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Degree of Master of Science

Turning the lights on for millions in Bihar, India:

Applying lessons from Kenya to promote the growth of the off-grid solar lighting products sector

SANDEEP June, 2017

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MESPOM



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ABSTRACT OF THESIS submitted by:

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for the degree of Master of Science and entitled: *Turning the lights on for millions in Bihar, India: Applying lessons from Kenya to promote the growth of the off-grid solar lighting products sector*

Month and Year of submission: June, 2017.

The federal government of India and the state government of Bihar, India's least electrified state, have always focused on grid expansion to bring power to those living in the dark. However, grid expansion has been slow, and 89.6% of rural Bihar still lives without electricity. In the 1980s, an alternative - a market for solar home systems and solar lanterns started to develop in Bihar, alongside markets in countries such as Kenya that shared similar conditions of low rural electrification. Today Kenya is a market leader, while the sector struggles in Bihar. The aim of this thesis, part of a joint study, was to investigate this divergence by identifying the drivers and barriers to growth of the Bihar sector, and contrasting them with a similar analysis of the Kenyan sector. Data collected through a literature review and interviews was analysed using Cherp et al. (2016)'s three perspectives theory. This thesis concluded that many political and socio-technical barriers exist in Bihar, and many of Bihar's barriers are Kenya's drivers. Bihar has a harmful kerosene subsidy, while expensive Kenyan kerosene is a driver. Further, Bihar entrepreneurs haven't been able to adopt the pay-as-you-go business model that has helped the Kenyan market rapidly expand. This thesis makes six key recommendations for Bihar based on lessons from Kenya: Bihar should adopt the Direct Benefit Transfer scheme, create a challenge fund for companies, conduct extensive education campaigns, cancel the counterproductive government subsidy on off-grid products, make grid expansion transparent, and RBI should remove mobile money restrictions.

Keywords: Solar Energy, Solar Home Systems, Solar Lanterns, Kenya, Bihar, India

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List of Abbreviations

AGRA	Alliance for a Green Revolution in Africa
APL	Above Poverty Line
BPL	Below Poverty Line
BREDA	Bihar Renewable Energy Development Agency
DBT	Direct Benefit Transfer
IEA	International Energy Agency
IRENA	The International Renewable Energy Agency
MFI	Micro Financing Institutions
MNRE	The Ministry of New and Renewable Energy
NABARD	National Bank for Agriculture and Rural Development
PAYG	Pay-As-You-Go
PDS	Public Distribution System
RBI	Reserve Bank of India
SHS	Solar Home Systems

UNDP United Nations Development Program

1. Introduction

1.1 Background

In developing countries, providing access to electricity for all is a significant challenge. According to the International Renewable Energy Agency (IRENA), an estimated 1.1 billion people, or one in every seven people in the world, does not have access to electricity (IRENA 2015). These people, who primarily live in rural areas, depend on kerosene and candles for lighting purposes, which causes serious social, health and environmental problems. For example, the United Nations Development Program (UNDP) found that indoor pollution caused by the use of kerosene for lighting and biomass for cooking has caused half a million premature deaths and around 500 million cases of illness in India alone (UNDP 2010). Many cases of poisoning caused by kerosene fuel ingestion (especially in young children) have been reported by people who use kerosene as a lighting source (Lighting Global 2016). Ample literature suggests that extending the centralized grid to all these areas may not be economically feasible, and even if it is possible, will happen very slowly.

Off-grid solar lighting products such as solar lanterns and solar home systems (SHS) are increasingly being seen as an alternative clean energy option that can help fill this electricity gap and improve people's health without harming the environment (Lighting Global 2016; Climate Group 2015). Aided by dropping solar prices, the off-grid solar lighting products sector has grown rapidly across Asia and Africa during the past decade. Approximately 89 million people in Asia and Africa are already using these products, and the sector holds tremendous potential for expansion in the future (Lighting Global 2016).

According to the Climate Group (2015), solar lanterns usually serve "basic lighting and mobile charging needs," while an SHS has more capacity and can power an entire house. A family typically owns one or more products depending on their needs and means. Solar lanterns are usually small, and have a low price and wattage. The wattage ranges from 0.1-10 W, and the cheapest solar lantern available on the market is 5 USD (approx. 4.5 EUR)

(Climate Group 2015). Figure 1 shows the cheapest solar lantern sold by leading off-grid solar company d.light.



Figure 1. d.light's 4.5 EUR solar lantern. Source: d.light 2017.

On the other hand, wattage for an SHS usually ranges between 8 to 200 W, and an SHS costs between 20 USD (approx. 18 EUR) and 600 USD (approx. 540 EUR) (Climate Group 2015). An SHS comes with a solar panel, which can power a few lights, charge mobile phones, and even run a television, depending on the size. Figure 2 shows an SHS sold by Germany based off-grid company Mobisol that can power multiple lights, charge mobile phones, and run a TV and radio. Both SHS and solar lanterns are plug and play systems. Typically, a solar lantern consists of a solar panel on one side and a light on the other. An SHS has a separate solar panel which is kept in the sun during the day. The power generated is used by the household during the day and the excess power generated is stored in a battery. This excess power is used at night or during cloudy days.



Figure 2. Mobisol's SHS product. Source: Mobisol 2017.

Almost 95% of people without electricity live in Africa and Asia (Lighting Global 2016). In India alone, almost 300 million people live without electricity (IRENA 2015). Governments, NGOs, and private entrepreneurs have been putting substantial effort into promoting solar products in India for a long time (MNRE 2016). However, despite the fact that the off-grid solar lighting products sector started in India three decades ago, researchers highlight the fact that the growth of the sector has been very slow (Climate Group, 2016). Harish *et al.* (2013) state that despite more than "three decades of programs, pilot projects, and several impressive case studies," the diffusion of the off-grid solar lighting products sector in India has "progressed at a snail's pace."

Even the north Indian state of Bihar, which has the lowest percentage (10.4%) of unelectrified rural households in India, has not seen much progress in the adoption of off-grid solar lighting products. Bihar has a total population of 100 million (as per the 2011 census), which is almost one-fourth the current population of all 20 east African countries taken together (Worldometers 2017). On the other hand, Kenya has seen significant success – with almost 30% of un-electrified households in Kenya using some kind of solar product (Lighting Global 2016).

It is interesting to note that Kenya and Bihar share similar conditions and history concerning the off-grid solar lighting products sector. More than two-thirds of the population in both places lives in rural areas, and more than four-fifths of the rural population lives without electricity. The market for off-grid solar products in both places started developing in the 1980's (Lighting Global 2016; Climate Group 2015). While it's difficult to compare the two places economically as it involves comparing a state and a country, it is notable that their GDPs are similar. In addition, the World Bank ranks both India and Kenya as lower-middle income countries, showing that the context of comparison for both is not very different (World Bank 2017c). Finally, while their GDP per capita varies somewhat, this is only a rough measure and is presented in the absence of reliable figures for GDP per capita (PPP) which is adjusted for the cost of living. Table 1 illustrates Bihar and Kenya's similar conditions.

	Kenya	Bihar, India	
Population	Approx. 46 million	Approx. 100 million	
	(2015 data. Source: World Bank 2016a)	(2011 data. Source: Census of India 2011)	
Rural population	74.0%	88.7%	
	(2015 data. Source: World Bank 2016b)	(2011 data. Source: Census Organisation of India, 2015)	
Percentage of un-	93.0%	89.6%	
households	(2016 data. Source: IEA 2016)	(2011 data. Source: Census of India 2011)	
GDP	63 billion USD (Approx. 56 billion EUR)	99 billion USD (Approx. 90 billion EUR)	
	(2015 data. Source: World Bank 2017a)	(2017 data. Source: PRS 2017)	
GDP per capita	1377 USD (Approx. 1239 EUR)	682 USD (Approx. 614 EUR)	
	(2015 data. Source: World Bank 2017b)	(2015 data. Source: Ministry of Statistics and Program Implementation 2016)	

Table 1. Comparing Kenya and Bihar, India

Despite sharing similar conditions and contextual similarities with Kenya, the Indian state of Bihar has not been able to achieve similar success in developing a market for off-grid solar lighting products. Moreover, while adequate literature is available regarding the diffusion of the off-grid solar lighting products sector in Kenya, very little academic work exists regarding Bihar, and almost no literature is available about its drivers and barriers.

This thesis (which is one part of a two-part joint study) intends to fill that knowledge gap and identify the drivers of and barriers to the diffusion of the off-grid solar lighting products sector in Bihar. Moreover, after identifying the drivers and barriers, this thesis will provide recommendations for stakeholders involved in the off-grid solar lighting products sector in Bihar, based on the Kenya case study. Ultimately, this may help promote faster diffusion of the off grid solar lighting products sector in Bihar.

This thesis will focus on the diffusion of the off grid solar lighting products sector in Bihar, while the second thesis will focus on Kenya using the same theoretical framework and methodology. Both theses will have a common discussion section.

1.2 Research questions and aims

The main research question is:

Why, despite their contextual similarities, has Kenya been more successful than Bihar in promoting the diffusion of off-grid solar lighting products?

This research question was further broken down into three sub-questions:

1) What drivers of and barriers to the growth of the off-grid solar lighting products sector exist in Kenya?

• Addressed by the second thesis

2) What drivers of and barriers to the growth of the off-grid solar lighting products sector exist in Bihar, India?

• Addressed by this thesis

3) Based on findings from the Kenya case study and reflections on drivers and barriers in Bihar, what steps can be taken to help overcome present barriers to growth of the off-grid solar lighting products sector in Bihar?

• Answered through joint analysis based on both theses' findings (i.e. a common, comparative section in the discussion section).

By answering these research questions, this thesis aims to (1) fill the knowledge gap regarding the development of the off-grid solar lighting products sector in Bihar, on which little to nothing is written, (2) update knowledge on the growth of the sector in Kenya, for which a paradigm shift has occurred since 2011 prior to which most academic literature was written, and (3) to develop policy recommendations for Bihar based on the Kenya case study. This may help the sector overcome its barriers in Bihar, India's least electrified state, helping bring clean energy options to the rural poor.

1.3 Outline

Chapter 2 contains the literature review and theoretical framework. The first part of this chapter contains a comprehensive literature review related to the off-grid solar lighting products sector in India and Bihar. The next part contains a review of relevant and applicable theories, and a description of the analytical, methodological, and theoretical framework applied in this thesis.

Chapter 3 details the methods used for the literature review, and for data collection (semistructured interviews) and data analysis (content analysis).

Chapter 4 outlines the results of the content analysis of the Bihar, India interviews.

Chapter 5 contains a common discussion section (together with the second thesis), which answers the research sub-questions and provides recommendations for Bihar's off-grid solar lighting products sector.

Chapter 6 concludes the thesis, describes the recommendations, and discusses the contribution of this thesis from a practical and academic point of view.

2. Literature review & theoretical framework

This chapter is divided into two parts. The first part provides an overview of the literature, describes the history of the off-grid solar lighting products sector in India, and analyses the literature from the point of view of key stakeholder groups for India and Bihar. The second part of this chapter deals with applicable theories & the theoretical framework applied in this thesis. Similar to this thesis, the second thesis provides a literature review of the development of the off-grid solar lighting products sector in Kenya.

2.1 Literature overview

There is a complete knowledge gap in the literature – both academic and grey – about the historical and current developments in the off-grid solar lighting products sector in Bihar. Further, a literature search did not generate any articles that discuss what factors helped the growth of this sector and what are its challenges. The 2 articles that were identified for Bihar also just briefly talk about some specific aspects of the off-grid solar lighting products sector in the state. This present study intends to fill that knowledge gap, and provide scientific knowledge about the development of the off-grid solar lighting products sector in Bihar.

Due to the significant gap in the literature regarding the growth of the off-grid solar lighting products sector in Bihar, the literature search in this thesis was expanded from Bihar to the whole of India. After reviewing articles generated from multiple keyword searches, and reviewing articles provided by experts, 12 articles were found to be most relevant for literature review. Clearly, reviewing literature for India will not provide complete information about the off-grid solar lighting products sector in Bihar. However, reviewing literature for India certainly helped to identify important themes and ideas that ultimately informed and shaped the Bihar interview protocols used during the field research.

As mentioned earlier, there are no articles that describe the historical and present developments in the off-grid solar lighting products sector in Bihar. However, for India, some scholars as well as a few government reports describe how the off-grid solar lighting products sector has grown over the years. Overall, for India, the existing literature has focused either on the technical and economic feasibility of the use of off-grid solar lighting products, or on some drivers of and barriers to its diffusion from either policy, or a business model perspective. There is no literature that comprehensively explains all the factors affecting the growth of this sector and the challenges faced by this sector.

Therefore, this literature review tries to explain how the off-grid solar lighting products sector in India has grown over the years, the factors helping its growth, and the various obstacles that hinder its growth. There are a wide variety of actors whose actions influence this sector. In order to capture all perspectives and explain all the important details given in the literature, this research paper approaches the literature from the perspective of 4 key stakeholder groups. This was done because most of the existing literature for India identifies 4 key stakeholder groups whose actions directly impact or affect the off-grid solar lighting products sector in India. The main stakeholder groups are: government, customers, off-grid solar manufacturing and distributing companies, and finance institutions. The themes generated for Bihar from the 2 articles reviewed are also examined and highlighted along with the literature for India.

Before providing details from the literature regarding drivers and barriers in Bihar, it is pertinent to explain the historical development of the off-grid solar lighting products sector in India. This development provides insight about the factors that helped the sector grow and the various challenges it faced. Apart from the 12 articles reviewed for India and 2 for Bihar, some government websites were also referred to explain the historical developments in this sector.

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2.1.1 The history of India's off-grid solar lighting products sector

India has huge potential for expansion in the solar electricity sector (Kathaiyan 2015; Urpelainen 2014; Shrimali and Rohra, 2012; Oda and Tsujita 2011; Climate Group 2015; Singh 2016; Choragudi 2013). For example, Kathaiyan (2015) wrote that India has the potential to generate around 20-25% of the total global solar electricity potential of 463 GW by 2050. On the demand side, more than 300 million people in India have no access to electricity who could be potential users of this solar electricity (IRENA 2015). Given the huge scope of solar and its need from an energy security and environmental point of view, off-grid solar lighting products (which are a type of solar electricity) like solar lanterns were introduced in India by the federal government more than 3 decades ago (MNRE 2016).

The oil shocks of the 1970s forced the federal government to formalize the process of developing different forms of energy sources including solar - till then fossil fuels were the only sources of energy in India (MNRE 2016; Basak et al. 2013). In the year 1981, the federal government formed the Commission for Additional Sources of Energy (CASE) within the Department of Science & Technology. Subsequently, the very next year, the Department of Non-Conventional Energy Sources was formed and CASE was merged with it. This was the first time a separate department was formed to formulate policies and implement programs to promote new and renewable energy sources such as biomass, solar and small hydro (MNRE 2016). In the 1980's, in the solar sector, DNES focused mainly on small-scale distribution of solar lanterns, solar water heating, and solar cook stoves. Apart from the government, some non-governmental organizations (NGOs) with the help of aid money also distributed a few thousand solar lanterns in some rural areas (Palit and Singh 2011; MNRE 2016). Subsequently, in 1991, DNES launched the solar photovoltaic program for dissemination of solar lanterns in a systematic matter by providing subsidies to rural customers (Palit and Singh 2011). Next year, the federal government formed the Ministry of Non-Conventional Energy Sources (MNES), a separate ministry to peruse and develop nonconventional form of energy sources (MNRE 2016). This was a significant development in

the renewable energy sector, as the newly formed ministry introduced numerous programs for the promotion of different renewable energy sources including solar.

The formation of this ministry also coincided with the liberalization of the Indian economy - opening up various sectors to the private sector. In line with the national mandate, MNES devised various programs that incentivized private sector participation in renewable energy generation and distribution (Palit and Singh 2011). Due to the incentives provided by the federal government, from the mid-1990s, a handful of domestic social enterprises started working in the off-grid solar products space (MNRE 2016). The 2 most recent articles that studied companies operating in the off-grid solar products space claim that most of the companies in this space are only a maximum of 10 years old, and only a few companies have been operating since the 1990s (Singh 2016; Climate Group 2015). According to Singh (2016), there are both formal and informal market players. The formal market players include big and small registered companies like SELCO, Tata solar, and ORB energy, who sell standard solar products in rural areas. However, the informal sector is made up of entrepreneurs who assemble "electronic components, ordering parts wholesale in order to create customized solar home lighting products for rural customers" (Singh 2016). Both the articles say that it is hard to predict the exact number of informal players in the off-grid solar space.

With regard to the formal players, Climate Group (2015) in their report predicts that there are at least 80 formal players – half upcoming and the other half well established. Literature also suggested that the federal government's MNRE has been running different programs to support some entrepreneurs by way of providing "...subsidies, soft loans, concessional duty on raw material imports, excise duty exemption on devices/systems etc" (Choragudi 2013). Despite starting 3 decades ago, several researchers highlighted that the growth of the off-grid solar lighting products sector has been very slow in India, and its penetration is still very low (Harish *et al.* 2013; Climate Group 2016). The exact number of SHS and solar lanterns deployed in India is not available in the articles reviewed as the market is very fragmented – there are many players who are independently promoting these products. The MNRE (2016)

has so far distributed 985,012 solar lanterns and 1,207,576 SHS in India. This means government has managed to reach 0.26% of India's un-electrified households. Table 2, below, shows the percentage of households where MNRE has distributed off-grid solar lighting products so far. This calculation is based on the assumption that there would be one off-grid solar product per household.

Table 2. Percentage of households using off-grid solar products compared to unelectrified households. Source: Census Organisation of India 2015; MNRE 2016 (with amendments).

India (Households without electricity access)	Number of SHS (till 2016)	Number of Solar Lanterns (till 2016)	Total off-grid solar products	Percentage of households using off- grid solar products compared to un- electrified households
80.7 million	1,207,576	985,012	2.1 million	0.26%

Since no literature is available that provides details of the growth of the off-grid solar lighting products sector in Bihar, the following section utilizes the literature pertaining to India to indicate possible factors that helped the sector grow, and factors that stood in the way of growth.

2.1.2 Literature analysis: key stakeholders perspective

Government

Policies & national energy planning

Scholars Oda and Tsujita (2011), state that the MNRE's policies and actions – providing subsidies, loans, and rebates – were the initial drivers of the off-grid solar lighting products

sector. However, most of the other scholars differ and claim that the government policies did not make much of an impact as they were either badly formulated, or poorly implemented (Urpelainen 2014; Choragudi 2013). Urpelainen (2014) claims that the federal government has pursued both grid expansion and the growth of the off-grid sector without any coordination. While the federal ministry of power runs a program called Deen Daya Upadhyaya Gram Jyoti Yojana to extend the grid, MNRE runs the Remote Village Electrification program that aims to provide a 30% subsidy for any off-grid electricity. Urpelainen (2014) in his article describes the problem, "Entrepreneurs in the field do not have a clear understanding of all the villages designated for grid extension in the coming years." This is a huge investment deterrent as it creates insecurity among entrepreneurs about their profitability. Urpelainen (2014) also claims that entrepreneurs think that MNRE is riddled with bureaucracy, and the clearance processes are not very transparent.

Moreover, although MNRE has existed in different names and forms for a long time, it was never integrated into national energy planning (Choragudi 2013). In the national scheme of things, the off-grid solar lighting products sector has always been seen as a temporary stopgap option, till the national grid is extended (Choragudi 2013). Leading Indian researchers state that MNRE runs numerous programs to promote off-grid renewable energy (and offgrid solar), but most of them are poorly coordinated (Palit *et al.* 2014). There is also a multiplicity of programs and these programs have always taken a top down approach with almost no consideration of the local factors (Palit *et al.* 2014). In a report, the Prayas group (2012) claims that while the federal government provides numerous subsides for the off-grid solar sector, it does not bother to check whether their subsidies have produced the desired results.

Another barrier created due to wrong government policies is that Indian entrepreneurs are not able to use innovative payment collection options because India's central bank, the Reserve Bank of India (RBI), has a rule that mandates all mobile payments must be linked to bank accounts (Climate Group 2015). Across the world, the majority of off-grid rural customers have no access to formal banking services, but have mobile connections (Climate Group 2015). Companies in successful off-grid solar countries like Kenya and Bangladesh have come up with mobile payment options for their customers (Climate Group 2015). Singh (2016) in her article states that in India, as most rural customers do not have bank accounts, this RBI rule has been a barrier for Indian off-grid solar products companies. This rule was only recently relaxed in 2015. While the rule is still problematic and in general there is a lack of clarity about it, this promising development could potentially help the sector grow in the future.

Moreover, the federal government's policy of providing kerosene subsidies to poor households acts as a hindrance to the growth of the off-grid solar lighting products sector. This barrier was highlighted by at least 5 of the 12 articles (Climate Group 2016; Singh 2016; Palit *et al.* 2014; Prayas 2012; Choragudi 2013). Rural customers get kerosene at a subsidized price, which they use for lighting purposes, and hence they are not willing to invest in offgrid solar products (Prayas 2012).

Entrepreneurs

Entrepreneurial innovation

While government policies and their implementation have not helped the sector much, literature suggests that off-grid solar companies in India have also not been innovative themselves (Climate Group 2016). This has been one important hindrance to the growth of this sector (Prayas 2012). Most solar companies face huge distribution losses, yet they never perform actual performance evaluation in the field (Prayas 2012). Climate Group (2016) claims that while many companies are not innovative in this space, some companies like Simpa Networks and SELCO have come up with innovative business models such as network metering, and pay-as-you-go (PAYG) for payment collection. Thus, innovative business models and systems have been a key driver for a handful of successful off-grid solar companies (Climate Group 2016). Another key factor that acts as a hindrance to the growth of off-grid solar companies is access to finance and investments.

Business finance & investments

Off-grid solar companies have to invest a great deal in the beginning as installations of solar systems come with high upfront costs (Ulsrud *et al.* 2011; Climate Group 2015). Furthermore, even the operation and maintenance cost are very high as the companies operate mainly in the rural areas, and thus have, "long and uncertain break-even periods" (Prayas 2012). In fact, the Climate Group (2015) report found that the profit margin for off-grid companies selling SHS is currently between 1-4%. Despite the need for financing, scholars Palit *et al.* (2014) claim that the companies find it hard to access financing from either banks directly, or through government subsidies. For instance, under the solar voltaic program, a company can avail the government subsidy only after they have installed the SHS system (Choragudi 2013). Procuring this subsidy is a long and tedious process (Singh 2016; Choragudi 2013). The only reason why the companies in this space are not backing out is because most of them are social enterprises (and are not purely profit driven) (Climate Group 2015). This nature of entrepreneurship is a main driver, and has so far kept the off-grid solar sector afloat.

In their analysis of the off-grid solar lighting products sector, many scholars have not focused on the role of foreign investments. However, Climate Group (2015) claims that investments in the off-grid solar space could act as an important driver for this sector. In their report, they claim that investment from international players in the off-grid solar sector in India has been minimal. The report further adds that "...few enterprises [in India] have been able to raise large scale equity investments" (Climate Group 2015). The report describes 2 main reasons for this. First, most domestic companies in India have no off-shore contacts, and find it difficult to reach out to international investors. Second, overseas investors have to deal with a lot of bureaucracy to invest in the Indian off-grid market (Climate Group 2015). Despite all the financial challenges, the Prayas (2012) report claims that the companies operating in this sector have somehow survived because of aid money and some local investments.

Quality of off-grid solar products & services

Scholars claim that there is no monitoring of the quality of off-grid solar products and services provided by solar companies in India (Shrimali and Rohra 2012; Oda and Tsujita 2011). Urpelainen (2014) states, "One possible obstacle to expansion of off-grid electrification is the spread of low quality off-grid electrification systems." Several instances have been found where companies or government partners have provided customers with substandard solar products, and disappeared at the time of after-sales service (Singh 2016). This has 'ruined the market,' creating a negative image for solar products among rural customers (Singh 2016). However, in places where good quality products have been sold or distributed, customers have been happy and have shown willingness to pay (Ulsrud *et al.* 2011).

Customers

Several articles state that low consumer awareness and a lack of affordability are the 2 most important reasons why the off-grid solar sector has failed to thrive in India (Palit and Bandyopadhyay 2016; Urpelainen 2016; Climate Group 2016; Shrimali and Rohra, 2012).

Customer affordability

Rural customers have limited and irregular incomes, and because of this, they are generally not able to afford solar products on their own (Climate Group 2016). Further, rural customers find it challenging to procure loans or subsidies from banks for investing in solar products such as solar lanterns and SHS (Singh 2016; Climate Group 2016). In addition, Singh (2016) states that although the federal government has several programs that provide subsidies to rural households interested in buying solar products, bankers who are to actually extend this subsidy are not aware of these subsidy programs run by the government. Kathaiyan (2015), while highlighting all the above issues in his article, also states that the benchmark cost calculated by the government for providing subsidies to rural customers for the purchase of solar products is very low compared to the actual cost of the product. Thus, even if banks provide subsidies to customers, the amount is generally not enough for rural customers (Kathaiyan 2015).

User practise & culture

Two articles state that rural customers in India still prefer grid power and are not aware of off-grid solar lighting products (Palit and Bandyopadhyay 2016; Urpelainen 2016). The reason is that in India, grid power is highly subsidized and people in rural areas think that sooner or later they will be connected to the grid and they will get inexpensive power (Palit *et al.* 2014; Palit and Bandyopadhyay 2016). In addition, a survey conducted by Urpelainen (2016) in Barabanki district, Uttar Pradesh, found that rural customers don't trust private companies providing solar products. Urpelainen (2016) adds that this is not an isolated case, and several other researchers have also highlighted similar results. Urpelainen (2016) also claims that rural customers don't understand the way government agencies and ministries, entrepreneurs, and NGOs operate in this sector. Shrimali and Rohra (2012) agrees and added that the reason is that none of these stakeholders have done much to educate rural customers, and make them aware of the importance of solar products.

Lending institutions

Historically, financial institutions in India have never considered lending to renewable energy projects and are sceptical about lending to this sector (Climate Group 2015; Prayas 2016). In addition, Climate Group (2015) states that banks require, "At least three years of positive cash flows, detailed credit histories, as well as profitability before they are willing to lend." Singh (2016) said that few off-grid companies in India meet this requirement, and thus they find it difficult to procure loans. However, Choragudi (2013) states that despite the above issues, some companies are still able to procure loans.

When it comes to customers, bankers do not trust rural customers as they don't own any assets, and are reluctant to lend them. In addition, micro finance institutions (MFIs), which cater to more than 40% of the rural population, so far haven't participated in lending for solar products (Kathaiyan 2015). The reason is that MNRE has set an upper limit of 5% on lending rates offered on solar products, which is way below the normal lending rates of MFIs (Kathaiyan 2015). MNRE did that to keep the loans affordable, but it had the counter-productive effect of preventing MFIs from offering loans at all because they were too risky.

Apart from the issues highlighted in the literature pertaining to India, 2 articles provide specific points pertaining to Bihar's off-grid solar lighting products sector. These mainly fall in the customer category.

Bihar: Customers

User willingness to pay

Urpelainen (2014) states that people in Bihar are willing to pay Rs 50-100 (0.65-1.30 EUR) per month for solar products. Since large parts of the state are not connected to the grid, villagers think off-grid solar electricity is a good option (Urpelainen 2014).

Off-grid solar resources & demand

More than four-fifths of rural households in Bihar have no access to grid connected electricity. On the other hand, Bihar has 289 sunshine days, making it a suitable place for diffusion of off-grid solar products (Jha 2016). Thus, there is a huge requirement for solar off-grid products and there is potential (Jha 2016). Whatever little of the off-grid solar sector has developed in the state is a result of this demand-potential factor (Jha 2016).

Conclusion

The initial drivers and barriers, and elements of those drivers and barriers, derived from this literature review are depicted below in Table 3.

Driver	Driver Elements	Barrier	Barrier Elements
		Consumer Ability to Pay	Consumer's limited/irregular incomes make it difficult to afford SHS & lanterns
		Consumer Finance	Difficult for rural customers to procure loans
			Most microfinance institutes don't participate in solar sector lending
		Company financing	High upfront costs & long/uncertain break-even periods
		& profitability	• Government regulations impeded ability of companies to obtain foreign financing
			Government subsidies unreliable
			Difficulty obtaining bank loans
		Grid expansion	• Lack of coordination between grid expansion & growth of off-grid creates uncertainty for
			entrepreneurs
			Cheap grid power
			Uncertainty about when grid is coming creates consumer uncertainty
Government	• Subsidies,	Government	• RBI regulations delayed the implementation of mobile money, and thus PAYG
	loans &		MNRE's top down approach is disconnected from on the ground reality
	rebates acted		MNRE not integrated into national energy planning
	as initial		• Initial govnt. attempts to grow SHS sector primarily using aid funding worked poorly
	sectoral		Kerosene subsidy a major hindrance
	growth		
		Ease of Doing	• Fragmented government policies & bureaucracy make it hard for companies to attract foreign
		Business	investment
		Consumer	• Rural consumers not aware of the use & potential of solar power
	tion	Awareness	
	llect	Quality Issues	• Absence of common technical standards makes it hard to regulate quality
	C C		Instances of vendors disappearing after poor quality products break has ruined market
	eTI		confidence in some areas
	CEU	Weak Supply Chains	• Several off-grid companies have weak supply chains, which hinders their operations

Table 3. Drivers and barriers in India

2.2 Applicable theories & theoretical framework

The few comparative studies of the diffusion of renewable energy technology in developing countries that were reviewed in the course of preparing this thesis do not use a particular theory to study this type of research problem. However, one study by Ahlborg and Hammar (2014), which looks at the drivers of and barriers to on and off-grid rural electrification using renewable energy in Tanzania and Mozambique, applies a helpful methodological and analytical framework set out by Painuly (2001). Painuly (2001)'s framework is a straightforward, simple, and intuitive methodological and analytical approach that can be used to identify the drivers of and barriers to the diffusion of renewable energy in developing countries. Painuly suggests a tiered, nested approach to identifying, analyzing, and categorizing drivers and barriers, which shares similarities with the approach suggested by other scholars such as Ostrom (2007), who writes about the need to organise variables into nested multitiered frameworks in order to understand complex systems and avoid simplistic and universalized policy prescriptions.

However, while Painuly (2001)'s framework, as adapted by Ahlborg and Hammar (2014), is helpful in outlining appropriate methodology for collecting data, and an approach for categorizing drivers and barriers, it lacks any theoretical insight into the type of drivers and barriers that present themselves in the diffusion of off-grid renewable energy technology in developing countries. Recent research by Cherp *et al.* (2016) describing three perspectives on national energy transitions provides added theoretical value for analyzing and discussing drivers and barriers in this thesis.

The aim of this section is to (1) describe Painuly (2001)'s methodological and analytical framework, as applied in Ahlborg and Hammar (2014), and (2) describe Cherp *et al.* (2016)'s three perspectives on national energy transitions, and how it can be combined with Painuly's framework to help analyse and understand the drivers and barriers that are identified.

2.2.1. Painuly (2001)'s methodological and analytical framework, applied in Ahlborg and Hammar (2014)

Ahlborg and Hammar's 2014 article, "Drivers and barriers to rural electrification in Tanzania and Mozambique – Grid-extension, off-grid, and renewable energy technologies" is a similar study to this thesis. The difference is that Ahlborg and Hammar (2014) look at Tanzania and Mozambique, and examine drivers of and barriers to the diffusion of on and off-grid renewable energy technologies for rural electrification (as opposed to looking at Kenya and Bihar, and solely the diffusion of the off-grid solar lighting products sector).

In their article, Ahlborg and Hammar (2014) observe that few studies have taken a systematic approach to identifying the drivers and barriers of renewable energy, and that the focus is typically much more on barriers than on drivers. They adopt Wilkins (2002) definition of drivers and barriers where a barrier is "any technical, economic, institutional, organizational, political, social, or environmental factor impeding the deployment of a new technology." Drivers, according to Wilkins (2002) and quoted in Ahlborg and Hammar (2014), are "any technical, economic, institutional, organizational, political, social, or environmental factor that enhances the deployment of a new technology." This thesis adopts Wilkins' definitions of drivers and barriers. Ahlborg and Hammar (2014) also note that drivers and barriers are often interrelated, and it may be difficult to isolate one particular driver or barriers' impact.

Ahlborg and Hammar (2014) apply a methodological and analytical framework derived from Painuly (2001). Painuly (2001) specifically sets out a framework for analysis of barriers to renewable energy penetration, and suggests the following steps for analysis:

1. Identify a particular renewable energy technology that has potential in a particular country or region as a subject of study

- 2. Conduct an initial literature survey to make a preliminary identification of drivers and barriers
- 3. Make site visits, where possible, to study renewable energy technology projects closely
- 4. Interact with (and interview) a wide variety of stakeholders

Painuly (2001) states that these steps complement one another, and recommends that "all three approaches [i.e. 2-4] be used for the identification of barriers." Following this process (which this work follows in exact form with the exception of site visits, which were not conducted due to cost and time barriers), Painuly (2001) sets out a framework for the identification of barriers. He states that "barriers can be explored and analyzed at several levels," and suggests a hierarchical approach to identifying barriers. He states that the researcher should first examine detailed "elements" of barriers, then categorize these elements into barriers, then categorize these barriers into barrier categories. An example, adapted from Painuly (2001), is set out in Figure 3, below.



Figure 3. Barrier identification. Source: Painuly (2001) (with amendments).

Painuly (2001) also includes an optional, fourth level that breaks down barrier elements into more specific discrete variables (i.e. the percentage by which interest rates are higher than a reasonable level) but this optional level has been omitted in this work, as it was not possible to go into such great detail with our interviewees in a preliminary, exploratory study.

Painuly (2001)'s approach to barrier identification has been applied in this study to identify both drivers *and* barriers, following the caution of Ahlborg and Hammer (2014) that while the literature has focused more on barriers, studying both is informative to understanding the diffusion of a renewable energy technology.

While Painuly's framework, as adapted by Ahlborg and Hammar (2014) is useful for structuring a methodological and analytical approach for this study, and for describing how to categorize drivers and barriers, it lacks theoretical insight into the types and categories of drivers and barriers that present themselves in the diffusion of off-grid renewable energy technology in developing countries. Cherp *et al.* (2016)'s recent research setting out three perspectives on national energy transitions fills this gap.

2.2.2. Cherp et al. (2016)'s three perspectives on national energy transitions

Cherp *et al.* (2016) puts forward three perspectives – the techno-economic, socio-technical, and political – for understanding national energy transitions. Cherp *et al.* (2016) define energy transitions as "long-term structural changes in energy systems." The topic of both theses is a transition from the use of kerosene as a lighting source to the use of off-grid solar lighting products in Kenya and Bihar. This is a long-term structural change – a total transformation in the way energy is captured, transformed and used by communities (Palit *et al.* 2014). Thus, studying the shift towards off-grid solar lighting products in Kenya and Bihar from an energy transitions perspective will help enhance and inform understanding of the shift taking place.

Cherp *et al.* (2016)'s three perspectives is a "meta-theoretical framework," that brings together the three major perspectives on energy transitions under one umbrella for the first time. Previous academic work regarding energy transitions typically focused on examining energy transitions through only one of the three perspectives. However, energy transitions are complex and one perspective may not give the full picture. Therefore, Cherp *et al.* (2016)'s meta-theoretical framework allows a full analysis of factors shaping energy transitions, and is a powerful tool for developing a holistic understanding of how and why they occur in a particular situation.

According to Cherp *et al.* (2016)'s three perspectives, national energy transitions involve the coevolution of three systems, each of which corresponds to one of the three perspectives: (a) energy flows and markets (techno-economic perspective), (b) energy technologies (socio-technical perspective), and (c) national energy policies (political perspective). The following section briefly describes the perspectives and related systems (depicted in Figure 4, below), and concludes by discussing the co-evolution of perspectives.

The techno-economic perspective deals with the techno-economic system, defined by Cherp *et al.* (2016) as, "Energy flows, extraction, conversion and use process involved in energy production and consumption as coordinated by energy markets."

The socio-technical perspective looks at the socio-technical system, defined by Cherp *et al.* (2016) as, "Knowledge, practices, networks associated with energy technologies."

The political perspective looks at the policy system, defined by Cherp *et al.* (2016) as, "Political networks and power relations involved in formulation and implementation of energy policies."



Figure 4. Three perspectives on energy transitions. Source: Cherp *et al.* 2016, incorporating Foxon, 2011, (F); Norgaard, 1994, (N); and Freeman and Louca, 2001, (FL).

Co-evolving systems

According to Cherp *et al.* (2016), it's clear that the systems involved in these three perspectives can evolve independently – for example, governments may develop new energy policies separate from new technological developments, irrespective of the magnitude of national fossil fuel deposits. At the same time, the three systems can have areas of overlap, and can affect one another. For example, policies can encourage technological development and diffusion. Therefore, these systems may interact or "co-evolve." However, despite co-evolution, there may be one perspective that is a better fit than the others when it comes to explaining a certain instance of transition.

This thesis applies Cherp *et al.* (2016)'s three perspectives by using this theory to analyze and discuss the driver and barrier elements derived from the data. This approach strengthens Painuly (2001)'s adapted methodological and analytical framework for the purposes of this thesis. The three perspectives inform the description of driver and barrier elements by (1) helping to ensure no perspective is overlooked in the identification and analysis of driver and barrier elements, and helping highlight dominant or under represented perspectives present in the driver and barrier elements, and (2) informing the search for additional theories that may further understanding of the driver or barrier element.

Having analyzed the literature, and setting out the methodological, analytical, and theoretical approach this thesis will follow, the following methodology chapter describes the data collection and data analysis approach applied in this thesis.
3. Methodology

The aim of both theses making up this joint study is to obtain a clear understanding of the development of the off-grid solar lighting products sectors in Bihar and Kenya, in order to compare the two and draw policy recommendations for growth of the Bihar sector. Each thesis uses multiple, staged data collection strategies to achieve its aim, following Painuly (2001) and Ahlborg and Hammar (2014)'s approach: 1) a literature review, and 2) interviews of key stakeholders in Bihar, Kenya, and California. The interview data is complemented by additional, independent collection of additional data sets and figures.

This thesis focuses on outlining the development of the off-grid solar lighting products sector in Bihar, India. The second thesis focuses on outlining the development of the off-grid solar lighting products sector in Kenya. The theses have distinct literature review sections. They share the same theoretical framework and methodology, as they are designed to be combined as a comparative study, and aligning these sections facilitates accurate comparisons. They have distinct results sections. The two theses have a common discussion section, where results from both theses are discussed separately, and then synthesized and compared to draw recommendations for Bihar. They have separate conclusion sections. This study design is outlined in Figure 5, below. Yellow indicates a common section.



Figure 5. Thesis project structure overview

The data collection strategies and data analysis approach used in both theses are described in detail below.

3.1 Data collection

3.1.1 Literature review

The literature reviews were completed in January, 2017, prior to the start of the interviews and data collection, and the results informed the interview protocols used for the interviews and additional data collection. The aim of the literature reviews was to determine what was already written about the development of the off-grid solar lighting sectors in Bihar and in Kenya, respectively, and to identify drivers of and barriers to the development of the sector in both countries. The literature reviews were conducted in the following way:

- The authors, via their supervisor, reached out to subject experts and asked them for their literature recommendation: Dr. Shonali Pachauri, Senior Research Scholar, International Institute for Applied Systems Analysis (IIASA), and Dr. Benjamin Sovacool, professor at the University of Sussex.
- Independently, the authors also searched for academic literature and grey literature. One author conducted the literature search for Bihar, and the other conducted the literature search for Kenya. The author conducting the literature search for Bihar expanded this search to all of India when it became clear that there was little relevant literature written on Bihar. The authors followed the following procedure:
 - o 1) They searched for relevant material in three databases (Ebsco, Science Direct, and LUB-search, Lund University's academic literature database). While LUB-search picked up on some relevant grey literature, they also searched Google to find grey literature. The authors chose to only search Google in English, as opposed to devanagari (Hindi script) as neither author reads Hindi fluently.
 - 2) They recorded the keywords used in the searches to avoid duplication and ensure consistency with one another. The following keyword searches were conducted for India, as well as Bihar and Kenya (replacing 'India' with 'Bihar' or 'Kenya')
 - India 'and' off-grid 'and' solar
 - India 'and' solar home systems
 - India 'and' solar lantern
 - India 'and' solar electricity
 - India 'and' solar
 - India 'and' off-grid 'and' drivers
 - India 'and' off-grid 'and' barriers
 - off-grid 'and' India 'and' policy
 - off-grid 'and' India 'and' history
 - India 'and' renewable energy
 - 3) To further ensure consistency, they agreed on pre-determined screening criteria for articles: they only retained articles that were written in the last 10 years, in English. However, they kept an eye out for classic articles in the field that were

heavily referenced in the literature, and where these were identified, retained these as well.

 Following article identification, articles were reviewed and analysed using the method described in the data analysis section, below.

3.1.2 Key stakeholder interviews and additional data collection

The literature review revealed that little (only 2 relevant articles) was written about the development of the off-grid solar sector in Bihar. When the author expanded the search to India as a whole, 12 additional articles were identified. In contrast, a modest quantity of literature about the development of the sector in Kenya was available – approximately 16 relevant articles. However, the most recent academic literature regarding Kenya was written in 2013, and since then, significant changes have occurred in Kenya's off-grid solar sector due to technology development, and the influx of new companies and new business models such as PAYG (Ondraczek 2017). These data gaps highlighted the importance of collecting further data via interviews with key stakeholders in Bihar and Kenya. The interviews were also used to collect additional data for Bihar, and to update data for Kenya, in order to complement data collected from the interviews themselves.

Conducting interviews required considerable effort, including travel to Bihar, Kenya, and California, and extensive networking to set up interviews with appropriate players. Challenges included having to rebook interviews several times when the interviewee cancelled the day of, needing to contact interviewees persistently to fix an interview in the first place, and needing to visit government agencies multiple times to procure the requisite data for the additional quantitative data sets. In total, 3 sets of semi-structured interviews were conducted: one set in Bihar in late January/early February, one set in Kenya in February, and one set in California, United States in March. The interviews in California were included because a notable cluster of off-grid solar product companies and funders of such companies have offices in San Francisco, California, representing a rich additional source of information for our research.

Sampling

In total, 10 semi-structured interviews were conducted solely about Bihar, 10 were conducted solely about Kenya, and 3 comparative interviews were conducted that touched on topics in both countries and provided a comparative perspective. In addition, a Seattle based company operating in Uttar Pradesh, a state adjacent to Bihar, was interviewed, as they are the only company currently operating a PAYG off-grid solar lighting product business in India. Sixteen interviews were conducted in person. Seven were conducted on the phone or via email, when that was the only way to reach the subject. Nine interviews in Bihar were conducted in Hindi, and 1 in English. All interviews in Kenya and California were conducted in English.

Interview subjects were selected using a mixture of purposive quota sampling, and snowball sampling. Quota sampling is a flexible sampling strategy that involves setting out a number of sampling categories, and establishing a minimum number of cases required for each category (Robinson 2014). For the initial quota sampling, the literature review was used to determine relevant categories of stakeholders to interview, and then a minimum of 2 potential interviewees were identified in each category. The researchers also used snowball sampling to help ensure that relevant stakeholders were not overlooked: after each interview, the authors asked the interviewee for suggestions about additional relevant stakeholders to interview. See Table 4 below for a breakdown of categories and interview subjects for interviews solely regarding Bihar, and Table 5 for a breakdown for Kenya. Table 6 contains the list of interview subjects for the comparative interviews. Stakeholders identified by snowball sampling are included in blue text. Select interviewees have been listed as anonymous, as per their request.

Category Interviewee Anonymous, Bihar Renewable Energy Development Agency 1. Government (BREDA) representative Deepak Gupta, former Secretary, Ministry of New and Renewable Energy, Government of India 2. Companies Sudipta Ghosh, Assistant General Manager - Operations, SELCO Solar Light Pvt. Ltd Akhilesh Kumar, Owner, Sree Krishna Enterprises Anup Agarwal, Head, Dudhwa Power Industries Kunal Amitabh, Chief Operating Officer, Decentralized Energy System India Pvt Ltd Shreya Jai, Journalist, Business Standard 3. Experts Archana Tiwari, State Project Manager - Social Development, Bihar Rural Livelihoods Promotion Society 4. Finance Anonymous, State Bank of India representative Anonymous, National Bank for Agriculture and Rural Development representative

Table 4. Interviews solely regarding Bihar

Table 5. Interviews solely regarding Kenya

Category	Interviewee
1. Government	Eng. Ephantus M. Kamweru, Chief Manager, Research & Development Dept., Rural Electrification Authority (REA)
	Anonymous, Renewable Energy Dept. representative, REA
2. Companies	Caroline Odera, Founder, Smokeless Homes Initiative
	Cedrick Todwell, Marketing Manager, Mobisol
3. Experts	David Njugi, Project Co-ordinator, Kenya Association of Manufacturers (KAM)
	Kamal Gupta, Chairman, Kenya Renewable Energy Association (KEREA)
	Janosch Ondraczek, External Associate, University of Hamburg
	Leonard Akwany, Founder & Co-ordinator, Eco-Finder Kenya
4. Finance	Karen Basiye, Sustainability and Social Policy Senior Manager, Safaricom
	Victor Ndiege, Program Manager – Renewable Energy and Adaptation to Climate Change Technologies (REACT), East Africa at KPMG-International Development Assistance Services (IDAS)/Africa Enterprise Challenge Fund (AECF)

Table 6. Comparative interviews about Kenya and Bihar

Category	Interviewee
Companies	Radhika Thakkar, Vice President of Global Business Development, Greenlight Planet
	Purnima Kumar, Vice President, Business Development, Lumeter Networks
	Nikhil Nair, Director of Sales, M-Kopa

In addition, Mitali Sahni, Investor Relations Analyst, Simpa Networks was interviewed. Simpa Networks is a Seattle based company that operates in Uttar Pradesh, a state adjacent to Bihar, operating the only PAYG off-grid solar lighting product business in India.

The interviewees represented a fairly balanced sample in both Bihar and Kenya. In Kenya, both government interviewees came from the Kenyan Rural Electrification Authority, which is tasked with electrifying rural Kenya via a combination of grid extension and deployment of renewable energy. While it would have been possible to contact additional government departments (i.e. the Kenya Ministry of Energy, the Kenya Energy Regulatory Commission) the authors elected not to when it became clear that the Kenyan government played very little role in the private off-grid solar lighting products sector. The authors' focus was on only conducting interviews that provided relevant data for answering the thesis research questions.

The expert interviewees included a variety of stakeholders with diverse outlooks: the head of the KEREA, the industry body composed of and representing private companies in this sector, a member of the Kenya Manufacturing Association, Janosch Ondraczek, an academic employed at the University of Hamburg who has written several of the most relevant, detailed, and up-to-date journal articles in this field (which are referenced in the literature review section of this paper), and a social entrepreneur who has worked with several off-grid solar non-profit projects.

The companies interviewed included an initiative delivering solar lanterns, and a company selling SHS on PAYG plans that is one of the primary players in this space in Nairobi. Finally, the finance institutions included Safaricom, the main telecom company in Kenya that provides the platform for the M-Pesa mobile money service, and the head of the Renewable Energy and Climate Technologies portfolio at the African Energy Challenge Fund (AECF), a fund that helped jump-start the off-grid solar sector.

In Bihar, from the state governments' side, a representative of the Bihar Renewable Energy Development Agency (BREDA) was interviewed. The agency is responsible for promoting renewable energy including off-grid solar in Bihar. Since the role of the federal government is crucial in the off-grid solar sector in India, a former secretary of the federal Ministry of New & Renewable Energy was also interviewed. Other than that, interviews were also conducted with an expert working in Bihar and a journalist who has extensively researched and reported on this sector. Representatives of the State Bank of India and NABARD were also interviewed because they are meant to provide soft loans and subsidies to the off-grid solar consumers. Representatives of 4 offgrid solar lighting product companies in Bihar were also interviewed for the purpose of this research. Finally, 3 comparative interviews with 3 major companies with expertise in both Bihar and Kenya were conducted, which helped round out the information collected in the interviews and provided an invaluable comparative perspective.

One limitation of this research is the omission of customers. Off-grid solar lighting product customers are highly relevant stakeholders. However, the researchers did not have sufficient resources to survey the opinions of customers in a meaningful way. The authors concluded that rather than conducting a handful of non-representative interviews with customers, it would be better to save this for a subsequent research study that could focus specifically on filling this data gap and employ a more comprehensive method such as a survey.

Interview protocols

Tailored interview protocols were created for each category of stakeholder in each country. The interview protocols began with an introduction that prompted the researchers to explain the purpose of the research study, state the estimated interview time (between 30-40 minutes), ask the interviewee for consent to record the interview, and ask the interviewee if they had any questions prior to beginning the interview.

Following the introduction, the interview protocols were divided into two parts: general and specific. The general part consisted of open-ended questions, such as "what do you think has helped the offgrid solar sector in Bihar develop?" For the specific part, themes from the literature review were used to generate specific, thematic questions for each interview protocol, such as the Bihar question, "how do the state government and federal government coordinate their initiatives related to the offgrid solar sector?" Specific questions were only asked if they had not already been touched upon in the general part. Occasionally the interviewers used improvised follow-up questions or prompts to clarify a response or to keep the interviewee on track. The number of questions in each protocol ranged from 10-20, and the average number of questions was 15. In general, the researchers made an effort to create effective questions that were open ended, allowing respondents to share their experience in an unconfined way, used neutral (as opposed to judgmental or evocative) language, and were worded clearly (Turner 2010). The questions were pilot tested on colleagues in the MESPOM program and refined further before the interviews were conducted.

All interviews were conducted using the abovementioned interview protocols. They began with the introduction as described, and then the researchers asked the general and then specific questions. After the interview the researchers thanked the interviewee for their participation and told them how to get in touch with the researchers if they had any questions after the interview.

Additional data collection

Prior to the interviews, the authors generated a list of data they would like to gather to better understand the themes revealed by the literature reviews. For example, the literature had not provided any information about the total number of SHS and solar lanterns sold or distributed in Bihar. Following the interviews, the authors asked the interviewees if they could provide this additional data. A significant amount of additional data was collected.

3.2 Data analysis

Data from the literature review was analysed in the following way. Once the screening process for articles was complete, the authors read all articles and took notes on each article for their respective theses. Subsequently the authors engaged in data analysis, using content analysis to develop themes from their literature review data. This was done by reading the content in the literature review, coding it for barrier and driver elements, and organizing these elements into overarching barriers and drivers in a table. One table was created for Kenya and one for Bihar, India.

In addition to the content analysis performed on the literature review, data from the recorded interviews was also analysed. The interview recordings were transcribed and then analysed using content analysis. Content analysis was performed using an inductive method, in the following way (Elo and Kyngas 2007). First, the researchers read through the interview transcripts. Then they coded the transcripts for barrier and driver elements, and organized these coded elements into barriers and drivers, based on Painuly (2001) and Ahlborg and Hammar (2014)'s methodology. Next, the researchers transposed the coded barrier and driver elements and overarching barriers and drivers into an excel matrix organized by interviewee and interviewee category. The resultant themes from this data analysis were compared with the results from the literature review analysis, and the additional data collected during field research. Results are presented in the next chapter, followed by a discussion in Chapter 5 that adds value to the description of barrier and driver elements via an analysis using Cherp *et al.* (2016)'s three perspectives theory.

4. <u>Results</u>

This chapter describes the results from the interviews, as well as additional data collection. Since the results of the literature review for India are not specific enough to offer lessons for Bihar, this thesis will use the below results from interviews during the final discussion. The second thesis provides the results of the content analysis of interviews conducted in Kenya.

4.1 Results from the interviews

This section presents the results of the content analysis of 13 interviews conducted with different stakeholders between January 20 and March 1, 2017. The interviews conducted for this research helped to address the significant knowledge gap regarding the history and the present status of the off-grid solar lighting products sector in Bihar. While the interviews were focused on determining the drivers and barriers to the growth of the off-grid solar lighting products sector in Bihar, each interviewee was also specifically asked to describe the historical and current developments in the off-grid solar lighting products sector in Bihar. Although there is some literature available regarding the development of this sector in India overall, no literature specific to Bihar is available on this subject. Thus, what follows is the first description in any research paper of the historical growth of the off-grid solar lighting products sector in Bihar.

4.1.1 History of the off-grid solar lighting products sector in Bihar

All 13 interviewees were specifically asked how the off-grid solar lighting products sector in Bihar developed over time. However, only 6 of them were able to provide some information about this topic. The 2 representatives reflecting government's views said that the sector in Bihar started to develop in the 1980s when the federal government initiated the distribution of solar products under the village electrification scheme. This was done through the state governments' renewable agency BREDA from the year 1983. The representative of the state government from BREDA added that the agency was created in 1983 and was doing only small scale solar work until 2005. Till then promotion of biogas was the main focus of the agency, and it was only after 2005 that the state

government really turned its attention towards solar. A representative of a local NGO that assists BREDA in identifying beneficiaries and distributing off-grid solar products said that it was only in 2012 that BREDA scaled up its off-grid solar product distribution scheme.

An expert who has researched and written extensively about the sector added that the scale of distribution of these products was negligible throughout the 1980s and the 1990s. In the mid 1990s, private sector players entered the market for the first time when the federal government started promoting *Akshay Urja* shops (solar product shops). Basically, the federal government was helping companies/ individuals and NGOs start *Akshay Urja* shops meant to sell solar products. The uptake of these shops was slow but it was the beginning of private sector intervention in the off-grid solar space. During the early 2000s, big companies like Tata came into the picture, and started manufacturing and selling solar products. A local entrepreneur from Bihar added that it was during that time that small regional companies and NGOs came into existence in Bihar and started selling these products in the private market. A representative of a large solar company assembling and selling products in Bihar said that currently every district in Bihar has a large number of shops selling solar products.

After the Indian National Congress led United Progressive Alliance (UPA) government came into power at the federal level in 2009, they enacted various programs for promoting solar energy. With this, even the off-grid solar lighting products sector got a push. Currently, the federal government runs 2 subsidy programs to promote off-grid solar lighting products. Under the off-grid and decentralized solar applications program, the federal government provides a 30% subsidy on the cost of every solar system to the state agencies who procure and distribute off-grid solar lighting products in their states. In the case of Bihar, the subsidy money is given to BREDA for distributing off-grid solar lighting products to beneficiaries in the state. The second program is implemented by NABARD. Through NABARD, the federal government provides a 40% subsidy on the cost of a solar product, and provides soft loans for the additional 60% of the product cost. Experts estimate that between 162,303 – 212,303 SHS and 350,117- 450,117 solar lanterns have been sold or distributed in Bihar. Table 7 provides a breakdown of the number of SHS and solar lanterns sold and distributed in Bihar.

Торіс	Federal government through BREDA + through NABARD	Estimates of distribution by private companies & NGOs	Total Number
Number of SHS sold/ distributed in Bihar	12,303 (MNRE 2016) (till 31/12/2016)	150,000 (Agarwal 2017) 200,000 (Tiwari 2017)	162,303 – 212,303
Number of solar lanterns sold/ distributed in Bihar	50,117 (MNRE 2016) (till 31/12/2016)	350,000 (Agarwal 2017) 300,000 – 400,000 (Tiwari 2017)	350,117- 450,117

Table 7. Number of SHS & solar lanterns. Source: Interviews & MNRE 2016.

Because the sector is very fragmented and there are numerous unregistered players selling off-grid solar lighting products, no official figures are available in any academic and grey literature for the total number of off-grid solar companies in the state. The information is also not available from BREDA or other state government agencies. However, 2 interviewees gave estimates of the number of companies in the off-grid solar lighting products sector. Table 8, below shows the estimates of the number of private solar lighting product players in Bihar.

Table 8. Estimates	s of the num	ber of solar co	mpanies in Bihar
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	Tiwari 2017	Agarwal 2017				
1. Total number of companies operating in Bihar	5000 shops (including both registered and un-registered players)	500 registered shops				
2. Total number of manufacturing companies operating in Bihar	4-10 companies assembling products	7 companies assembling products				

Overall, the off-grid solar sector in Bihar developed in three phases. In the first phase (1980s-mid 1990s), the federal government was distributing off-grid solar products through BREDA. In the second phase (mid 1990s to early 2000s), along with the government, some private entrepreneurs and NGOs started selling these products to people. In the final phase (year 2000 onwards), the private market expanded and hundreds of small and big players started selling off-grid solar products across the state. Even in the last phase, the federal government continued to run schemes providing subsidies for off-grid solar products through BREDA and NABARD. A timeline of the off-grid solar sector in Bihar is shown in Figure 6.

1980s-mid 1990s	Federal government distributed solar productsNo private players
Mid 1990s- Early 2000s	 Federal government distributed solar products Emergence of private players and NGOs
2000 onwards	 Federal government distributed solar products Expansion of private sector and NGOs

Figure 6. A timeline for Bihar's off-grid solar lighting products sector. Source: interviews.

Drivers and Barriers Derived from Content Analysis of the Interviews

Content analysis of the interviews revealed 5 key drivers that aided the growth of the off-grid solar lighting products sector in Bihar, and 9 barriers that are holding it back. The 5 factors promoting growth include (1) enhanced ability of the customer to pay, (2) push from government, (3) issues with the grid drive consumer demand, (4) customer's perceived benefits of solar, (5) nature of companies. Each of these drivers has multiple driver elements, listed in Table 9, below.

Table 9. Drivers of the off-grid solar lighting product sector in Bihar

Identified Drivers	TOTAL	Govt: A, BREDA	Govt: DG, MNRE	Expert: AT, Jeevika	Expert: SJ, Jour- nalist	Comp: SG, SELCO	Comp: AK, Ohm Krisna	Comp: KA, Desi Power	Comp: AA, D. Power	Comp: PK, Lumeter	Comp: NN, M-Kopa	Comp: RT, Green- light Planet	Fin.: A, State Bank of India	Fin: A, Nabard
ENHANCED ABILITY OF THE CUSTOMER TO PAY														
Post 2005, decrease in solar prices	2	1			1									
PUSH FROM GOVERN- MENT														
India's solar mission promotes solar	2	1			1									
Favourable VAT/ Import duties	1		1											
Initial promotion by department of new and conventional energy	1 Collection				1									
Starting of Akhay Urja Shops	1				1									

ISSUES WITH THE GRID DRIVE CONSUMER DEMAND										
Unmet electricity demand	5	1	1	1	1					1
Unreliable grid power	3	1		1			1			
CUSTOMERS PERCEIVED BENEFITS OF SOLAR										
Women understand drawbacks of kerosene and benefits to solar	2	1		1						
Livelihood opportunities for local businesses	1			1						
Customers associate solar products with social status	1			1						
NATURE OF COMPANIES	Collection									
Social entrepreneur- ship nature of companies	1				1					

The 9 barriers inhibiting the growth of the off-grid solar lighting products sector include: (1) ability of the customer to pay, (2) customer awareness of solar, (3) difficulties faced by companies, (4) customer preference for grid power, (5) government subsidies harming the solar sector, (6) lack of government support, (7) issues with product quality, (8) bureaucratic, inept, corrupt government and, (9) other. Each of these barriers has several elements, listed in Table 10, below.

Table 10. Barriers to growth of off-grid solar lighting products sector in Bihar

		Govt: A, BREDA	Govt: DG, MNRE	Expert: AT, Jeevika	Expert: SJ, Jour- nalist	Comp: SG, SELCO	Comp: AK, Ohm Krisna	Comp: KA, Desi Power	Comp: AA, D. Power	Comp: PK, Lumeter	Comp: NN, M-Kopa	Comp: RT, Green- light	Fin.: A, State Bank of India	Fin: A, Nabard
Identified Barriers	TOTAL											Planet		
ABILITY OF THE CUSTOMER TO PAY														
Initial high cost of solar (1980s & 1990s)	2	1			1									
Customer affordability	5	1		1			1			1				1
Lack of financing for customers	4				1				1		1		1	
CUSTOMER AWARENESS OF SOLAR														
Customer's lack of knowledge of government schemes promoting solar	3	1		1										1
Customer's lack awareness of the benefits of solar	7	1						1	1	1	1	1		1

DIFFICULTIES FACED BY COMPANIES													
Payment collection from customers	4	1		1				1			1		
Financing for companies	8		1		1	1		1	1	1		1	1
Company uncertainity about when the grid is coming	3		1		1			1					
Hard to procure bank loans	1						1						
Demanding customers in India and Bihar	1									1			
Weak supply chain in rural areas	2					1				1			
Nobody lobbying for off-grid solar	2							1	1				
Lack of skilled workers to act as employees	1					1							
Chinese imports killed local manufacturing	1				1								
Expanding grid reduces customer base	Collection						1	1	1	1			
CUSTOMER PREFERENCE FOR GRID POWER	CEU eTI												

Customer preference for grid power	3	1					1		1				
Customers think grid power is coming & is cheap	5	1			1	1	1						1
GOVERNMENT SUBSIDIES HARMING THE SOLAR SECTOR													
Kerosene subsidy disincentivizes customers purchases	9	1	1	1	1		1	1	1		1		1
Counterproductive MNRE/BREDA subsidy for solar product giveaways	6		1		1			1		1	1	1	
Corruption in government schemes	2						1		1				
LACK OF GOVERNMENT SUPPORT													
Bihar government's focus on grid expansion and not solar	3 _E		1		1				1				
Lack of government support for Bihar solar manufacturing	CEU eTD Collecti			1	1								
Federal government's focus	1				1								

on grid expansion and not solar											
Bihar government doesn't promote local companies	1						1				
ISSUES WITH PRODUCT QUALITY											
Issues with product quality	8	1	1	1	1		1	1	1	1	
Poor after sales service	4		1			1		1	1		
BUREAUCRATIC, INEPT, CORRUPT GOVERNMENT											
Federal and state government bureaucracy	2			1					1		
Corruption in general	1									1	
Corrupt government bank officials providing solar subsidies/loans	2				1		1				
Lack of mobile money as a barrier for PAYG	2 llection							1	1		
Too much government intervention	2 DEL C							1	1		
Lack of awareness among government	1								1		

about govt subsidies								
Hard to set up a company in India	1						1	
OTHER								
Aid model suppresses company development	1			1				
Freebie culture promoted by politicians	1							1

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5. Discussion

Based on the literature review and interview results discussed in both theses, this chapter discusses the following three sub-questions:

5.1 What drivers and barriers to growth of the off-grid solar lighting products sector exist in Kenya?

Substantial literature has been written about the drivers to growth of the off-grid solar lighting products sector in Kenya, yet substantially less has been written about the barriers. Overall, the results from the interviews generate fresh insights about this topic. First of all, the interviews fill in the gap in the literature about the barriers to growth of the off-grid solar lighting products sector in Kenya. Second, the results from the interviews outline gaps in our understanding of the historical timeline of how the off-grid solar sector in Kenya developed, and help flesh out what happened in the sector after the early 2000s. Third, and most importantly, this is the first academic study to fully consider the drivers and barriers of growth of the off-grid solar lighting products sector in Kenya since a paradigm shift in the sector occurred: the introduction of mobile money and PAYG business models, which have been very successful since they took off around 2011, and have made products affordable for poorer sections of the population.

This part is divided into section. The first section discusses the most significant drivers identified in the interviews, within the context of the literature analysed in the literature review. The second section contains a similar analysis for barriers.

5.1.1 Significant drivers

This section discusses the most significant drivers identified through the interviews, in the context of the literature review. The most significant driver elements were selected by identifying topics that were raised by at least 2 interviewees. However, any driver element that was mentioned by only one interviewee but was emphasized by them as a very

important factor is also discussed here. The discussion of drivers also draws parallels to and comments on the results from the literature review. Cherp *et al.* (2016)'s three perspectives theory is applied to discuss the significant drivers, as well as some facets of their interaction. The same method applies for the barriers, which are discussed in a subsequent section.

According to the criteria outlined above, there were 17 significant driver elements. Given the number of significant driver elements, the top 7 significant driver elements are discussed in detail below. They are:

- 1. PAYG technology and business models (raised by 9 interviewees, emphasized by 2)
- 2. Expensive grid power (raised by 9 interviewees, emphasized by 1)
- 3. The VAT exemption (raised by 8 interviewees)
- 4. Education and awareness campaigns (raised by 7 interviewees, emphasized by 1)
- 5. Unreliable grid power (raised by 7 interviewees)
- 6. Expensive kerosene (raised by 6 interviewees)
- 7. Need for power in areas where it is not available (raised by 5 interviewees)

Other significant driver elements are: consumers think the grid won't reach them anytime soon (raised by 4 interviewees, emphasized by 1), Kenyan entrepreneurship (4), government creates an enabling environment for business and investment (4), people want power for TV (3, emphasized by 1), availability of financing for companies (3, emphasized by 1), NGOs/international agencies promoting systems (3), availability of financing for companies (3, emphasized by 1), light touch and ex-ante regulation by government (3), technology has improved (2), SACCO and CHAMMO models (2), and development finance from large international organizations (2).

First, **PAYG technology and business models** were raised as the most important modern driver of growth of the Kenyan off-grid solar lighting products sector. According to one company we interviewed, "what has really trigged the growth of solar in Kenya is the PAYG system." Interviewees told us that PAYG has been important both for customers and for companies. For customers, it makes solar products an option, financially speaking, and a

solution they can be reasonably confident in. An expert academic interviewee explained that with respect to SHS, "without a means to spread the initial high cost of investment... if we are talking about a 150 dollar SHS, then only a small proportion of the population would ever be allowed to afford it. With PAYG they can spread it over a longer period... it brings these products into reach for a much larger proportion of the population." A large SHS company interviewee explained it in concrete terms: "before PAYG, people faced issues of making upfront payments. For example a Mobisol system costs you 500 dollars, and people don't have that much money. But when you tell them to pay 1 dollar every day, then it is possible." A company representative running a solar lantern social enterprise told us that PAYG has also helped customers' access solar lanterns. In addition, PAYG is a solution that is easy to implement and one in which customers can be reasonably confident. As one interviewee explained, "Imagine I'm a customer. I walk to M-Kopa, and come back with something I start using immediately. I don't need to go buy lights from somewhere else, or other components, or get it installed. And it includes not just hardware but also after-sales service. I'm sure I'm going to get a permanent solution for my problem." Interviewees also explained that PAYG makes sense for companies, because it is easier for companies to collect payments, and to deal with non-payment (they can just switch off the system, instead of having to go in person). This represented new information not in the literature review, given the literature review only extended to around 2013, when the PAYG sector was starting to take off.

One of the reasons that demand exists for solar lighting products in the first place is that grid power is often unavailable, or so prohibitively expensive as to be inaccessible. First of all, grid power is often simply not available in all areas, and there is **need for power in areas** where the grid is not available. This factor was also emphasized in the literature review by researcher Ondraczek (2013), who cited this as an important factor for early and continuing growth of the sector. Although our interviewee at the Rural Electrification Authority told us that 70% of Kenyans are connected to the grid now, and by 2020, it should be 100%, other interviewees were not so optimistic. The head of KEREA estimated that only 20-30% of the population had access to the grid. In addition, there is no uncertainty about when the grid is coming – interviewees made it clear that most Kenyans know it's not coming any time soon.

Yet, even for the small number of people for whom grid power is physically available or nearby, people can't use it because it's so prohibitively expensive that it's inaccessible. **Expensive grid power** was the second most important driver of growth mentioned by our interviewees. There are two significant expenses associated with obtaining grid power. The first is paying for the grid connection. According to Kenya Power (2014), it costs approximately 34,980 KSH (approx. 300 EUR) for new connections. The cost of grid connection has changed over time and can vary by area – for example, in the literature review researcher Opiyo (2016) cited a grid connection fee of 750 USD (approx. 670 EUR). Nevertheless, it's clear that it is always expensive. As of September 2015, there is an exception if you are within 600 m of a transformer, in which case a consumer can pay 15,000 KSH, or approximately 130 EUR, for the connection under the governments "Last Mile Connectivity Program." However, an interviewee told us that if you are not within 16 km of the grid, you have to purchase a transformer for Kenya Power – which is prohibitively expensive, and only really an option for industry. The second significant cost after grid connection is paying the monthly electricity bill. The cost of electricity in Kenya varies by area, but interviewees provided us with an estimated range of 15 – 20 KES per unit (about 0.13 EUR– 0.17 EUR), where one unit is one kilowatt hour. The information is provided below in Table 11.

Table 11. Grid power charges per unit in Kenya

	Kamweru 2017	Njugi 2017	Kumar 2017
Grid power cost estimate	17 KES/ unit	20 KES/ unit	15 – 20 KES /unit

One interviewee living in Nairobi told us his monthly electricity bill was 45 USD (approx. 40 EUR), and for that amount of money "you can own a system." To compare, Mobisol Kenya's smallest solar home system, the "Buffalo 80W," which comes with three LED lights, costs 59 KSH per day, or approximately 1770 KSH per month (about 16 EUR) (Mobisol Kenya 2017). While the solar system clearly offers less to a customer in terms of power, it is what many people can afford. An interviewee from a large company selling solar lanterns offered a holistic summary: "our target customers are really low income, very

unlikely to be able to pay for that connection, even if they could afford, its expensive to pay for electricity – it's an impractical reality for our target customers."

Finally, even if people can connect to the grid and pay for it, the power supplied is often **unreliable**, with frequent blackouts. A government interviewee stated that SHS are also popular with people connected to the grid because they supply reliable power when there is a blackout, and can reduce peoples' monthly electricity bills. A company interviewee stated that most people are still convinced that solar lighting products will be useful even if the grid comes, due to power blackouts. This point was also raised in the literature review by Opiyo (2016).

Another powerful driver is kerosene. Kerosene, which Kenyans use for lighting, is the leading alternative to grid power for rural people in Kenya. It's also very expensive. Interviewees cited **expensive kerosene** as the sixth most important driver of growth in the off-grid solar lighting product sector. In Kenya, kerosene is not subsidized, and an average off-grid household spends about 50 KSH a day on it (approx. 0.43 EUR) (Faris 2015). In contrast, the PAYG solar lanterns that the non-profit Smokeless Homes Initiative provide to villagers in Kisumu cost about 30 KSH per day, and M-Kopa's SHS, the M-Kopa IV Solar Home System, which is sold on a PAYG plan, costs 50 KSH per day (M-Kopa 2017). And as an added bonus, these plans are pay-to-own – so after about 5-6 months, the consumer has paid off the lantern and owns it, and after one year consumers own the M-Kopa SHS (M-Kopa 2017; Odera 2017). A company told us that, in short, unsubsidized kerosene "makes our proposal compelling."

However, PAYG is a crucial part of solar's relative cost compared to kerosene. Without the ability to make daily or monthly payments that roughly match their kerosene expenditure, the up-front cost of a lantern or SHS may represent more cash than consumers have on hand or are willing to part with. As a representative from the Smokeless Homes Initiative explained, "if you tell people that the lantern costs 5000 KSH in cash [the upfront cost] they will say, 'I can't afford that right now.' So we offer daily payments that look like something they are used to – daily payments for kerosene. And they see it as affordable." It is

interesting that many interviewees raised kerosene as an important driver, but it wasn't discussed in the literature reviewed for this thesis.

Education and awareness campaigns have also played a major role in spurring demand. Interviewees told us that private companies, universities, women's groups, NGOs, and organizations such as Lighting Africa had done of a lot of work to promote solar in rural areas of Kenya, which was also clear from the history outlined in the literature review. Awareness and education campaigns make people aware of solar products, and educate consumers about the health benefits of clean energy and the negative health impacts of kerosene. Private companies have also played an important role – interviewees told us that initial pioneers in the sector such as d.light for solar lanterns and M-Kopa for SHS did wideranging awareness campaigns for consumers via newspapers and radio, and that these worked well. One interviewee told us the government is also running awareness campaigns to educate the population about the negative health impacts of kerosene, such as "eye infections and lung problems."

Finally, several interviewees mentioned that **the VAT exemption** was a very important driver helping the sector grow. This is interesting because other interviewees cited it as an important barrier. This was also an apparent tension in the literature review. One common point that came to light from the interviews was that most interviewees were confused about whether the VAT was currently in place or not. One interviewee succinctly captured the reason why: "the Kenyan government does have a VAT exemption but the policy is always changing. They bring it back and then they remove it. There is confusion about whether there is currently relief from import duties." Overall, it seems that prior to 2013 there was a VAT and import duty exemption for off-grid solar lighting products, and companies had to apply on a per-shipment basis. After 2013, the government reintroduced VAT (but not import duties), in the course of reimposing VAT on a number of other products. Due to lobbying, it was removed again almost immediately. Government reimposed VAT again in 2016, because, as one company stated "based on M-Kopa's success they see it as a revenue stream." Overall, most interviewees that construe this as a driver point to periods where there were no import duties as a helpful boost to sales, as it helped keep product prices low.

According to an expert academic interviewee, this was particularly important in the 80s and 90s, when equipment was quite expensive. Most interviewees that construe it as a barrier point to the uncertainty created by constantly changing government policy, and to the fact that even when the exemption is in place, it is difficult to get for some companies. The Kenya Association of Manufacturing told us that sometimes products are held up at the port, which is expensive, and they have to intervene on behalf of their member companies to get them released.

With reference to Cherp *et al.* (2016)'s three perspectives, two of these significant drivers are socio-technical (PAYG technology and education and awareness campaigns), four are techno-economic (expensive grid power, unreliable grid power, expensive kerosene, and the need for power in areas where it is not available). One, the VAT exemption, is political. This raises a few interesting observations. First, it is clear that the political perspective has not played a large role in the development of the off-grid lighting sector, but instead the socio-technical and techno-economic perspectives have dominated. Second, while there are many techno-economic drivers, the most important driver is socio-technical: the implementation of PAYG technology and business models. This suggests that while the techno-economic factors set out above created the preconditions for a successful sector, PAYG was the necessary element that built on these preconditions and made the sector a success. Therefore, it was necessary to have interaction between the techno-economic system, in the form of strong consumer incentives to find a better lighting source, and the socio-technical business model and technology that made an alternative possible for a large part of the population.

5.1.2 Significant barriers

Having discussed 7 drivers in greater detail, this section turns to the barriers. According to the criteria set out above, the interviews results highlighted 7 significant barrier elements. These significant barrier elements are:

- 1. Quality of products (raised by 10 interviewees)
- 2. Customer affordability (raised by 7 interviewees)
- 3. Financing for customers prior to PAYG (raised by 6 interviewees)
- 4. The inconsistent VAT/import duties exemption (raised by 4 interviewees)
- 5. Financing for companies (raised by 3 interviewees)
- 6. Lack of local manufacturing (raised by 2 interviewees)
- 7. After sales service (raised by 1 interviewee but emphasized as very important)

These barrier elements are discussed in further detail below, with the exception of #4, which was discussed above in the drivers section.

The most important barrier mentioned by interviewees was **quality of products**. Many interviewees mentioned this as one of the most significant barriers, and cited it as both a historical and a present problem. This was also reflected in the literature review. Historically, during the 80s and 90s, there were many quality issues because systems were often rough and poorly designed. As an expert academic interviewee told us, "I would have a bit of a problem comparing in any way the systems of the 80s and 90s with now. People built their own systems, they weren't designed properly. Now you have people with SHS that are plug and play."

Today, almost all products are manufactured in China, whether it is a more expensive large SHS sold by an established player, or a cheap solar lantern sold by an informal player in a village market. The main issue is with the cheap products sold by informal players. As a government interviewee explained, "say one person buys a solar lantern, and it breaks in 1-2 months. Then other people might not consider buying it." The government teamed up with

Lighting Africa to develop a quality standard for solar products, which is supposed to help consumers identify good quality products. However, there are at least two problems with the standard. The first is that not all companies comply with the standard program – including M-Kopa, which has roughly about half the SHS market. The second is that poorer consumers, who are not as educated about the standard and quality issues, will often still go for the cheaper option. As one interviewee explained, customers who have the choice between a cheap product sold in a market and a more expensive quality verified product sold in a shop will often "grab the cheaper product." However, he told us that "government has tried regulating, but you can't call them counterfeits – they are just cheap products, getting to a market where people need cheap products."

However, the quality issue is not only with cheap products. Two company interviewees told us that they also had significant issues with Lighting Global certified lanterns sold by a leading brand, which had almost collapsed their businesses. One of these interviewees told us that they had faced two main problems related to quality with these Lighting Global lanterns. The first was that the lanterns were not robust. This interviewee stated that 50% of the lanterns she sold didn't last until the end of their 2 year warranty. The panels broke easily if you dropped them, and the cables broke easily if they were pulled. When it came to fixing the products, there were few local technicians trained in fixing them. The second issue was that the manufacturer was located outside the country, far away. The products had a warranty, but the interviewee's business couldn't ship one lantern to the manufacturer every time it broke, because it would be very costly. They had to wait until there were enough broken lanterns to ship to the manufacturer, and send them in a batch, and then wait for them to come back. This interviewee told us they had sent a batch last year and were still waiting for it to come back. Overall, this interviewee told us, it made her customers very unhappy. She told us that "quality issues could really have a long term impact on the solar sector – people might choose to wait for the grid and use kerosene."

Two interviewees suggested that PAYG business models are helping to overcome issues with quality because the customer doesn't pay all the money up-front, and if the product breaks they can return it to the store. However, even PAYG does not address the fact that the product may break a short time after the customer has made sufficient payments to own the systems, once the warranty has run out. In addition, some customers may live far from the place where they can return the product to the store.

One interviewee suggested that the future of the sector may be 'lighting as a service' to counteract this problem. He imagined a future where companies leased the system to consumers and they simply made monthly payments for power. As he explained, "It's my responsibility as a company that you get the service – whether I replace the system a hundred times, that's not your problem. Your problem is that you have light and power. That's what the customers are buying. That's what I see the market moving to."

Interviewees also talked about **customer affordability** as a barrier – which refers to the ability of customers to financially afford products. This was especially pressing in the 80s and 90s when SHS were very expensive. Back then SHS were mainly the preserve of the middle and upper class. As one interviewee stated, "it was mainly for elite people." However, today, customer affordability is still a problem. An expert interviewee told us that "In the rural areas, finance for solar products is still a challenge. A good solar product will go for 40 dollar a month. Many people in Kenya have food as a big priority [and can't afford this]." The same is true for solar lanterns sold without a PAYG plan. One interviewee told us "solar lanterns are still very expensive. Lots of people are still using kerosene because they are not able to buy these lamps. The financial inaccessibility is the problem." These comments about customer affordability were also reflected in the literature, which highlighted this as a major barrier.

Interviewees raised **financing for customers prior to PAYG** as another major barrier, which is related to customer affordability. One company interviewee described customer financing as the "key challenge" for customers prior to PAYG. In essence, PAYG has helped sections of the population that were previously unable to access solar lighting products gain access. Interviewees discussed similar themes to those covered in the literature review. Previously, bank loans were not an option. Poor rural customers were asking for small amounts, yet didn't have credit history, and therefore banks chose to ask for

prohibitively costly interest rates. Microfinance was also difficult to obtain, often for similar reasons – microfinance institutions saw the risk of lending as too significant. Some customers financed their SHS through "hire-purchase" agreements, but this was only a possibility for a niche of the population who had a formal contract with an employer and earned a high enough income through that contract.

While financing for customers was discussed as a major barrier, **financing for companies** was also raised as an important barrier. A major solar lantern company commented on this, stating "one of the biggest challenges right now and in the last five years, in different forms, is access to financing." She told us that companies are often at a loss whether to use limited funds to pay for inventory to meet demand, or to use funds to create demand. She said it is difficult for companies to get bank loans, stating "banks will say first of all you are selling to unbanked customers, they don't have bank accounts, they're poor, do they even need this, you're four years old as a company, you're too risky, I don't understand your business, I don't understand the value of your assets." She told us that often banks either don't grant a loan, grant a loan with a prohibitively high interest rate, and/or request 100-120% collateral. She stated "They're also only comfortable if you give up 100-120% collateral, which doesn't work – like give 500,000 cash in account for 50 million shilling loan, and we're like well, if we had that..."

She added that there is a need for more local funding facilities. She told us that as the industry has grown, suppliers have been able to tap into facilities from the west and pass on funding, but that this is also difficult because suppliers aren't set up to act as financial institutions. And the issue is changing with the growth of PAYG, which requires a lot more capital, and "patient capital" – investors who are willing to wait longer to see returns. The two financial institutions we spoke to echo the fact that it can be difficult for companies to secure financing in this sector, although one of the financing institutions said that the AECF Challenge Fund has played a large role in de-risking companies and helping them attract capital.

Interviewees also spoke about **lack of local manufacturing** as a barrier. Interviewees agreed that there is only one significant manufacturer in Kenya, Ubbink, which manufactures solar panels. It started production in 2011 (Solinc East Africa 2016). Some companies, such as Mobisol, buy a portion of their solar panels from this company. However, apart from that, most products are manufactured in China. That makes it more difficult for companies to follow up on warranties for customers. An expert interviewee suggested to us that tax incentives could help foster a manufacturing industry in Kenya, and that government policy could help too. They told us that the Kenyan government started requiring 50% of transformers to come from local sources, which incentivized a lot of companies to set up shop, and that a similar policy could help foster a solar lighting product manufacturing industry. So the policies in the Sub-Saharan Africa should be aligned and should be consistent." They suggested that if a local manufacturing industry developed, it could help lower costs for consumers and increase consumer satisfaction by making it easier for companies to follow through on warranties.

Finally, **after sales service** was raised an important point by one expert interviewee, who told us that "after sales service is a big problem for extremely rural areas. If you go beyond the major towns it is a big challenge." In other words, it can be difficult for very rural customers to access shops to repair or replace broken products, which is especially challenging given the pressing quality issues described above. The literature reviewed for this thesis was silent on this topic.

All of these barriers are socio-technical, with the exception of the VAT/import duties exemption, which is political. This shows that in general, the political and techno-economic perspectives are not a source of barriers in Kenya. In fact, the political perspective is largely absent, and techno-economic factors are largely positive. However, multiple socio-technical barriers, such as product quality, lack of company financing, lack of manufacturing companies, and lack of adequate after sales care, will need to be overcome for the off-grid solar lighting products sector to reach its full potential. Having reviewed the drivers and barriers to growth of the off-grid solar lighting product sector in Kenya, the next part goes on to discuss drivers and barriers to the growth of the sector in Bihar.

5.2 What drivers and barriers to growth of the off-grid solar consumer lighting product sector exist in Bihar, India?

Overall, 5 main drivers with a total of 11 driver elements were identified through content analysis of interview results. In addition, interviewees discussed 9 main barriers with 34 barrier elements. Many of the drivers and barriers were identified by multiple interviewees and were also emphasized by some interviewees. The next sections offer an in-depth analysis of the top driver and barrier elements discussed by the interviewees. The top drivers and barriers, as well as some facets of their interaction, are also discussed using Cherp *et al.* (2016)'s three perspectives theory.

5.2.1 Significant drivers

While all the 11 driver elements positively impact the growth of the off-grid solar lighting product sector in Bihar, this section will only discuss driver elements mentioned by at least 2 interviewees. Based on this criterion, 5 driver elements are significant. They are:

- 1) Unmet electricity demand (raised by 5 interviewees)
- 2) Unreliable grid power (raised by 3 interviewees)
- 3) Post 2005, decrease in solar prices (raised by 2 interviewees)
- 4) India's solar mission promotes solar (raised by 2 interviewees)
- 5) Women understand drawbacks of kerosene and benefits of solar (raised by 2 interviewees)

The most significant factor that led to the growth of the off-grid solar lighting products sector in Bihar is the **unmet electricity demand**. This was pointed out by 5 interviewees. Bihar is India's least electrified state – in 2011, 89.6% of Bihar's rural population had no
access to the electricity grid. All 5 interviewees pointed out that unmet electricity demand for millions of people in the state is an incentive for people to buy solar products. A representative of a local NGO that works in the sector said that many people in the state have never seen any electricity, and hence for them any form of lighting source is an attractive proposition.

Not only is there a lack of electricity in large parts of the state, even the areas which are connected to the grid face power outages. Three interviewees said that the **grid power in Bihar is highly unreliable** and is quite intermittent especially in the rural areas. An interviewee heading a large solar company in Bihar said that people in Bihar face long hours of power cuts and in some cases only get 2-4 hours of power a day. The representative of BREDA said, "Since the grid power is intermittent, some people prefer off-grid solar products."

While unmet electricity demand and lack of reliable electricity enhances the market potential for solar products, the fall of solar prices globally and in India post 2005 has also helped make off-grid solar products affordable for customers in Bihar. Two interviewees (the BREDA representative and an expert) stated that the fall in solar prices has had a significant impact on the sector. The expert explained that after 2008-2009, cheap Chinese solar products flooded the Indian market and brought down the cost significantly. "This made the products much more affordable for the poor people in Bihar," the expert stated. The fall in solar prices coupled with the federal governments' thrust for solar power by launching the National Solar Mission in 2010 has contributed to the growth of the off-grid solar lighting products sector in Bihar. The mission was meant to "create an enabling policy framework to achieve this objective and make India a global leader in solar energy" (MNRE 2017). As part of the mission various schemes and programs were launched for the promotion of off-grid solar lighting products. For instance, in 2010, NABARD in association with MNRE launched the capital subsidy-cum-refinance scheme for installation of SHS. Under the scheme, NABARD gives a 40% subsidy to consumers for SHS along with a bank loan at 5% interest per annum for the rest of the cost of the SHS (Jog 2010).

In addition, **India's solar mission** has helped to promote off-grid solar lighting products. The BREDA representative stated that his agency started focusing on the off-grid solar lighting product sector only after the federal government launched the National Solar Mission. He stated, "After the federal government launched the National Solar Mission, our agency got more support from MNRE and we expanded our activities in the off-grid space."

Furthermore, 2 interviewees said that some women in Bihar understand the drawbacks of the use of kerosene and the benefits of using solar, and this is a driving force for the sector. The expert from the NGO was very vocal about this point and said that women suffer the most due to lack of electricity because they are exposed to the smoke coming out from the kerosene lamps. Typically, women use kerosene lamps for cooking and doing household chores at night, and for some livelihood activities like sewing.

With reference to Cherp *et al.* (2016)'s three perspectives, the first 3 drivers (unmet electricity demand, unreliable grid power, and a post-2005 decrease in solar prices) fall within the techno-economic perspective. India's solar mission falls within the political perspective, while women's understanding of the drawbacks of kerosene and benefits of solar falls within the socio-technical perspective. It's interesting that Bihar has some of the techno-economic drivers necessary to create demand for alternative lighting products like solar lanterns and SHS, but it lacks both the socio-technical force to make it possible (i.e. PAYG business models), and there are multiple strong socio-technical and political barriers in place, which will be discussed in the next section.

5.2.2 Significant barriers

Interviewees identified 9 barriers and 34 barrier elements for Bihar. Given the number of significant barrier elements (i.e. mentioned by more than 2 interviewees), the top 7 significant barrier elements were identified. Each of these top 7 elements was discussed by 5 or more interviewees.

- 1. Kerosene subsidy disincentivizes customer's purchases (raised by 9 interviewees)
- 2. Financing for companies (raised by 8 interviewees)
- 3. Issues with product quality (raised by 8 interviewees)
- 4. Customers lack awareness of benefits of solar (raised by 7 interviewees)
- Counterproductive MNRE/BREDA subsidy for solar product giveaways (raised by 6 interviewees)
- 6. Customers think grid power is coming & is cheap (raised by 5 interviewees)
- 7. Customer affordability (raised by 5 interviewees)

Nine interviewees stated that the biggest reason why the off-grid solar lighting product sector in Bihar has not grown significantly is the **kerosene subsidy**. This factor was highlighted by representatives from all stakeholder groups – government representatives, experts, finance institutions, and company representatives.

Kerosene is sold through a public distribution system (PDS) at Rs 14.96 (0.21 EUR) per litre against the actual cost of Rs 29.91 (0.42 EUR cents) per litre, with the difference subsidized by the federal government (PTI 2015). Across India and in Bihar, people in three categories can receive PDS cards and thus the subsidy: the above poverty line (APL), below poverty line (BPL), and antyodaya (poorest of the poor) categories. Every family in Bihar that holds a PDS card is eligible to receive 2.75 litres of subsidized kerosene every month (Food and Consumer Protection Department 2015). Table 12, below, shows the number of families in Bihar eligible for subsidized kerosene every month.

Table 12. Number of families in Bihar eligible for kerosene subsidies. Source: Foodand Consumer Protection Department 2015.

Category	Number of families under each category
BPL families	13,737,607
APL families	2,900,000
Antodaya	2,500,000
Total:	19,137,607

Every year, the amount of subsidized kerosene allocated by government is increasing. Table 13, below, shows the amount of subsidized kerosene the federal government provides to the people of Bihar.

Table 13. Kerosene subsidy in Bihar provided by the federal government. Source: Lok Sabha 2016.

Year	Kilo Litres
2014-2015	796,704
2015-2016	812,964

As a result of this subsidy, a large number of people in Bihar have become totally dependent on kerosene for lighting purposes. Table 14, below, shows the percentage of rural households that depend on kerosene for lighting.

Year	Percentage of rural households that depend on kerosene for lighting
2001	89.3%
2011	82.4%

Table 14.Use of kerosene for lighting by rural households in Bihar. Source: Census of India 2011.

The former federal government secretary said that without the kerosene subsidy the solar sector would do very well. This former government official added that nowhere in the world has any country provided this kind of subsidy. An expert interviewee added, "People think why we should buy solar products when they are getting almost free kerosene. For solar products, there is a one-time initial investment, which people either don't like to invest or don't have the money to invest." A small-scale entrepreneur in Bihar stated that since people in Bihar don't spend a lot of money for lighting purposes because of the kerosene subsidy, it is very hard to convince them to buy solar products. Table 15, below, shows people in Bihar spend less than 2.63 EUR a month on kerosene for lighting purposes.

Table 15. Household monthly	expenditure on	kerosene in	Bihar.	Source:	Jain :	and
Ramji 2016.						

Category	Monthly kerosene expenditure of rural households in Bihar
PDS & Non- PDS	Rs 186 (2.63 EUR)
Non-PDS	Rs 156 (2.21 EUR)
Only PDS	Rs 66 (0.93 EUR)

Apart from the availability of subsidized kerosene, which disincentivizes customers from buying off-grid solar lighting products, 8 interviewees also identified company financing and the quality of solar products as other key barriers. Most of the off-grid solar companies in Bihar are not able to scale up because they are not able to access adequate financing. The SELCO company representative identified financing as a big challenge for private off-grid solar companies in Bihar and said, "Many of the companies need financing from the financing organizations to make their overall operations sustainable, hire skilled people, and expand their operations. Getting finance from banks or micro finance institutions is not easy and the financial market is not so mature in Bihar." Another Bihar based large solar company representative confirmed that his company had difficulty accessing finance, despite being well known in the state. The bank representative said that they are hesitant to lend to off-grid solar companies because they feel that the technology is new and the companies are too small to lend money to. The NABARD representative said, "Forget about off-grid solar, even the grid solar is a negligible component of the total lending by banks. Banks consider solar lending as a loss making proposition. Banks sometimes reluctantly lend for solar just to show a diversified portfolio."

Several interviewees also pointed out that **poor quality of solar products** creates a bad name for the sector among customers. The expert from the NGO said that there is no quality control for private entrepreneurs, either from the government of India or the government of Bihar. The expert said, "When we meet people who have bought solar products, many of them complain of being cheated by private companies." Another expert stated that large numbers of cheap Chinese products are imported by small private entrepreneurs and sold to people, and their quality is quite low. She stated that, "The quality of Chinese products is low and people who have used them hated them. Thus, it created a bad name for solar products among rural people." A Bihar based solar company representative lamented that customers don't trust private companies and don't want to buy solar products. "Most customers have either been cheated themselves or heard of someone else being cheated. This factor makes it hard for us to sell our products to the customers," the company representative said. Further, the interviewees also highlighted that many **customers in Bihar lack awareness of the benefits of solar**, and hence are not willing to buy solar products. This was one point highlighted by all company representatives interviewed for this research, except one. The Bihar based big solar company representative said, "The kerosene subsidy and their experience with bad quality solar products, along with a lack of understanding of the solar products, makes it very difficult for solar companies to sell their products." The SELCO representative added that many people in Bihar are aware that there are solar products but are not aware of the advantages of these products from an environmental, health or financial point of view.

Six interviewees, including the NABARD representative, stated that the **federal government subsidy through BREDA** is counterproductive to the growth of the off-grid solar lighting products sector. The expert from the NGO, which distributes solar lanterns for BREDA as well as for private companies, said that the BREDA scheme is counterproductive for the entire off-grid sector. "It was difficult to explain to people why for some lanterns we were charging money and for the others we weren't, because it was subsidized by BREDA," the expert said. Another company representative stated, "I think if you look at government interventions creating problems in the market, it's very significant in India. Any player will talk to you about it."

Interestingly, the NABARD representative elaborated on the problem created by the MNRE and BREDA subsidy. The NABARD official said that this huge subsidy from BREDA is a deterrent for even NABARD's off-grid solar scheme. Overall, BREDA sells solar products to people at 10% of the cost and provides a 90% subsidy. The NABARD representative stated, "The number of beneficiaries is very low and only very few people get BREDA lanterns. Compare this to the NABARD scheme where the subsidy amount is 40% and the other part is a loan. People say thank you very much, we don't want this subsidy or loan. Someday we will get it for almost free from BREDA. I am sure the private entrepreneurs also hear that when they try to sell their products."

The 2 other barriers pointed out by 6 interviewees each are: **customers in Bihar think cheap grid power is coming** and many customers are not in a position to pay for solar products. If grid power reaches a customer, connecting to and using grid power in Bihar is cheap, as it is highly subsidized by the state and federal government. The main customers who would purchase solar lanterns and SHS are domestic rural customers who live in huts (*kutir*) or built houses (*pukka*). Table 16, below, shows that grid connection charges for *kutir* and *pukka*, and even for bigger houses in rural areas, are less than 2.7 EUR. Similarly, Table 17, below, shows the low tariff charges for rural households in Bihar.

	Table 16. F	Fee for new	grid conned	ction in Biha	ar. Source:	NBPDCL 2016
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Type of house	Amount
Huts (<i>kutir</i>)	Rs. 20.00 (0.28 EUR cents)
Build houses (pukka)	Rs. 75.00 (1.06 EUR)
Larger house	Rs. 200.00 (2.83 EUR)

Category		Charges (1 unit = 1 kilowatt hour)
Huts (kutir)		
	Metered	a) First 30 units at 170 Paisa/ unit (0.02 EUR cents/ unit)
		b) Remaining units, similar amount charged to the above, but variable
	Non-metered	Rs. 60 (0.85 EUR cents)/ connection/ per month
Built house (<i>pukka</i>)		
	Non-metered, up to 2 kW	Rs. 170 (2.40 EUR)/ connection/ per month
	Metered, up to 2 kW	First 50 units Rs 210 (2.97 EUR)
		51-100 units Rs 240 (3.39 EUR)
		Above 100 units Rs 280 (3.96 EUR)

Table 17. Average cost of grid power in Bihar. Source: NBPDCL 2016.

One expert interviewee stated that people believe that someday they will be connected to the grid by the government and then they can access cheap grid power. This acts as a disincentive, making people less likely to want to purchase off-grid solar lighting products. The NABARD representative stated that this problem is exacerbated by politics. During election campaigns, politicians often promise that grid power will be made available to

everyone if they are voted into power. "This happens during every election. Since the grid power is cheap, people want to believe that this is true," said the NABARD representative.

Finally, many customers cannot afford to buy solar products because they cannot afford the one time up-front cost. Therefore, they are not interested in these products. While none of the interviewees explained this point in detail, most of them stated that people in Bihar are poor and therefore are not able afford solar products.

With reference to Cherp *et al.* (2016)'s three perspectives, all the barriers are either political (kerosene subsidy, MNRE/BREDA subsidy, and the fact that customer's think cheap grid power is coming), or socio-technical (financing for companies, issues with product quality, customer's lack awareness of the benefits of solar, and customer affordability.) This suggests that while techno-economic preconditions may be in place, political disincentives and socio-technical weaknesses must be changed or overcome for the sector to succeed. In addition, quite a few of the political and socio-technical barriers interrelate and out-compete the drivers. For example, the kerosene subsidy makes the alternative to solar, kerosene, cheap and attractive, while issues with product quality and a lack of knowledge about the benefits of solar make solar products seem like even less of a good investment.

Having discussed the drivers of and barriers to growth of the off-grid solar lighting products sector in Kenya and Bihar, the next, final part offers some comparative reflections and develops recommendations for growth of the sector in Bihar.

5.3 Based on findings from the Kenya case study and reflections on drivers and barriers in Bihar, what steps can be taken to help overcome present barriers to growth of the off-grid solar lighting products sector in Bihar?

This section contains recommendations for steps that could be taken to help overcome present barriers to growth of the off-grid solar lighting products sector in Bihar. These recommendations are based on findings from the Kenya case study as well as reflections on drivers and barriers in Bihar.

The results from the Kenya case study make it clear that Kenya differs from Bihar on several points that are central challenges for Bihar. One of the top 7 drivers of growth in Kenya is high kerosene prices, whereas cheap kerosene is the top barrier in Bihar. PAYG technology and business models have helped the sector take off in Kenya and helped start to surmount issues with customer affordability, whereas customer affordability remains a leading challenge in Bihar. In Bihar, the fact that customers think cheap grid power is coming is a main barrier, whereas in Kenya expensive grid power that everyone knows isn't coming is a main driver of the sector. In Kenya, education and awareness campaigns have helped the sector grow, while in Bihar customer's lack of awareness of the benefits of solar is a top barrier. However, both countries share some drivers in common - the unreliable grid, and the need for power in areas where it is not available - and share some challenges, such as low quality products. Finally, both countries have a few unique factors, such as Kenya's on again/off again VAT and import duties for solar products, and Bihar's NABARD/BREDA subsidy.

These factors give fruitful ground for comparison between the two places, and the development of recommendations. The following sub-sections discuss what Bihar can learn from Kenya, and how Bihar can overcome barriers to the growth of the off-grid solar lighting products sector.

The harmful kerosene subsidy

As discussed in the previous section, kerosene is subsidised in Bihar for PDS card holders. This disincentivizes customers from buying solar products. In Kenya, the cost of kerosene is more than double that of India because it is unsubsidized. For that reason, Kenyans see solar products as a more viable option. Table 18, below, compares the cost of kerosene in both countries.

Table 18. The difference in kerosene price between Kenya and Bihar

Bihar	Kenya
0.21 EUR/ litre	0.43-0.52 EUR/ litre

The fact that Kenya does not have a kerosene subsidy made it difficult to draw lessons from Kenya for Bihar with respect to this barrier. However, this key difference informed our research, as it made it clear that unsubsidized kerosene can send price signals to customers that act as a significant driver of growth in the sales of off-grid solar lighting products.

Any discussion of removing the kerosene subsidy would be a very politically and socially sensitive issue in Bihar. However, other Indian states have already taken a creative approach to moving away from the kerosene subsidy, via an innovative Direct Benefit Transfer (DBT) scheme. The DBT scheme was launched by the federal government of India in October 2016. Under the scheme, kerosene is sold to customers at non-subsidised rates. The amount of money formerly used to subsidize the kerosene is directly transferred to PDS card holding customers' bank accounts (PIB 2016). Then customers have the option of using the money to pursue other methods of lighting their home – such as off-grid solar lighting products. While many states in India have volunteered to adopt this scheme, Bihar hasn't yet enrolled in this scheme. If Bihar enrols in the scheme, customers in Bihar could have more purchasing power for off-grid solar lighting products, which would also assist companies operating in this sector. This study recommends that Bihar consider adopting the DBT

scheme, in order to move away from the kerosene subsidy and support growth of the offgrid solar lighting products sector.

Financing for companies

There are two main reasons financing for companies is a challenge in Bihar. The first is that it is difficult for companies to obtain financing from international sources because the federal and state governments are bureaucratic, and investors find it difficult to enter the Indian market (Climate Group 2015). The second is that in part because it is difficult to get funding from outside sources, companies rely on more traditional lenders like banks, who are very wary of lending to the solar sector, which they see as chancy and potentially unprofitable.

It is clear that a wider variety of funding mechanisms could assist companies, along with a less bureaucratic system for international investors. One idea for diversifying the funding mix and making banking loans more accessible comes from Kenya. Financing for companies is an ongoing challenge in Kenya for many companies. However, several major players in the PAYG off-grid solar lighting products industry received a large boost from the AECF Challenge Fund, which is a funding window of the Alliance for a Green Revolution in Africa (AGRA) run by KPMG. As our interviewee at AECF described, four years ago in Kenya, off-grid solar wasn't attractive to commercial investors. Some factors, such as the government's program on electrification, and giveaways of lanterns by donors, created uncertainty in the sector, and the investors didn't see "solid commercial opportunity." This is where the AECF Challenge Fund stepped in.

As the interviewee described, "we try to finance a number of companies doing a similar thing so we can create systemic change. We have done that. The role of the AECF is to start companies up. Begin the race with them, and help them reach a level where they become attractive to commercial financing. Actually, that is our main objective. We go for companies that would not otherwise get any other form of funding and make them attractive for external funding." He described the fund: the fund pools donor money and advertises for companies to compete for it. KPMG operates the competition, which is usually around 10 million USD (approx. 8.93 million EUR). They select winning companies that they then finance for up to a million USD (approx. 893,000 EUR) to implement their businesses in Africa. They disburse funds for three years, and then the company is expected to pay back the loan between the third and sixth year, when the contract terminates. He explained that this helps "de-risk" companies in a way that grants never could because other investors see that that the company is paying back the loans, and this inspires confidence in the company. He told us that the AECF challenge fund was the first to finance M-Kopa 3 ¹/₂ years ago, and since then has financed several other major players in the off-grid solar industry.

Given that banks are wary of lending to off-grid solar lighting products companies in Bihar, a similar challenge fund could help de-risk these companies and make them more attractive to investment. This paper recommends that a similar challenge fund be established for Bihar in order to support companies in this sector, and help companies reach the customers who need these products.

Issues with product quality

Both Bihar and Kenya continue to struggle with product quality as a top barrier. Although a Lighting Africa quality standard is in place in Kenya, it is not clear that this standard is resolving product quality issues, especially given companies are reporting problems with the Lighting Africa products themselves. PAYG business models partially resolve quality issues, but only for the life of the warranty of the product, and only if a person lives close enough to a shop to make repair or replacement feasible. One idea given by an interviewee was that if businesses move towards lighting as a service, this could resolve quality issues. However, this does not appear to be imminently on the horizon for Kenya, let alone Bihar. More immediate solutions to the quality issue are a topic for fruitful further research.

Customer's lack of awareness of the benefits of solar

Customer's lack of awareness of the benefits of solar is one of the top barriers cited by interviewees in Bihar. Because consumers don't know about the benefits of solar (such as the environmental, health, and financial benefits), they are less motivated to buy the products. This lack of knowledge is compounded by negative pressure from the kerosene subsidy, and issues with poor quality products. On the other hand, education and awareness campaigns by the private sector, NGOs, universities, government, and institutions such as Lighting Africa are cited as one of the top driving factors of sector growth in Kenya. These campaigns have been very successful at spreading awareness about solar products and educating people about the benefits of such products compared to kerosene.

Although there have been efforts to spread awareness in Bihar, both on the part of private companies and institutions such as Lighting India, these campaigns have been substantially more limited than in Kenya. For example, the Lighting Africa (2013) awareness campaign in Kenya reached 22 million people - nearly half the population - whereas a Lighting India campaign in Bihar reached only 200,000 people in three states - Bihar, Uttar Pradesh, and Rajasthan, and visited only 6 districts out of 38 districts in Bihar (Lighting Asia 2017). Overall, it is clear that more work is needed to spread product awareness in Bihar and educate people about the benefits of solar and negative impacts of kerosene.

Counterproductive MNRE/BREDA subsidy for off-grid solar lighting products

The MNRE/BREDA subsidy is a top barrier for Bihar that is clearly having a detrimental impact on the off-grid solar lighting products sector. However, cancelling any subsidy that helps provide the low-income rural population with light is a difficult political and ethical issue. This paper recommends cancelling the subsidy, and redistributing the funds used for the subsidy to a more helpful scheme that will still benefit the rural population, but also help create a sustainable market for solar products. For example, the funds could be allocated directly to rural consumers, in tandem with an awareness campaign about solar products.

Customer think cheap grid power is coming

The fact that customers think cheap grid power is coming is a major barrier to growth of the sector in Bihar. The root of the issue seems to be unreliable grid expansion. If customers don't know whether the grid is coming in 10 months or 10 years, but believe it may come in 10 months, they are unlikely to invest scarce savings in a solar product. This stands in contrast to Kenya, where most of the population seems certain the grid isn't coming. The government should implement and follow a more transparent grid extension process, where information about grid expansion is easily accessible to the rural population. Fostering certainty about grid extension will help customers decide whether it is in their interest to wait 10 months for cheap grid power, or whether to purchase a SHS because it is going to be 10 years until the grid arrives. The solution is not making grid power more expensive – it is making grid expansion more predictable and transparent.

Customer affordability

Customer affordability is a top barrier in both Bihar and Kenya. However, in Kenya, this barrier is slowly being overcome thanks to innovative business models such as PAYG. PAYG helps break down a relatively large and unaffordable one-time purchase of a solar lantern or SHS into smaller daily or monthly payments that often mimic what a household would typically spend on kerosene. PAYG in Kenya is helping a wider range of the population access off-grid solar lighting products, and also has knock on benefits for quality. PAYG customers are reassured about quality issues, as they pay periodically for the product over a relatively long time period, as opposed to a lump sum up front.

However, in India, PAYG business models have not worked so far. This is because India's central bank, the RBI, has a rule that mandates all mobile payments be linked to bank accounts (Climate Group 2015). As most rural customers do not have bank accounts, this RBI rule effectively bans mobile money for the rural population, and acts as a barrier for Indian off-grid solar lighting product companies that are interested in pursuing a PAYG business model (Singh 2016).

This thesis recommends that RBI immediately remove restrictions on mobile money and allow private mobile operators to set up mobile money platforms and allow unbanked customers to transact using mobile money. RBI can look to Kenya for an example of how this type of system functions effectively. Enabling the rural population to use mobile money and thus enabling companies to pursue PAYG business models could allow new segments of the population to access off-grid solar lighting products, and help the sector really take off. However, if RBI is unwilling to ease the mobile money rules, companies in Bihar could consider adopting Simpa Networks PAYG business model. Simpa Networks, a company operating in Uttar Pradesh, has developed a model that allows them to offer a PAYG style service to customers without mobile money. During an interview, a Simpa Networks representative described their business model: "On making a recharge at a local shop, customers receive a unique code on their phone, which they feed into a PAYG meter at home. The meter, once recharged, shows the number of energy days the customer has bought. For example, if a customer recharges for 1 month of energy, the meter will start a countdown of 30 days."

6. Conclusion

The aim of this thesis is (1) to fill the knowledge gap regarding the development of the offgrid solar lighting products sector Bihar, on which little to nothing is written, (2) update knowledge on the growth of the sector in Kenya, for which a paradigm shift has occurred since 2013 prior to which most academic literature was written, and (3) to develop policy recommendations for Bihar based on the Kenya case study. To achieve the objectives of this thesis, a main research question was formulated: Why, despite their contextual similarities, has Kenya been more successful than Bihar in promoting the diffusion of off-grid solar lighting products? In order to answer this question, this research question was further broken down into three sub-questions: 1) What drivers of and barriers to the growth of the off-grid solar lighting products sector exist in Kenya? 2) What drivers of and barriers to the growth of the off-grid solar lighting products sector exist in Bihar, India? 3) Based on findings from the Kenya case study and reflections on drivers and barriers in Bihar, what steps can be taken to help overcome present barriers to growth of the off-grid solar lighting products sector in Bihar?

Since nothing was known about the diffusion of the off-grid solar lighting products sector in Bihar, this thesis had to rely on available literature for all of India. Drivers and barriers identified by the literature analysis conducted for India were used to prepare interview protocols, and interviews were conducted with key stakeholders in Bihar. The interviews were also used to collect additional data for Bihar, which complemented data collected from the interviews themselves. A similar process was followed in the second thesis to generate interview data and additional data for Kenya. Conducting interviews required considerable effort, including travel to Bihar, Kenya, and California, and extensive networking to set up interviews with appropriate players. Content analysis of interview data was structured using Painuly (2001)'s framework, as adapted by Ahlborg and Hammar (2014). Cherp *et al.* (2016)'s three perspectives theory was used to analyze the significance of the top driver and barrier elements identified through the content analysis. In Kenya, techno-economic factors (expensive kerosene, expensive and unreliable grid power, and unmet electricity demand) provided the initial thrust for sectoral growth. However, when PAYG business models (a socio-technical factor) were implemented in 2011, this lead to rapid market expansion. In the case of Bihar, despite techno-economic factors (such as unmet electricity demand and unreliable grid power) that provided an initial push, the sector did not thrive. Several political and socio-technical barriers held it back.

Overall, the results showed that some of the top barriers in Bihar are actually the top drivers in Kenya. The availability of cheap kerosene due to a government subsidy is the top barrier for Bihar's off-grid solar products sector. This is actually one of the top 7 drivers of growth in Kenya, which has high kerosene prices and no government subsidy. Another key barrier in Bihar is the fact that customers think cheap grid power is coming, whereas in Kenya the grid power is expensive and most people are certain it isn't coming. Furthermore, educational campaigns have played a significant role in the growth of the sector in Kenya, while in Bihar customer's lack of awareness of the benefits of solar has held the sector back. Finally, and importantly, while customer affordability is a big challenge in Bihar, innovative PAYG technology and business models in Kenya have helped to overcome issues with customer affordability. These results make it clear that stakeholders in Bihar can learn from the Kenyan case study in order to promote the growth of the sector in the state.

Based on these results from Bihar and Kenya, this joint study made 6 important recommendations for Bihar that could help the Bihar sector overcome its barriers:

 Bihar should adopt the DBT scheme, like other Indian states. In a DBT scheme, instead of a kerosene subsidy, the government transfers the subsidy amount to the beneficiary's account. If Bihar adopts this scheme, it will help move away from the harmful kerosene subsidy and enhance customer affordability, supporting the growth of the off-grid solar lighting products sector.

- The Bihar government should create a challenge fund for off-grid companies in Bihar along the lines of AECF's challenge fund for Kenya. This will help address off-grid solar companies' financing issues.
- Stakeholders in the off-grid solar lighting products sector in Bihar must carry out education campaigns like Kenya to spread awareness about the benefits of solar and negative impacts of kerosene.
- 4) This thesis also recommends cancelling the counterproductive government (BREDA and NABARD) subsidy on off-grid solar lighting products, and redistributing the subsidy to a more helpful scheme. For instance, the funds could be allocated directly to rural consumers, in tandem with an awareness campaign about solar products.
- 5) Grid expansion should be made more predictable and transparent.
- 6) RBI should immediately remove any restrictions on mobile money and allow private mobile operators to set up mobile money platforms. This thesis recommends that RBI look to Kenya as a successful case study country that has effectively implemented mobile money.

There are many areas where additional, future research would be helpful. In the future, researchers could study the quality issues that create a bad name for this sector in both places, especially Bihar, and develop solutions for them. Other than that, this kind of comparative research can also be conducted in other Indian states and other countries with substantial off-grid populations like Bangladesh.

Given that identifying the main drivers and barriers to the growth of the off-grid solar lighting products sector in Bihar is completely new research, it holds tremendous academic significance as it brings new understanding about the issue. The research findings and the recommendations generated based on the Kenya case study also hold importance for government agencies, private companies, NGOs, and civil society organizations who are striving to push the growth of this sector in Bihar. In addition, while the results of this study are specific to Bihar and Kenya, and thus not generalizable, other similar North Indian states with low electrification rates such as Uttar Pradesh could benefit from this case study of Bihar, as the sectors in these states face similar challenges. As this research is built on and expanded, through further study in Bihar and Kenya, and potentially other countries, it has the potential to help turn on clean lights for the millions of people who currently live offgrid.

7. <u>References</u>

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