emitted. One of the disadvantages of solar energy is that it is intermittent due to the clouds that decrease the output. The advantage in this case for the SIP is that on those moments also less irrigation is needed as shown in Figure 7, which shows the fluctuations in usage of water for irrigation and the generation of electricity from a solar panel during the different months. For example the water usage in the month July is 27% of the usage in March. The only problem arises in March which would mean that the SIP has to be oversized in order to supply the full need in March. The advantage with respect to availability is that the output of a SIP can be forecasted based on the weather forecast. This is a more predictable source of energy than the electricity grid currently supplied in most states, due to unexpected power outages.

![Solar generation vs water usage](image)

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What is found by many to be the biggest disadvantage and the ultimate reason for the slow progress of solar irrigation pumps is the high initial investment cost. A solar irrigation pump system is approximately 15-30 times more expensive in the initial investment cost than a diesel or an electric pump.

The factors that are needed for growth of agriculture, like electricity, cold storages and good road network, are more available in the Western states of India in states like Gujarat and Rajasthan than in the East in states like Bihar. These factors have an effect on what kind of crops are grown, which in term has an effect on the amount of irrigation. In this paper there will be a distinction made between the farmers in the West who are generalized to use low cost electricity for pumping water and farmers in the East who are currently not using any kind of irrigation technique or expensive irrigation like diesel pumps.

The groundwater levels in the East and in the West of India are also different. In the East of India the groundwater is very shallow and abundantly available. In the West the groundwater is currently at a much deeper ground level than in the East and it is getting more depleted.

Since one of the problems in the Eastern side of India is having no connection to the electricity grid, mostly only diesel is available for pumping water. Diesel pumped water is available at a rate of Rs 25/Katha\(^6\) for

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\(^6\) A katha is a unit of area. Approximately 79 Katha in Bihar = 1 hectare. Irrigation is normally billed per katha except for when the crop needs extreme high or low amounts of irrigation.
irrigation, which is not affordable for all farmers. Most farmers decide to not irrigate (a part of) their crop, due to the high price of irrigation, so that this part is only rain-fed irrigated. It is shown that proper irrigation will lead to more crop output which leads to an increase of more than 60% in the gross revenue when compared to rain-fed irrigation (Jin et al., 2012).

For most farmers in the Western side of India electricity is supplied to their farms. This electricity is mostly available only during certain pre-defined hours of the day. In the state of Gujarat the farmers will get 8 hours of 3 phase electricity supply for 15 days a month during daytime and 15 days a month during night time. The electricity delivery is reliable in Gujarat which is not the case for Rajasthan, the state just north of Gujarat. Farmers who get reliable electricity supply are generally contented since the price of electricity is highly subsidized and the farmers only pay 60 paisa/unit\(^7\), while the cost of generation is around Rs 5/unit depending on the state.

Due to the low prices of electricity there is no real incentive for the farmers to stop running the pump which leads to groundwater depletion. Raising the electricity prices showed to be impossible over the last years due to the large amount of population depending on farming and so the lack of political will. As an incentive for a farmer to purchase SIP and to not excessively pump ground water, facility to sell the additional electricity generated with a SIP to the grid should be introduced. Till a certain point it would be beneficial for farmers to pump water in order to irrigate their lands but after that point is reached it would be more beneficial for the farmer to sell power instead of pumping water so to decrease the constrains on the water level. This is currently not implemented except for one pilot project.

### 5.4 Methodology

For this study experts were interviewed who shared knowledge about the current state of agriculture and the problems that are encountered. A literature review was done on the current ways SIPs were financed and the different subsidies that were given. To develop the idea of a loan or lease product, further literature review was done looking at other loan and lease products both meant for the agricultural sector as well as loan products meant for different sectors.

To get an idea about the cost of SIPs, experts were interviewed as well as a literature review was done. All the data was used as inputs into a Microsoft Excel model. The model simulated earnings over the years as well as the cost and calculated the payback period of the loan for the farmer.

### 5.5 Results

The experts told that most farmers would like to have a payback time of maximum 6 to 7 years. When a payback is chosen that is longer than that, farmers would not take the loan since it is considered too risky. Current subsidy for solar irrigation pumps are, as said before, between 70-90\% depending on the different states.

It was found that a preferential tariff can be used for the loan to these farmers. National Bank for Agriculture and Rural development (NABARD), is financing loans for agricultural crops at a rate of 4.5\% interest (NABARD, 2015). Experts say that a preferential tariff for SIP loans could be set on 6\% interest (Shilp Verma, 2015).

A distinction will be made between East and West India since the two cases are completely different both in cost of the SIP system and the way of earning a revenue with the SIP.

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\(^7\) A paisa is a monetary unit. 100 Paisa = 1 Indian Rupee. A unit is a kilo watt hour (kWh). Electricity is billed per kWh.
5.5.1 East of India: Irrigation Service Provider

To solve the problem of the expensive irrigation which leads to under irrigation of the crop, irrigation can be provided by a SIPs connected to a PVC\(^9\) buried pipeline network. The water can be provided to the farmers via the pipeline network for a cost of Rs 12/katha this is less than half of the current price and according to the experts, farmers would be able to afford this rate. The owner of the pump will be the irrigation service provider, this can be a farmer who doesn't own any land who will then operate the pump as a fulltime job. Irrigation service provider will manage which farmers will get water when and will keep account of which land was irrigated so as to properly bill the farmer later. This landless farmer will sell all the water since there is no connection to an electricity grid and the farmer has not any own land to irrigate.

A cooperative is proposed so that the cost of the pipeline network will be shared by the different irrigation service providers, reducing the total costs and providing an extra advantage: it is easier to sell the water since the farmers who want to buy the water have a greater water supply security, even if one pump fails there will be enough other pumps to back it up. In the past it has been seen that pumps got stolen or destroyed if only a few people benefitted from a solar irrigation pump subsidy scheme. In this case more people will benefit so the chances of theft or damage might decrease. Further inputs and outcomes are shown in Table 5.

A cost of Rs 7.5 Lakh (approximately $12,000) will be incurred for the off grid system. The system will consist of 8 kW solar panels, 7.5 hp pump, inverters and 1000 m of PVC buried pipeline (Neha Durga and Vipson Ltd., 2015). The pump will be installed with 8kW panels this will be sufficient in the East to supply the water since the water levels are shallow. This system will be able to supply 4 kathas per hour of irrigation and 2250 hours per year of irrigation can be supplied.

Looking at the subsidies needed in this model, it can be seen that these subsidies are much lower than the subsidies currently supplied for Solar Pumps in the east by the local and central government. Here the subsidies would be 55% compared to the current 90% used in the East.

The rest will be covered through a bank loan, which uses the preferred interest rate. The bank will then give the solar irrigation pump as a lease for the first seven years. After the seven years the salary will be a bit more than Rs 1 lakh\(^{10}\) per year.

Since these solar pumps are given without any upfront payment of the farmer, while they will still be able to make a reasonable income, it will be very attractive to get these pumps. This model can be used by farmers who don’t own any piece of land to earn a reasonable income. This will generate extra prosperity for the these farmers but since the selling price of water, the price charged per katha, is also lower than currently with diesel, farmers not owning the pumps will also benefit.

The benefit of these farmers will depend on the price that is charged for the current irrigation. The price of irrigation depends in these states mostly on the price of diesel. The price of diesel will vary from region to region but in general the cost will be higher compared to the price in the city due to transportation cost. The price of diesel has to come down to Rs 30 ($0.47)/liter to make it compete with the price that is charged for

\[1 \text{ USD} = 64 \text{ INR (Xe.com 10 June)}\]

\[9 \text{ PVC stands for Polyvinyl chloride which is a strong plastic polymer}\]

\[10 \ 1 \text{ Lakh} = 100.000\]

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**Table 5 Inputs and outcomes of the Financial Model for the East**

<table>
<thead>
<tr>
<th>Pump size</th>
<th>7.5hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar panels</td>
<td>8 kW</td>
</tr>
<tr>
<td>Total cost</td>
<td>Rs 7.5 Lakh</td>
</tr>
<tr>
<td>Central government subsidy</td>
<td>Rs 2 Lakh</td>
</tr>
<tr>
<td>Local government subsidy</td>
<td>Rs 2 Lakh</td>
</tr>
<tr>
<td>Interest rate</td>
<td>6%</td>
</tr>
<tr>
<td>Salary per year</td>
<td>Rs 40,000</td>
</tr>
<tr>
<td>Repayment per year</td>
<td>Rs. 65,000</td>
</tr>
<tr>
<td>Repay time</td>
<td>7 years</td>
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</table>
irrigating a piece of land with solar. This price has not been reached, in the city, since November 2004 (mypetrolprice.com, 2015).

Another opportunity cost saving is the cost of not having to connect farmers to the electricity grid. While the cost changes per state and depends on how far the farmer is from the nearest electricity cables, the cost is between 1 and 2 lakh rupees, $1500-3000. The farmers that can get water from the service irrigation provider do not have to get their own electricity supply so this amount of money can be saved.

5.5.2 West of India: selling solar electricity to the grid

At the Charanka Solar Park in Gujarat, it was measured that, per 1 kW of installed solar panels 1620 kWh (units) were produced per year (Prasanth Elavarthi, 2014). A 7.5 hp pump required 8 kW input to run for the full 100% and in order to supply 8 kW during the majority of the year the system should have 12 kW installed solar panels since it was seen that solar PV will only reach 66% of the installed capacity as real output (State Load Despatch Centre (SLDC), 2015).

Farmers would still need to use the pump for the irrigation of their crops. Estimated is that farmers will use the pump for 2 peak hours per day, this would mean between 12-2PM. If the pump is used at different times the farmer will use more hours to get the same water output but the effect on the amount of exported electricity is the same since these hours would also generate less electricity. They would use this for 300 days in a year.

It will be beneficial for farmers to save water (so to use the pump less) by for example using drip irrigation technique instead of flooding. For flooding, bigger quantities of water and more hours of pumping are needed and this will reduce the amount of electricity exported hence increasing the payback period.

Since electricity is highly subsidized, utilities would benefit as well from not having to pay for this subsidy anymore. Farmers in Gujarat pay 60 paisa per unit while the unit cost of power supply in 2012-2013 was 485 paisa (Planning commission government of India, 2014, p. 171). The subsidy per farmer is approximately Rs 40,000 per year (S.B. Khyalia (MD MGVCL), 2015). The utilities could pay upfront up to 7 years of subsidy if the farmer decides to take the pump off the grid, which would mean 7 years of not paying subsidy while the lifetime of the pump is 25 years. So this would be a win-win situation for the farmer and for the utilities. Currently farmers who are using solar irrigation pumps are mostly still connected to the electricity grid, but in Rajasthan most farmers said they would agree to not take electricity from the grid if they could choose bigger pumps than 3 hp. The assumption is that more and farmers will agree to just use a solar irrigation pumps instead of electric pumps when it is properly showcased that SIPs can reliable replace electric pumps.

Central government currently gives a subsidy of Rs 40,000 per Wp of the solar panels (Shilp Verma, 2015). As showcased before to run the pump properly 12 kW solar panels should be installed for a 7.5 hp pump. This would mean a subsidy of 4.8 lakh rupees could be given but only 2 lakhs are needed in this case. There is also no need of subsidy from the state government. This would decrease the subsidy normally given by central and state government from 70% (currently in Rajasthan) to around 20%.

Farmers will be able to cover at least 5% upfront of the initial investment cost themselves, in Rajasthan applicants for a subsidized solar irrigation pump need to pay 30% upfront (RHDS, 2015). The rest of the

<table>
<thead>
<tr>
<th>Table 6 Inputs and outcomes for the model in the West</th>
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<tr>
<td>Pump size</td>
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<td>Solar panels</td>
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<tr>
<td>Total cost</td>
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<td>Utilities subsidy</td>
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<td>Central government subsidy</td>
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<td>Own investment</td>
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<tr>
<td>Interest rate</td>
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<tr>
<td>Maintenance per year</td>
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<td>Salary per year</td>
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<tr>
<td>Repayment per year</td>
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<tr>
<td>Total repayment time</td>
</tr>
<tr>
<td>Equivalent pumping hours for own use</td>
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money that is needed would be made available by a loan. It should be noted that selling power to the grid is not a fulltime job like being an Irrigation Service provider. Farmers will still have water to irrigate their fields and can so still earn the same amount as they earn now.

In less than seven years the farmer will be able to repay the loan and from then enjoy a salary of more than Rs 1,00,000 per year as an extra on top of the normal farmer’s salary.

In the west a cooperative model would also have benefits, except from being able to buy material together a big benefit would be to find a buyer of the electricity more easily. Buyers could be cold storages for example. Also for utilities it would be better to get the electricity from one single point than from multiple small points and this would also decrease the transaction cost.

Another advantage of solar pumps in the West would be that farmers don’t have to depend on the utilities. Utilities are not always able to supply energy. While utilities are not always able to supply energy, solar energy can be a reliable source due to the constant solar radiation in most part of the year.

5.5.3 Carbon dioxide mitigation cost
This model does not take carbon dioxide (CO₂) mitigation into account as another financial benefit. When taken into account that 1 kg of carbon dioxide emission has an external cost of Rs 0.49 (IRAP 2012). A 7.5 hp diesel pump will run the same amount of hours (1500) in a year and will use 1.25 litre of diesel per hour. 1 litre of diesel consumed releases 2.64 kg of CO₂. This would lead to an additional benefit of more than 5 ton of CO₂ saved or more than Rs 2500 per pump per year. This does not take into account the amount of transport needed to transport the diesel until the farmer.

Compared to electric pumps just taking into account that one MWh produces 0.96 tonnes of CO₂ emissions (ABB, 2011) and that one pump (with 12 kW panels) produces almost 20 MWh in a year it means that in total almost more than 24 tonnes of CO₂ are saved in either not using electricity from the grid and in delivering electricity to the grid. In money value this means a social cost saving of Rs 12,000 per year.

5.6 Discussion
Solar irrigation pumps cannot currently compete with the subsidized market of electricity and diesel if the pumps are not given any subsidy. When a sensitivity analysis is done looking at the payback period it is seen that all factors have a big influence on the payback period.

The water selling price has an influence on the payback period. When the water selling price is below the Rs 8/Katha, the cost of the loan is higher than the revenue and so the loan will never be paid off. The interest rate has a smaller influence on the payback period but can still easily drive the payback period out of the requested range of under 7 years. The subsidy given at the beginning has the biggest influence. As can be
seen if 90% of subsidy is given, as currently is the case, the payback period is below 2 years. In Figure 10 the same can be seen but than for the West side.

![Figure 10 Sensitivity analysis with Payback period as the outcome for the West side of India. Blue means lesser than the current 7 years of payback while orange means more than 7 years of payback.](image)

For all the different factors an optimum point should be reached. For the groundwater levels it is best if no water is pumped but that would result also in less crop output which is also not desirable.

The price given per unit electricity exported to the grid changes from project to project. For the Charanka Solar Park a price is set for Rs 15/unit for the first 12 years, afterwards Rs 5/unit will be paid by the government. The electricity priced used in the model of Rs 7.72/unit is the official price the government will pay for any unit generated by PV panels.

Setting the price for this specific project will be important for the policy makers. They can choose to supply a higher tariff per unit (kWh) and to supply less upfront or to supply a higher upfront fee but a lesser tariff unit, as is currently the case. These different scenarios can be seen in Figure 11. So for a payback period of ten years Rs 0 initial capital subsidy can be given but then the electricity selling price should be 10.2 Rs/kWh, $0.16, on the other hand ten years can also be reached by giving an initial subsidy of 8 lakh Rs, $12,500, but giving only 2.7 Rs/kWh, $0.042.
Figure 11 Rupees given per kWh supplied to the electricity grid (y-axis) vs initial capital subsidy given when pump is bought. The different colours represent a certain payback period.

Since in the west the farmers are connected to the grid their behaviour could also be used by the state load dispatch centres, the government bodies that manage the electricity grid, for demand-side management. This would mean that farmers will for example be asked, on a day with a lot of electricity demand, to evacuate all electricity the SIP is producing to the grid at a rate of, for example, Rs 8/unit and so not to pump but they will be given power during the night for example Rs 5/unit. In India most power plants run all day and all night leading to too much power in the night. This would only work when the electricity taken in the night should be at a lower cost than the price the farmer gets during the day but should be high enough to have the incentive for the farmer to use the water efficiently.

5.7 Conclusion
Implementing a loan model for solar irrigation pumps will lead to benefits for both the farmer and for India as a whole. A subsidy will still be needed for the SIPs but the subsidy per farmer will be much lower than currently given. One of the reasons why this model is attractive for farmers is because the SIPs are reliable, they offer a predictable output with the help of weather forecasts and historical data. Furthermore there is no need to get fuel (in contradiction to diesel) since solar radiation is available everywhere. A solar irrigation pump will lead to almost zero marginal cost for pumping, offering the farmers inexpensive irrigation. The opportunity in the West side of India of selling power instead of pumping will lead to less groundwater depletion and an additional income for the farmer.

For the people of India it will lead to paying less subsidy to farmers. The current subsidies that are given on SIPs in the East can be decreased from 90% to 55% when a loan is included. In the West the subsidies can be even further decreased since currently farmers are getting a subsidy on their electricity bill of approximately Rs 40,000 per farmer per year and a capital subsidy on the SIP between 70-90%. When the model is followed the total subsidy given on the pump is actually half of the current electricity subsidy given over the total lifetime of the pump.

The amount of greenhouse gases produced will also reduce leading to another benefit for the people of India or actually the whole world. Five ton of CO₂ is produced less per year when an SIP is used instead of a diesel pump and even 24 ton of CO₂ per year when an SIP is used instead of an electric pump.

Overall, it can be said that solar irrigation pumps will lead to benefits for farmers but when implemented with the suggested scheme it will lead to even more benefits for the farmers and for the people of India.
5.8 Future work
This paper gives a suggestion of how SIPs could be expended quicker, increasing the benefits for both the farmers as well as the other citizens of India. This model generalized the situations of the farmers and more research needs to be done in order to make this model specific for certain a certain group of farmers. There might be farmers that are willing to take longer loan periods or there might be banks that will not offer loans under 12% interest. As shown in the sensitivity analysis this will have a big influence on the payback period. In that case the assumptions made need to be changed and solutions need to be found in order to make SIPs still attractive for both groups.

6 Effect of solar on the stability of the grid in India

6.1 Introduction
All around the world more and more renewables are added to the grid. Often it is heard that the renewables will make the grid unstable since they are intermittent in nature.

India has launched an ambitious plan to add a total installed capacity of 100 GW of Solar, 60 GW of Wind, 10 GW of biomass and 5 GW of hydro power by 2022 (“Press Information Bureau English Releases,” 2015). The current installed capacity is less than 4 GW for solar in India (Central Electric Authority, 2015). This will mean a big increase in the amount of electricity coming from solar panels in the future. Other countries, especially developed countries have already gained some experience in dealing with a large percentage of electricity coming from renewables. It is interesting to see if the solutions proposed for those countries would also be applicable in India.

6.2 Objectives
This paper will look into the integration of solar energy into the grid on three levels. First the broader level of the plans of the Indian government related to solar and renewable energy as a total will be discussed as well as the potential problems and solutions for adding renewables to the grid. The problems and the solutions will be partly based on current problems and suggested solutions in countries with a higher percentage of electricity from renewable energy. The second level of this study will look with more detail into the current generation and usage of electricity in the state of Gujarat. It will look into the possibilities of how much solar energy can be added to the grid. The third level will very specifically look at the implementation of solar irrigation pumps into the grid in the state of Gujarat.

6.3 Background
India is a developing country that since 1992 mostly relies on cheap coal for the production of electricity. Currently around 70% of the total electricity is generated by coal. (Trading Economics, 2011b). The current
The installed capacity of India is 273 GW (Central Electric authority, 2015) which is split as shown in Figure 12.

![Installed Capacity (GW)](image)

*Figure 12 Split of installed capacity for the whole of India as of 31-5-2015 (Central Electricity Authority, 2015)*

The reason why coal has less than 60% of the installed capacity but still generates almost 70% of all the electricity is because it will run for more hours in a year than the other generation sources.

1 MW of Solar will generate approximately 150 MWh per month (Ministry of New and Renewable Energy, 2013). So 100 GW would be able to generate approximately 180 TWh per year. According to estimations by the Central Electric Authority, 1914 TWh needs to be generated in 2021-2022 (Central Electric authority, 2007). This would mean that the 180 TWh generated by Solar would generate less than 10% of the electricity in 2022. This would still be a substantial increase from the 0.6% currently.

### 6.3.1 Grid management

Grid management means that in order for the electricity grid to work properly demand and load must be (almost) similar. This is because electrical appliances will be damaged when the frequency, in Hertz (Hz), is outside the specified range. The frequency will be lower when the demand for electricity is higher than the supply. Currently the people that are managing the load, called the state load dispatch centre (SLDC), are unable to manage the demand, for example the households that use electricity, of energy but they can manage the supply, for example gas power plants.

Electricity is demanded by households, industry and agriculture. The demand changes over time and will depend from day to day. For example a household will most likely switch on their air conditioning on a different time today as they did yesterday. While this might be a spike in the electricity usage for that household when taking more households into account it will be more predictable as shown in Figure 13. This is called the law of large numbers. It applies for all kinds of less predictable sources so also for the supply of electricity by distributed solar PV.
All the electricity that is demanded needs to be supplied so when an AC turns on or off, more or less electricity needs to be generated. There are different types of plants that can generate electricity. These plants differ in cost of generation and the response time as shown in Table 7.

Gas turbines could be made as a fast response unit with a response time of several seconds. Coal could also be made to respond faster, several minutes, as is the case with the new coal plants in Germany. Unfortunately specific data about India was not given due to confidentiality reasons, but the assumption was made that India uses conventional plants and not the high tech plants as in Germany.

Current generators are also providing voltage control (by providing reactive power) and frequency control (because of their large rotating inertia and by maintaining spinning reserves). Solar can be designed to perform these services as well but for an additional cost. (Tom Brown et al., 2014)

### 6.4 Methodology

A literature review was done to first fully understand what the problems are that countries are facing who already have implemented high capacities of renewables. Literature review was also done to what the plans are of the Indian government and what solutions are planned to be implemented in order to have a stable grid. Experts were interviewed to hear more about the solutions that are used in Germany and to hear how generation methods differ. Data was gathered from several government websites that showed generation and consumption during different time periods.

### 6.5 Results

#### 6.5.1 On the country level

The plans that India has are according to most experts ambitious but not impossible. It is not fully clear yet how the 100 GW of solar will be implemented. These plans need to be announced soon in order for the states
to implement the right policies. Furthermore setting up MW scale solar plants will take time as well as setting up the right subsidy models for rooftop solar.

As said before the current plans of India will lead to less than 10% of the total electricity supply being supplied by solar on an average. But at peak time, for solar that is between 12-1 PM, historical data shows that a MW scale solar plant of 100 GW installed capacity will produce 66MW only, mainly due to temperature losses.\(^{11}\)

The peak power requirement of India will be 298 GW in 2022 (Central Electric authority, 2007). It means that if at that time the 66 GW was produces it would be 22% of the total electricity production. Most probably the peak in the generation and consumption will not be exactly the same. Furthermore the addition of wind and hydro without a reservoir will also add to the total of electricity from renewable sources. Currently already 23 GW of wind has been installed, with the addition of another 60 GW of wind it will lead it will lead to a total of 83 GW, with a capacity factor throughout the year of 28% it means that on average 23 GW will also produce electricity. The total of wind and solar would then come to 33% of the total electricity. Expected peaks should be even higher and might come to 40-50% renewables.

Less than 10% of renewables, as is currently the case in India, will not lead to any problem but a higher percentage without any adaption will (Peter Thomson, 2015). So a high percentage of renewables might lead to instability in the grid, because of the unpredictability of the output of these sources. The following solutions will help implementing renewable energies successfully in India.

6.5.1.1 Solutions

6.5.1.1.1 Smart grid
India wants to implement a smart grid (an electricity grid that is able to coop with the increasing amount of intermittent sources) by 2022 in major urban areas and in 2027 nationwide. (Ministry of Power, Government of India, 2013)

6.5.1.1.2 Demand-side management (DSM)
Demand-side management is a method where you incentivise the users of electricity to use it at a time when there is less demand from the major users. Examples of this would be to incentivise a household by making the electricity cheaper to run their washing machine in the night. The idea is to make this fully automatic in the future as so to tell your washing machine that you want the laundry to be done by 8 PM and then let the machine decide when the cheapest time is. That would also mean that for most countries it would change the way electricity is priced. In most countries currently prices are fixed. Some countries have a different rate for households for night and daytime but for DSM to work properly the price should be flexible on a minute basis. In Europe DSM is planned to be used as well in cold storages, which operate in a certain range of cold temperature. They stop using electricity when the price is high (and so the demand of the other users is high) and so to let the storage be a little bit hotter but to cool them down more when the price is low. (Dr. Thomas Ackermann et al., 2009)

This could also be used in India where there are also cold storages. Other ways DSM is actually currently already done is by cutting the power for certain parts of the city when the demand is too high. While this controls the amount of electricity being used it also has negative consequences for example the World Bank estimated that in 2014 2% of the sales was lost due to power outages (World Bank, 2014). Another method currently used in India for managing the demand is by allowing farmers to only pump during certain hours a day. If in the future famers can choose for themselves when they want to pump there is still a possibility of having demand-side management: they could pump water during times of cheap electricity and store the water for later use.

6.5.1.1.3 Phasing out coal and nuclear
As shown before the response time of coal and nuclear is very slow compared to other generation techniques. The problem is that India is based a lot on coal and nuclear as shown before. There need to be more sources that can follow the load. Typical technologies which can do this are combined-cycle gas turbines (CCGT) or reservoir based hydro power stations because they have significant storage capacity to match the variations

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\(^{11}\) With every degree in temperature rise the efficiency drops 1.1% (Cindy Hill, n.d.).
over a day. Also Biomass plants can be used to follow the load as is done in Spain (Dr. Thomas Ackermann et al., 2009)

6.5.1.1.4 Curtailment of renewables
Curtailment means cutting the amount of power the systems are producing at a certain time. This will help when there is too much power being generated and other techniques cannot be switched off. Too much electricity being generated and not enough usage will lead to a too high frequency in the grid which might damage electrical appliances so has to be avoided. Curtailment can decrease the investment cost in the grid since a very high generation of a certain wind or solar park will only happen for a very small percentage of the time. If the solar or wind park is curtailed in such cases the cables to this solar or wind park have to be less thick (Tom Brown et al., 2014). The negative point of curtailment is obviously missing out on using clean energy. The government probably has to financially compensate the owners of the renewable energy plant.

6.5.1.1.5 Interconnection
Interconnection in the case of Europe means more connections to other countries so that more electricity can be bought from or sold to other countries. This is also applicable for India which can build a stronger grid with the neighbouring countries. India should also invest in an even better interstate connection. According to Ackermann this will help (Dr. Thomas Ackermann et al., 2009) to be more energy efficient, because utilization can be more and so less curtailment is needed.

Another factor that will help is the, before mentioned, law of large numbers. Since India and the neighbouring countries spread over a large area it is unlikely that the whole area will suffer from clouds or no wind. A study has been done to see how a well interconnected European grid would deal with extreme weather events. In the extreme summer event in 2003 with high demand and extreme low wind, the power generated from local PV was enough to compensate (Dr. Thomas Ackermann et al., 2009, p. 46). An extreme winter event with high demand, lower solar irradiation in most parts of Europe and low wind speeds, which happened in January 1997, could also be compensated by renewable energy. In this case Great Britain and Central Europe would generate not enough electricity but North and South Europe would generate too much. But the grid should be strengthened in order to be able to let South and North Europe supply the parts that were not able to generate enough (Dr. Thomas Ackermann et al., 2009, p. 47). According to Siemens electricity can be transported over 1000 km with just 3% losses (Siemens, 2011).

6.5.1.1.6 Concentrated solar power (CSP)
CSP is a technology in which solar light is directed towards one point in order to heat a fluid. This fluid is in most cases molten salts which can be stored. The heat of these molten salts is used in a steam turbine to generate electricity. The molten salts can be stored very efficiently and can be so be used to generate electricity at the hours when the sun is not shining (Rafael E. Guédez, 2014).

6.5.1.1.7 Storage
Not only CSP is a way to store energy, there are a lot of other ways to store energy in order to transform it to electricity when it is needed. But for most other forms solar radiation is first transformed into electricity before it stored as is the case in a battery or even another step is needed to transform the electricity into another product as is the case in for example power to gas and pump storage.

Electric vehicles can be used as a form of storage. India wants to have 6 million electric vehicles (4 million two wheelers and 2 million four wheelers) by 2020 (Ministry of Power, Government of India, 2013). In this case the batteries in electric vehicles are used to store electricity when too much electricity is generated and to give that energy back to the grid when there is too less energy generated. This idea has just been implemented in the Netherlands for a small pilot project (Mischa Blok, 2015). This project will show if people are happy with making money (by letting the car buy electricity when it is cheap and sell when it is expensive) but also having the negative consequence that they do not know how much the battery of their car is charged. Positive points would be that the extra investment cost is zero and that the car owners could earn extra income (Dr. Thomas Ackermann et al., 2009). Only one small pilot project has been set up till now so for India implementing this idea in the near future would be unrealistic since the far majority of India cannot afford an electric car.
Batteries outside electrical cars are also a possibility but it will mean that extra money has to be invested. Another option, used a lot, especially in Northern Europe is pump storage. Water is pumped from a lower elevation reservoir to a higher elevation during times of low-cost, off-peak electricity. During periods of high electrical demand, the stored water is released through turbines. Losses in the pumping process make the plant a net consumer of energy overall, however the system makes income by selling more electricity during periods of peak demand, when electricity prices are highest (literally quoted from (Dr. Thomas Ackermann et al., 2009, p. 37). It is 70 – 85% efficient, due to evaporation and losses in the turbines and pumps. Pumped storage can react to load changes within seconds. (Dr. Thomas Ackermann et al., 2009, p. 37)

Most experts agree that batteries and pump storage are the two most viable techniques of storage. There are other possibilities for example: using electricity to produce hydrogen which can then later be used, power to gas which makes gas from electricity and the storage of compressed air.

### 6.5.2 On the State level

In Gujarat in total almost 23 GW was installed with a split up as shown in Figure 14.

![Installed capacity in Gujarat](image)

*Figure 14 Installed capacity in Gujarat on 31-3-2014 (SLDC (State load dispatch centre) Gujarat, 2014)*

In Gujarat the load is quite balanced during the day as can be seen in Figure 15. This allows currently for a high percentage of coal and nuclear.
Adding 4.5 GW of installed capacity of solar will help to reduce the peak load around noon and also help for the peak load around 4 PM. Still almost 10 GW can then be covered by conventional generation methods like coal and nuclear. The difference between the 10 GW and the demand curve when solar is not able to supply the full need needs to be supplied by quick sources for example hydro plants that are connected to a reservoir or gas plants. As there is already more than 4 GW of installed capacity of gas power plants, no further investment is needed in flexible sources to have 4.5 GW of installed solar energy in the grid. Also wind might be able to help reduce the difference between what the baseload sources, nuclear and coal are producing, and what is needed for the demand. So Gujarat could fivefold the amount of installed capacity of solar without having to invest in solutions that can respond quickly. An investment will be needed in the grid in order to get the power from the solar plants into the grid. Currently it is also seen that there are many blackouts and that the transmission losses are high. When a higher amount of solar will be integrated into the grid solutions as suggested on page 29 and further should be implemented. One of the important prerequisites for implementing renewables successfully is to forecast the weather. The SLDC has implemented this last year. (SLDC (State load dispatch centre) Gujarat, 2014)

6.5.3 On a specific technology level: Solar irrigation pumps

While solar irrigation pumps (SIPs) are just one way of adding more solar to the grid it can have a big impact. In 2013-2014 SLDC (Gujarat) reported that 17805 GWh was used by Agriculture that was 26% of the total usage (SLDC (State load dispatch centre) Gujarat, 2014). If the electric pumps are all replaced by SIPs that are connected to the grid only to export electricity but are not allowed to import electricity, it will lead to extra solar power added to the grid and no more usage by farmers of electricity from the grid. Currently farmers are using the electric pumps for two sessions in a day in the area of MGVCL, one of the four DISCOMS (distribution companies) in Gujarat. Farmers will get three phased electricity, which is used for pumping, for 8 hours per day. Fifteen days of the month it is in the night, from 9:30 PM to 5:30 AM, and 15 days it is during the day, from 5:30 AM till 1:30 PM. According to the officials of MGVCL the farmers will use the pump during daytime almost for the maximum amount of 8 hours. During night time the usage will be 60% of that during daytime since hiring labour in the night is expensive. When taking into account that the 17805 GWh is equally spread over all days, which is conservative because during monsoon season a lot less will be pumped, in the morning session 3.8 GW of pumps are on and in the night session 2.3GW. If this would be true the load curve without agriculture will look as in Figure 16. It is questionable if the data as presented by the DISCOM represent the truth since most offices and industrial loads will not suddenly increase their

Figure 15 Electricity generated for 27 May 2015 and 28th May 2015. The blue shape indicates the expected output of 4.5 GW of solar during a clear sunny day based on the output of a solar park in Gujarat.
load at 13:30. There might be an increase because of the lunch break but it should be dampened afterwards. Unfortunately scientific data about the usage is not gathered by the DISCOMS nor by the SLDC.

As can be seen the peak in usage throughout the day will not change since agriculture load was not present at that moment. A scenario without agriculture will make it difficult to generate more than 7 GW with coal and nuclear. Solar will in this case also not help since it will decrease the demand for other sources even more in the morning. What would be a solution when this scenario is implemented is to oversize amount of PV panels for the farmers so that they can do enough pumping in the morning. When the peak in demand then comes instead of pumping they will supply electricity to the grid making the peak less high.

Also storage could be implemented so that electricity generated in the morning could be used during peak time. Water storage could also be used to help the grid as mentioned before. With a tank in which water can be stored during low demand hours of electricity less electricity is needed in other hours since the water in the tank can be used first. Since the solar irrigation pumps are new and there is currently only one project that allows an owner of a solar irrigation pump to sell power to the grid, there is no historical data that shows how much farmers will use the pump during daytime when not bound to times set by the DISCOMS.

6.6 Limitations of the study
Unfortunately the State load dispatch centre of Gujarat denied to give more specific data then the data already available on their website. The data that was asked for was data about the quickness of the response of the specific methods of generation in Gujarat, for example what the speed was at which a coal plant in Gujarat could respond to a load change. Other data requested was daily data about electricity produced and consumed by the different sources (agriculture, industry and households).

6.7 Discussion
6.7.1 What is the best solution?
As shown there are many solutions possible and probably there is not one best solution. Grid interconnection is in Europe seen as the best solution to implement a high amount of renewables with a relatively low cost. In India first priority should go to building a grid that can handle larger amounts of electricity with less losses than currently. In this way the solar that will be added in the upcoming years will be able to transmit power to the grid without any problem.

Other solutions definitely need to be implemented before the year 2022 in order to have a stable grid even when during peak time 50% of the electricity comes from renewables.
6.7.2 Spreading of renewables across the country
In different parts of the country the potential for renewable energies is different. The highest solar potential lays in the West of India as shown in Figure 17. According to this map it would make the most sense to build solar power plants in that part of the country as with the same investment more power can be generated than in the east of the country for example. But it should be taken into account that power is best produced where it is also utilized. Transporting electricity over large distances will lead with the current electricity network to high losses. The current losses are in the range of 25% while the best practise shows that only 3% has to be lost over a distance of 1000 km.

An interconnected grid will make the total grid more stable as shown before.

6.8 Conclusion
When the ambitious plans of the government of India of implementing a lot of renewables become reality some changes will need to be made. The implementation of a combination of the solutions suggested in section 6.5.1.1 will make sure that renewables can be implemented without any obstacles. This will also apply when India decides to have an even higher percentage of the electricity generated by renewable sources but then the solutions should be implemented in a higher number. No level of electricity from solar, even 100%, is technically impossible but then among other solutions storage should be implemented, but the question is if this would economically and politically be the best solution.

From the analysis of the current situation in Gujarat it can be seen that the current demand curve is quite flat. When a large percentage of the electricity comes from solar during daytime it will have the consequence that less coal and nuclear plants can run. The electricity these units generate need to be replaced by electricity
from other sources during the time the sun does not shine. The gas plants that are currently installed but which are not used, probably need to be used in the future as there is always the possibility that the expected amount of electricity from solar panels is not generated.

The implementation of solar irrigation pumps (SIPs) which are connected to the grid will lead to an extra problem compared to other sources that generate electricity with the help of PV panels. The problem is that the concept of a SIP is quite new in India and that there is no data about the usage throughout the hours of the day for such pumps. The idea of not letting farmers import electricity from the grid will lead to 26% less usage of electricity in the state of Gujarat. This is not equally spread throughout the day and will so lead to a less steady curve as is currently the case in Gujarat. That calls for the need of more sources that are able to respond to a change in demand.

6.9 Future work

In this study a brief introduction was given what the plans of the government are and how they could deal with renewable energies in the grid. The different solutions were not tested on basis of economic and political viability. In order to provide implementable ideas for the future much more specific research has to be done, for a specific region it has to be found out which grid lines have to be enforced in order to accommodate decentralized solar power and what solution suggested above would be the best.
7 Conclusion

Diesel and electric pumps have been around for decades while solar irrigation pumps (SIPs) are relatively new and are mostly installed in the last few years. SIP is a disruptive technology that can highly benefit the Indian economy and situation of farmers offering zero marginal costs. The negative consequence of installing SIPs is groundwater depletion due to excessive pumping. Solutions for this problem have been addressed in this thesis in form of incentives to not pump excess water and selling excess electricity to the grid.

Research on a way to rapidly deploy SIPs was divided into three main parts in this work. The first part looked at the experiences of farmers that are already owning SIPs for several years and showed that farmers were happy with the pump. Improvements were suggested to make the SIPs even more attractive by allowing pumps with more horse power. In that way farmers can just use SIPs instead of using a SIP in complementation with a diesel and an electric pump. It also showed that currently almost all pumps are highly subsidized because of the high capital cost. Since the total amount of subsidy is limited this imposes a barrier to the quick deployment of SIPs.

The next part of the thesis looked at how this subsidy could be decreased while still being attractive for the farmers. A loan/lease product was verified to be able to reduce the subsidy by almost 2-4 times and so allowing more pumps to be deployed with the same amount of money. For every pump that is deployed, electricity subsidy is saved and the actual amount of subsidy given over the lifetime of the pumps is twice as low as the subsidy currently given on electricity. Farmers will be able to repay the loan within 7 years and earn (extra) income when a SIP is installed. This product will hence be attractive for both farmers as well as for the government.

Implementing SIPs with a connection to the grid will also influence the stability of the grid, since solar energy is not a continuous source of energy unlike conventional sources. For having higher installed capacity of solar power, not only SIPs, flexible generation techniques that have access to a large amount of stored energy such as hydro power with access to a reservoir, gas turbines and biomass plants will be needed. Other solutions such as smart grids, demand-side management and storage should be implemented too for a stable grid when the share of renewables increases in the energy mix. The grid should also be amplified in order to handle larger amounts of electricity so that distributed solar power can be implemented without experiencing problems caused by thin cables. In the state of Gujarat five times as much solar power can be integrated without having to invest in new plants that are flexible enough to follow the load. The implementation of SIPs that are not allowed to import power from the grid and are only allowed to export power will lead to a less balanced demand curve throughout the day for Gujarat. This will require more flexible generation methods or other solutions as explained in section 6.5.1.1.

In general it can be concluded that, when paid attention to the negative consequences of solar irrigation pumps, these pumps have a bright future in India. The speed of implementation can be increased by offering farmers bigger pumps, so that they will not have to use a diesel or electric pump as well and offering them a viable loan/lease product. The grid has to be modernized to allow renewables into the grid since a large share of renewables will be present in the year 2022 when the government plans of having 15% of electricity consumption from renewables have been fully implemented.
8 Bibliography

Central Electric authority, 2007. 17TH ELECTRIC POWER SURVEY OF INDIA.
Central Electricity Authority, 2015. Executive Summary Power Sector.
Dr. Dinesh Kumar Goyal, 2013. SOLAR WATER PUMPSET PROGRAMME RAJASTHAN.
Dr. Thomas Ackermann, Sven Teske, Dr. Eckehard Tröster, Rebecca Short, 2009. [r]enewables 24/7, INFRASTRUCTURE NEEDED TO SAVE THE CLIMATE. Greenpeace.
EMIS, 2014. Utilities Sector India.
KPMG, Shakti Foundation, 2014. Feasibility analysis for solar agricultural water pumps in India.
LevelBasinFloodIrrigation.JPG (2100×1500) [WWW Document], n.d. URL http://upload.wikimedia.org/wikipedia/commons/a/ae/LevelBasinFloodIrrigation.JPG (accessed 5.11.15).

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HIGHLIGHT 35.


S.B. Khyalia (MD MGVCL), 2015. Subsidy to farmers per year.


Tobias Engelmeier et al., 2014. Beehives or elephants? How should India drive its solar transformation?

Tom Brown, Peter-Ohillipp Schierhorn, Eckehard Tröster, Dr. Thomas Ackermann, 2014. Optimizing the European Transmission System for 77% Renewables by 2030.


Who we are: IWMI [WWW Document], n.d. URL http://www.iwmi.cgiar.org/about/who-we-are/ (accessed 4.30.15).

World Bank, 2014. Value lost due to electrical outages (% of sales) | Data | Table [WWW Document]. URL 
XE, 2015. XE: (USD/INR) US Dollar to Indian Rupee Rate [WWW Document]. URL 
http://www.xe.com/currencyconverter/convert/?From=USD&To=INR (accessed 6.10.15).
Zankhana Shah, 2004. RATIONING OF POWER SUPPLY FOR AGRICULTURAL USE: ASSESSING 
THE FEASIBILITY AND IMPACTS.