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Lighting the Lives of Millions:

Overcoming barriers to the diffusion of off-grid solar lighting products in Kenya and Bihar, India

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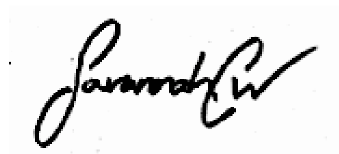
Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.



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ABSTRACT OF THESIS submitted by:
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for the degree of Master of Science and entitled: *Lighting the Lives of Millions: Overcoming barriers to the diffusion of off-grid solar lighting products in Kenya and Bihar, India*

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Millions of people in Bihar, a state in northern India, and Kenya, located in eastern Africa, live in rural areas without access to the electricity grid. Most of these people rely on dangerous, low-quality lighting sources such as kerosene, which can cause fires, respiratory illness, and environmental harm. Although governments in these areas are taking steps to extend the grid, progress is slow. An alternate solution, off-grid solar lighting products such as solar lanterns and solar home systems, is increasingly seen as an effective way to provide people with improved light. Yet, despite the fact that markets for solar lighting products started in both Bihar and Kenya in the 1980s, Bihar's has seen stunted growth while Kenya's has thrived. The aim of this thesis, one part of a two-part joint study, was to investigate why. Applying Cherp *et al.* (2016)'s three perspectives on national energy transitions to data collected via a literature review and extensive qualitative interviews conducted in both areas, this thesis concluded that the Bihar sector faces many political and socio-technical barriers to its growth, including a harmful kerosene subsidy, that are the mirror image of Kenyan drivers—where expensive kerosene promotes growth of the sector. Bihar also lacks important drivers present in Kenya, such as a pay-as-you-go business model that has led to explosive market growth. This thesis concludes with recommendations for how the Bihar sector can overcome significant barriers to its growth, based on insights from the Kenya case study.

Keywords:
Kenya, Bihar, Solar lantern, Solar home system, Off-grid lighting, Renewable energy

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1. Introduction

1.1 Background

According to IRENA (2015), about 1.16 billion people in the world today have no access to the electricity grid. Instead, they rely on low quality, dangerous light sources such as kerosene or candles, which can cause fires, respiratory illness, and harm the environment. Ninety-five percent of these people live in Sub-Saharan Africa and South and East Asia (Lighting Global 2016). Although governments in these areas are taking steps to extend the grid and bring electricity to non-electrified areas, progress is slow. An alternate solution, off-grid electricity derived from renewable sources such as solar, is increasingly seen as an effective way to provide people with improved light that is better for their health and the environment. This sector has grown rapidly across the world in the past ten years, aided by dropping solar prices, and many companies have entered the market in Sub-Saharan African countries such as Kenya and Asian countries such as India (Lighting Global 2016). Off-grid solar has already improved energy access for approximately 89 million people in Africa and Asia, and the sector has significant potential to grow further in the future and expand these benefits (Lighting Global 2016).

In the off-grid solar sector, companies have primarily focused on providing solar lanterns and solar home systems (SHS) (together referred to in this thesis as "off-grid solar lighting products") for individual families. Solar lanterns and SHS vary in their design, wattage, and price. A solar lantern is a smaller, simpler product that typically ranges from 0.1-10 W and may cost as little as 5 USD (approx. 4.5 EUR) for a quality, branded product (Climate Group 2015). Solar lanterns typically have a small solar panel on one side and a light on the other, and may also include additional capabilities like mobile phone charging. After charging the light via the solar panel in the sun during the day, it provides hours of light at night. Figure 1 contains two examples of solar lanterns. On the left are both sides of the d.light A1 solar lantern, priced at 5 USD (approx. 4.5 EUR); on the right is the Greenlight Planet/Sun King solar lantern, priced at 8 USD (approx. 7 EUR) (d.light 2017; Greenlight Planet 2017).

Figure 1. d.light A1 solar lantern (left); Greenlight Planet/Sun King solar lantern (right). Source: d.light 2017; Greenlight Planet 2017.

An SHS is a larger product that typically ranges from 8 to 200 W and may cost between 20 USD and 600 USD (approx. 18-538 EUR) (Climate Group 2015). It typically has a solar panel, along with one or more LED lights and/or portable lanterns. The solar panel is usually installed on a home's roof, and electricity generated during the day is stored in a battery for use at night or when it's cloudy (EMFP 2014). Some systems can also charge mobile phones and power fans and radios. The largest systems can power appliances like a TV/laptop, or a DC refrigerator. Figure 2 contains an example of an SHS, the M-Kopa 400 Solar Home System. This SHS has a 20 W solar panel, 16 inch digital TV, 3 LED light bulbs, 1 portable LED flashlight, a phone charging USB with 5 connections, and 1 rechargeable radio. It's sold on a one-year payment plan with a total cost of approximately 53,624 KES (approx. 466 EUR) (M-Kopa 2017).

Figure 2. M-Kopa 400 Solar Home System. Source: M-Kopa 2017.

India is currently the country with the most significant market for future business development in this sector, as it has the world's largest off-grid population (Lighting Global 2016). However, development of the off-grid solar lighting products sector to date has been less successful in Indian states with large off-grid populations, such as Bihar, than in African countries such as Kenya that also have large off-grid populations (Climate Group 2015; Overseas Development Institute 2016).

Kenya is widely considered in the literature to be a market leader in the off-grid solar lighting products sector, while Bihar has only a fledgling market, despite the fact that markets for solar lighting products have been developing in both places since the 1980s (Overseas Development Institute 2016). This is interesting given that Kenya and Bihar share contextual similarities. Table 1 shows that for both countries, 74% of the total population or higher lives in rural areas, and 89.6% of all households or higher have no access to the electricity grid. In addition, while it is difficult to compare the economic performance of a country and a state, the World Bank ranks both Kenya and India as lower-middle income economies, and Kenya's GDP is similar to Bihar's state GDP (World Bank 2017c). Their GDP per capita differs somewhat, yet this is only a rough measurement as GDP adjusted for purchasing power parity (i.e. for the cost of living) was not available.

Table 1. Comparing Kenya and Bihar, India

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

This divergence in performance, despite these areas' similar needs for improved electricity access, suggests that specific factors may be promoting and/or impeding the success of the off-grid solar lighting products sector in these two areas, such as policy frameworks, institutions, business models, and community attitudes. However, while literature is available analysing the growth of the off-grid solar lighting products sector in Kenya, little is available concerning Bihar. Furthermore, what is available for Kenya is dated, and doesn't include significant changes in the market that occurred when mobile money and pay-as-you-go (PAYG) business models swept the sector starting in 2011. Finally, nothing is written comparing these areas, despite the fact that Bihar may have a lot to learn from the Kenyan example given the two countries' similarities.

In order to address this research gap, this thesis will investigate why, despite their contextual similarities, Kenya has been more successful than Bihar in fostering the market for off-grid solar lighting products, and what Bihar can learn from the Kenyan case study to bolster growth of its markets. This thesis is one of two theses addressing this question and forming a joint study. This thesis will conduct a comprehensive overview of drivers of and barriers to the growth of the off-grid solar lighting products sector in Kenya. It will reference a similar analysis undertaken in the second thesis, which will focus on Bihar. The two theses will have a common discussion section that provides insight into potential reasons why the off-grid solar lighting products sector, which has achieved success in Kenya, has not achieved similar success in Bihar. The discussion section will also contain recommendations for bolstering the growth of the sector in Bihar, based on the Kenya case study.

1.2 Research questions and aims

The main research question that this thesis sets out to answer is:

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

Three sub-questions were developed in order to investigate this research question.

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

- Addressed by this thesis

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

- Addressed by the second 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).

Through 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 of this thesis contains the literature review and theoretical framework. It encompasses a review of literature regarding the growth of the off-grid solar lighting products sector in Kenya, a review of relevant and applicable theories, and a succinct description of the methodological and theoretical framework applied in this thesis. Chapter 3 contains the methods section, which describes the method used for the literature review, for data collection via qualitative interviews, and for data analysis using content analysis. Chapter 4 outlines the results of the qualitative interviews with stakeholders in Kenya, and sets out additional data collected from stakeholders during interviews. Chapter 5 contains a discussion section that answers each of the research sub-questions, and includes a common discussion of policy recommendations for the Bihar off-grid solar lighting products sector based on the Kenya case study. Chapter 6 contains the conclusion, which answers this thesis's research questions, describes the academic and practical significance of this study, and outlines areas for future research.

2. <u>Literature review and theoretical framework</u>

This chapter of the thesis is divided into two parts. The first, the literature review, provides an overview and analysis of existing literature regarding the development of the SHS and solar lantern sectors in Kenya. The second, the theoretical framework, includes an overview of applicable theories, and a description of the theoretical framework used in this thesis. The companion thesis to this work contains a similar literature review that discusses the development of the off-grid solar lighting products sector in Bihar.

2.1 Literature review

There is a fairly robust body of literature about the development of the off-grid solar lighting products sector in Kenya as a whole. However, the literature about the SHS sector is more robust than the literature about solar lanterns, as it details the growth of the SHS sector from the beginning onwards. The literature about the solar lantern sector, which developed later in Kenya, is limited to one detailed working paper, and incidental mentions in general literature about the off-grid solar sector in the country.

Notably, the most recent studies on this subject for both sectors were completed in 2013 (although articles were published later), just after a pivotal change occurred in Kenya. Around 2011, several businesses with PAYG business models for off-grid solar lighting products launched in Kenya. Existing literature describes the business models, and speculates about their potential ability to increase affordability and expand the market for off-grid solar lighting products to the rural poor. However, no study has been done examining the impact of these new business models.

In addition, most literature about the SHS and solar lantern sectors examines their development within the context of Kenya alone. Two studies compare the growth of the SHS sector in Kenya with other countries – with Tanzania (Ondraczek 2013), and with Tanzania and Uganda (Hansen *et al.* 2015). These comparative studies attempt to unpack why a more robust sector has developed in Kenya than in the other countries. However, no study has been conducted comparing the development of these sectors in Kenya with a country outside of Africa, despite the potential for the generation of interesting insights into the development of these sectors in countries such as India.

Finally, most of the literature about the SHS and solar lantern sectors in Kenya focuses on factors that have helped the sectors develop, leaving out or only incidentally touching on factors that have inhibited growth. However, these sectors are far from reaching their full potential in Kenya, and the distribution of SHS in particular has largely been limited to the affluent rural population. Therefore, it is interesting and instructive to also consider factors inhibiting growth when looking at the historical development of these sectors.

This literature review provides an overview and analysis of the current body of literature on the development of the off-grid solar lighting products sector in Kenya. The intention is to provide a basis for subsequent data collection in this thesis, which aims to update the state of knowledge about the growth of the off-grid solar lighting products sector in Kenya, with particular attention to a discussion of factors inhibiting the growth of this sector, and the impact of PAYG business models. In addition, it will provide a basis for comparison with the historical development of the solar lighting products sector in Bihar, India.

2.1.1 The history of the SHS sector in Kenya

The history of off-grid solar lighting products in Kenya begins with the development of the SHS sector. Several published academic articles detail this history. The authors of these articles largely agree on what took place and when, and agree on some of the reasons why. However, some authors emphasize the importance of certain factors over others. Ondraczek (2013), Byrne *et al.* (2014) and Hansen *et al.* (2015) have written the most recent, detailed, and helpful accounts of the history of this sector and the reasons for its development. These works build on and reference multiple older classics in the field such as Acker and Kammen (1996).

A market for SHS started in Kenya in the 1970s, when the Kenyan government started using solar to power remote broadcasting and signalling installations (Ondraczek 2013; Byrne *et al.* 2014; Hansen *et al.* 2015). In the 1980s, the Kenyan government expanded its use of solar, and began collaborating with international donors and development agencies to install off-grid solar systems on schools in rural areas for lighting, and in rural areas to support other purposes like refrigeration at medical clinics (Ondraczek 2013; Byrne *et al.,* 2014). During the 1980s, donors (unspecified in the article) also started to fund training workshops for solar technicians in Kenya, and other solar demonstration projects (Ondraczek 2013). Overall, this created an increase in demand for SHS that resulted in the development of a national supply chain for PV – including retailers, importers, and installers – in Kenya (Ondraczek 2013).

Private sector businesses operating in this sector began to appear in the early to mid 1980s (Ondraczek 2013; Hansen *et al.* 2015). During this time period, a few companies were established that aimed to provide SHS for private households. The development of this sector was led primarily by the work of two expatriate engineers, Harold Burris and Mark Hankins, who were both ex-Peace Corp volunteers (Hansen *et al.* 2015). Burris set up a company called Solar Shamba in Kenya and began to build a market for consumer SHS in the country (Byrne *et al.* 2014; Hansen *et al.* 2015). Burris's contribution was important because, alongside Mark Hankins, who he met in the early 80s, they trained local residents as solar installers, creating a skilled workforce, and ran several demonstration projects, generating interest in his products in many rural areas (Byrne *et al.* 2014; Hansen *et al.* 2015). Solar Shamba only ran until 1988, but it was important because it helped to create a "technical resource pool," and an "interested public" in Kenya (Acker and Kammen 1996).

The private market for SHS grew rapidly during the 1980s and 1990s (Ondraczek 2013; Byrne *et al.* 2014; Hansen *et al.* 2015). Ondraczek (2013) attributes this to, first and foremost, the lack of grid electricity and the spread of radio and TV signals into rural areas. The spread of signals created demand for a way to power radios and, for wealthier families, televisions in areas that did not have access to grid electricity—leading people to buy SHS (Ondraczek 2013). Other factors that helped the sector grow included falling prices for PV across the world, the introduction of smaller, more affordable solar systems, rising rural incomes due to an agricultural "boom period," and increased marketing from fledgling companies (Ondraczek 2013; Byrne *et al.* 2014; Hansen *et al.* 2015). However, despite the increase in SHS affordability, SHS remained the province of the elite. Acker and Kammen (1996) carried out a survey in 1994 that revealed that most people buying systems were still middle income or affluent.

While some researchers also attribute the 1986 removal of government import duties and value added tax ("VAT") on solar products as a growth factor, others state this had no impact as no savings were passed onto consumers (Byrne *et al.* 2014). Indeed, whether government's policy regarding solar product import duties & VAT has helped these sectors overall is a matter of debate. Following the 1986 removal, government reintroduced VAT and import duties in 1992 in an effort to increase government revenues (Acker and Kammen 1996), removed them again completely by 2002, and then reintroduced a 16% VAT on solar goods on October 1, 2013, which Byrne *et al.* (2014) report caused a dramatic fall in sales of solar lanterns. Byrne *et al.* (2014) state that the rationale for the October 2013 reintroduction was the Government of Kenya's need for tax revenue, and the fact that solar is of low priority to the government. Overall, while many articles state that government's policy regarding solar product import duties & VAT has been a growth factor for the SHS industry (for example, Hansen *et al.* 2015; ODI 2016), this typically depends on when the article was written and whether it took contemporary developments into account. Other academics such as Acker and Kammen (1996), and Byrne *et al.* (2014) actually see this flip-flopping policy as a force hindering growth of the industry.

Apart from the removal of import duties and VAT, government has adopted a 'light touch' regulatory approach to SHS by largely leaving the sector unregulated (Hansen *et al.* 2015). Until 2013, the Government of Kenya had not established targets for SHS uptake or enacted legislation to promote its diffusion, instead leaving the sector to be driven by private forces (Hansen *et al.* 2015; Urama *et al.* 2014). Government's only involvement had been, since 2006, running a program to install SHS on institutions such as schools in rural areas, and putting a (largely unsuccessful) feed-in-tariff in place for grid connected solar (Byrne *et al.* 2014). Most academics characterize the government's lack of involvement as a neutral factor, although Byrne *et al.* (2014) states that "the Kenyan policy environment has at times been hostile to the promotion of photovoltaic technology and policy support remains somewhat ambivalent."

In 2013, the Kenyan government showed some interest in promoting private SHS, but it didn't last. In the Government of Kenya's 2013 Draft National Energy Policy, they established some targets for SHS and solar lanterns: 100,000 new SHS in the short term (2013-2017), 200,000 new SHS in the medium term (2013-2022), and 300,000 new SHS in the long term (2013-2030), along with a goal to "roll out a programme to distribute solar lanterns as substitute for kerosene in lighting rural areas, poor peri-urban and urban settlements." However, these commitments were removed in their entirety from the updated Draft National Energy Policy of 2015, with only a modified version of the solar lantern commitment remaining.

Despite government's lack of involvement and interest in the SHS and solar lantern sectors, there have been a few significant programs driven by international donor organizations. The most notable program for SHS was the World Bank led photovoltaic market transformation initiative (PVMTI), which ran from 1998-2008 (Hansen *et al.* 2015). This program provided loans to suppliers and consumers of SHS out of a budget of 5 million, improving financing conditions for both (Hansen *et al.* 2015).

2.1.2 Other factors promoting growth of the SHS sector

Beyond the factors already mentioned that spurred the growth of the SHS sector, authors attribute additional factors. First of all, Ondraczek (2013) and Hansen *et al.* (2015) state that an overarching driver underlying the spread of SHS in Kenya is the need for electricity in areas without the grid. While inability to access the grid is certainly one factor, interestingly, other authors have shown that people may still prefer SHS as a source of electricity even if grid connection is available. This is because grid connection can involve costs for individual households that are unaffordable. Acker and Kammen observed this as early as 1996, and this finding was reiterated by Opiyo's 2016 survey of SHS in Kendu Bay, a community in eastern Kenya. Opiyo (2016) found that although national grid lines passed through the two main roads in the area, making grid connection feasible, many people chose to use SHS instead. This was because the cost of a SHS (either a 45 W system for 250 USD, approx. 225 EUR, or 100 W system for 400 USD, approx. 360 EUR), was cheaper than the unaffordable grid connection fee of 750 USD (approx. 670 EUR). Opiyo (2016) also reported that residents stated there were associated problems with grid connection, such as frequent blackouts, and corruption (having to bribe technicians to process applications for grid connection before they would go through).

Other factors that have promoted the growth of the SHS sector include the fact that Kenya's population is clustered in the central and western parts of the country, making it easier to reach customers and distribute product (as opposed to a country such as Tanzania, where the population is spread out across the country) (Ondraczech 2013; Hansen *et al.* 2015). As Ondraczech (2013) states, most potential SHS customers were "just a few hours' drive away" from the capital, Nairobi, which is located in the western part of the country. Ondraczech (2013) also cites "a strong entrepreneurial culture in Kenya and an openness to foreign investors and business practices/ideas" as a very important factor promoting growth of the sector. He states that this helped the sector develop more so than nearby countries such as Tanzania that lacked this environment due to a socialist past. Finally, Ondraczech (2013) and Hansen *et al.* (2015) agree that word of mouth was very important for the spread of SHS in Kenya, which grew synergistically with the number of systems in the country.

2.1.3 The size of the SHS sector

Ondraczek (2013) provides the most up-to-date information regarding the size of the sector, which is from 2009. In 2009, an estimated 15-40 companies supplied solar equipment including SHS, 5-8 companies imported solar lighting products and components, and there were "several hundred" solar product sales agents, and 2000 solar installers. As of 2010, the typical size of an SHS sold in Kenya was 14-20 W, and the majority of systems were below 100 W (Ondraczek 2013).

In addition, over time, a small manufacturing industry grew up around the SHS sector, manufacturing parts within the country and helping make the systems more affordable (Ondraczech 2013; Hansen *et al.* 2015). In 2009, there were an estimated 3 companies manufacturing lead acid batteries and 9 companies manufacturing lamps (Ondraczek 2013). In addition, in 2011, a company called Ubbink EA started manufacturing polycrystalline modules (Byrne *et al.* 2014).

Table 2, below, quantifies the growth of the SHS sector from the early 1990s to 2010. The information is as up to date as the literature, which only extends until 2013 (when PAYG first started to take off in Kenya). Therefore, this data paints more of a historical than a present picture.

Table 2. Growth of SHS in Kenya, early 1990s-2013. Data source: Ondraczek 2013 and Hansen *et al.* 2015.

	Early 1990s	**2000**	**2009**	**2013**
Estimated overall installed off-grid SHS PV capacity	1.5 MWp	3.9 MWp	8-10 MWp	20 MWp
Approximate percentage of overall PV installed in residential systems (versus institutional systems)	33%	75%	80%	No data
Estimated total number of SHS installed	5000	97,500	320,000	No data
Estimated annual sales of SHS	1000	No data	20,000-25,000	No data

2.1.4 Barriers to growth of the SHS sector

While a great deal of academic work has been done looking at factors promoting the diffusion of SHS in Kenya, reviewing the literature in this area makes it clear that not much work has been done that examines factors inhibiting growth of the sector. This presents a gap in the literature and an interesting area to explore.

The little that is said in the literature about who is using SHS, and further barriers to diffusion, suggests that affordability is a major barrier to further diffusion (Lay *et al.* 2013; Byrne *et al.* 2014; Lee *et al.* 2016; Opiyo 2016). Throughout the history of SHS, these systems have largely been the province of the relatively affluent rural population. Surveys have found that households using solar technology tend to be well-off, although not "the richest" (Lay *et al.* 2013), and that "home solar users are characterized by higher socioeconomic status across most measures: they are more educated, politically aware, have bank accounts, live in households characterized by high quality walls (made of brick, cement, or stone, rather than the typical mud walls), and have more land and assets" (Lee *et al.* 2016). Lay *et al.* (2013) also concluded that households only switch to modern fuels (i.e. from wood/kerosene to grid electricity/solar) with relatively high levels of income (approx. USD 27,000 per year, or approx. 24,000 EUR) (Lay *et al.* 2013).

It is difficult for other, less affluent members of the rural population to purchase SHS because of a lack of financing. For example, Byrne *et al.* (2014) state, "a shortage of credit for potential system buyers is the greatest impediment to expansion of PV sales. Many potential customers have steady incomes but are unable to amass the initial capital required to purchase systems." For consumers who cannot afford to pay for SHS up-front (largely the preserve of the middle class or even more affluent consumers), the typical methods of financing SHS are loans, microfinance, or hire-purchase agreements (hiring the product and paying in instalments until you eventually own it) (Rolffs *et al.* 2014). However, hire-purchase agreements in Kenya are usually restricted to people with fixed employment, such as teachers, and payments are taken directly from their salary. This restricts this financing method to those employed in stable, well-paying jobs (Rolffs *et al.* 2014). In addition, interest rates are typically high—around 40%—increasing the price of SHS and leading consumers to prefer cash payments (Rolffs *et al.* 2014). Microfinance and loans have also not successfully permitted poorer consumers to purchase SHS, as they are typically associated with very high interest rates (Rolffs *et al.* 2014), or their availability is restricted to particular groups, such as Savings and Credit Cooperative Organizations ("SACCOs") or employees of particular companies. Pode (2013) states "acceptance of SHS systems can be greatly enhanced if poor populations are provided with access to financing and credit to pay for the SHS systems." Finally, it is also clear that SHS product quality has been and still is a factor negatively influencing the sector. In the late 1980s, "amorphous," as opposed to crystalline, PV modules became available (Byrne *et al.* 2014). These products were cheaper, and thus popular, but often performed poorly. In 1996, Acker and Kammen reported, "the quality of the solar panels has not been consistently good." In 1998, due to pressure from business, the Kenya Bureau of Standards agreed to start developing standards for solar PV products in Kenya (Byrne *et al.* 2014). They founded a committee of stakeholders to take on this task, and deliberations took years—preliminary standards were not finished until 2002 (Byrne *et al.* 2014).

However, another result of the committee discussion was the idea to form a self-governing industry organization that would help to self-regulate the industry. The Kenya Renewable Energy Association (KEREA) was registered in 2002 (Byrne *et al.* 2014). Soon after it was formed, KEREA stepped in and conducted several tests on solar equipment and, by exacting peer pressure on importers, successfully removed some types of sub-standard modules from the market (Byrne *et al.* 2014). However, product quality issues persisted, due to KEREA's weak capacity to test products on an ongoing basis, lack of adequate product quality information for consumers, the continual entry to the market of new products, and poor installation by technicians (Byrne *et al.* 2014).

In 2006, the Kenya Energy Regulatory Commission (ERC) was founded as part of the Kenyan Ministry of Energy's new 2006 energy policy, with a mandate to regulate renewable and other forms of energy (Byrne *et al.* 2014). Quality continued to be an issue at the time. For example, researcher Arne Jacobson reported in 2006 "many small systems… are plagued by quality and performance problems." The ERC subsequently developed regulations for PV, which were published in 2012 (Byrne *et al.* 2014). These regulations introduced different classes of licenses for the various actors involved in PV (i.e. manufacturers, importers, vendors, technicians). There are requirements attached to the licenses: for example, licenses for technicians require them to have achieved a certain level of training and experience. However, the ERC Renewable Energy Department, in charge of implementing this regulation, is understaffed and the regulation appears to be functioning poorly – for example, as of 2014 the technician register had only 37 names, which likely represents only a fraction of all technicians operating in the country (Byrne *et al.* 2014).

Table 3, below, summarizes some of the most significant drivers of and barriers to the diffusion of SHS in Kenya identified in this literature review.

Table 3. Significant drivers and barriers identified in the literature review – Kenya

Driver	Driver Elements	Barrier	Barrier Elements
Consumer Ability to Pay	• Growing rural incomes in the 80s/90s • Increased SHS affordability since the 80s	**Consumer Ability to Pay**	• Lack of affordability for poorer customers prior to PAYG
International Aid	• Donor involvement in training & demonstration projects in the 80s, providing loans in the 90s, and promoting solar lanterns in the mid 2000's	**Consumer Finance**	• Lack of flexible financing
Grid Expansion	• Lack of grid electricity • Expensive grid electricity	**Government**	• Lack of government involvement specifically in the solar sector. Most authors portray this as neutral; some as negative.
Ease of Doing Business	• Strong entrepreneurial culture & openness to new business models/ideas • Government generally helps create an enabling environment for business, which helps all companies, including solar companies, attract new financing	**Quality Issues**	• Issues with SHS & solar lantern quality
Consumer Awareness	• Successful awareness campaigns have helped drive growth		
Local Champions	• Two early adopters, Harold Burris and Mark Hankins, played a big role as proponents of off-grid solar in the 1980s		

2.1.5 The history of the solar lantern sector in Kenya

Solar lantern technology took off later in Kenya, and its development charted a different pattern, one driven more by aid than by the private sector. Individual entrepreneurs became interested in the emerging technology of solar lanterns in the 1990s, and started market testing them (Byrne *et al.* 2014). Solar lanterns were targeted at a different market segment than SHS—they were simpler, less expensive products aimed at the rural poor, as opposed to the middle class (Byrne *et al.* 2014). However, market testing was not very successful. Consumers found the products too expensive, and didn't like the type of lighting they provided (Byrne *et al.* 2014).

Years later, solar lanterns finally took off with an International Finance Corporation and World Bank project called "Lighting Africa" which began in September 2007. The aim of this project was to help lighting products such as solar lanterns take off with poorer people who wouldn't be able to afford SHS (Byrne *et al.* 2014). Through this program, several companies won large grants to work on dissemination of solar lanterns in Kenya. In addition, Lighting Africa intervened directly. In 2007, Lighting Africa began to do market research in Kenya, as well as product testing, identification of financing needs, and evaluation of policy constraints (Byrne *et al.* 2014). In 2009, Lighting Africa began "marketing development interventions" in Kenya (Byrne *et al.* 2014). They started providing business support, which essentially means they ran trade shows bringing suppliers and dealers from rural areas together. They also helped promote access to finance for customers and, perhaps most importantly, provided consumer education (Byrne *et al.* 2014). They ran road shows in rural areas, did other outreach and education activities in rural areas, and set up a text message service where consumers could text a number for free and receive information about products (Byrne *et al.* 2014). Finally, they also focused a great deal on quality assurance and on creating quality assurance criteria for customers.

The market for solar lanterns grew rapidly over the 4 years the Lighting Africa program was running. Lighting Africa estimates that sales of quality verified (as opposed to poor quality or counterfeit) solar lantern products grew from 85,000 in 2011 to 626,000 in 2013 (Lighting Global 2016; Byrne *et al.* 2014) (see Figure 3, below). The program has now concluded, with a cumulative cost of 5 million USD (approx. 4.5 million EUR). Byrne *et al.* (2014) state that it is difficult to say whether all the growth in solar lanterns can be attributed to the Lighting Global program, but it was certainly a significant driver of growth in the sector.

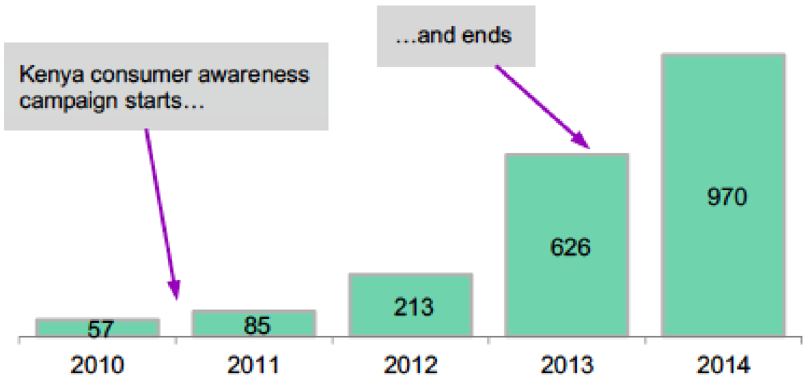

Figure 3. Lighting Africa's consumer awareness program & sales of quality verified products in Kenya (thousands). Source: Lighting Global 2016.

Perhaps given that the solar lantern sector took off later than the SHS sector, little is written about the development of the sector beyond Byrne *et al.*'s 2014 working paper. This means that less is known about factors promoting and inhibiting growth of the sector. However, it is clear that product quality for solar lanterns is one factor inhibiting growth of the solar lantern sector (Byrne *et al.*, 2014). Efforts to overcome this barrier have been driven by Lighting Africa, not the government. Following a 2009 product quality test in which Lighting Africa tested 14 lights and only one passed the quality test, they began to conduct research about solar lantern product quality, advocate for better quality lanterns, and give prizes at conferences for the best quality lanterns (Byrne *et al.* 2014). Following these interventions, quality improved. When Lighting Africa tested 20 lanterns in 2010, 8 passed a minimum quality standard (Byrne *et al.* 2014). Lighting Africa also pursued efforts to have the International Electrotechnical Commission adopt minimum quality standards for solar portable products, and these mandatory standards were subsequently adopted by the government of Kenya (ODI 2016). Finally, Lighting Africa also helped the University of Nairobi develop a product quality-testing laboratory to help enforce these standards (Byrne *et al.* 2014).

However, quality issues still remain. Tong *et al.* (2015) conducted a two year questionnaire study regarding the introduction of solar lanterns into a village in the Laikipia district of Kenya, and found that one of the main issues with the lanterns, and main barriers to future successful expansion of the solar lantern sector, was poor product quality. In particular, the LED lights in the lantern tended to burn out, which was disappointing for consumers who had spent a considerable portion of their monthly wages on the product (Tong *et al.* 2015).

2.1.6 The rise of PAYG in the Kenyan SHS & solar lantern sectors

The literature reviewed above does not discuss a pivotal change that began to occur in Kenya in 2011. Around 2011, several businesses with PAYG business models for off-grid solar lighting products launched in Kenya. Some preliminary studies, such as the one by Rolffs *et al.* (2015) suggest that these new business models are more likely to better facilitate poor people's access to sustainable energy than past finance approaches. This next subsection examines what is known about these new business models.

In the past, solar technologies such as SHS or solar lanterns were typically purchased up-front with cash (Rolffs *et al.* 2015). This made these technologies the preserve of only the relatively wealthy, who had access to that kind of capital (Rolffs *et al.* 2015). However, there are suggestions that things have begun to change with the advent of PAYG business models for off-grid solar technology, which started to take off in Kenya in 2011.

PAYG is an emergent approach to financing off-grid solar technologies such as SHS and solar lanterns that has taken off alongside the advent of mobile money in Kenya. PAYG is a business model that depends on two technologies: machine-to-machine connectivity, and mobile money (Pailman *et al.* 2015). Machine-to-machine connectivity means that companies can install GSM chips (the same radio technology used in cellphones) in their solar devices in order to remotely control the system, monitor its function, and process payments (Pailman *et al.* 2015). Mobile money refers to mobile phone operated virtual banking networks that allows a customer with a mobile money account to make payments or cash transfers via their cell phone, even if they do not have a formal bank account. This allows "unbanked" people from rural areas to access a type of financing that may have been previously unavailable.

Companies with PAYG business models use both types of technology to allow customers to buy a product such as an SHS, and pay for it in instalments from their home via cell phone, instead of in cash up front (Alstone *et al.* 2015). Interestingly, in Kenya, the development of mobile banking outpaced regulation. Central banks issued letters of "no objection," allowing mobile banking operators to continue their operations while regulations were being developed. This facilitated growth of the sector (Pailman *et al.*, 2015).

Rolffs *et al.* (2015) report that in 2013, there were six companies in Kenya offering PAYG payment plans for SHS. The three largest players were Mobisol, Azuri, and M-Kopa (Rolffs *et al.* 2015). All three companies were launched in 2011 (Rolffs *et al.* 2015). Mobisol, Azuri, and M-Kopa use different versions of PAYG business models, but all of the models share the same characteristics (Rolffs *et al.* 2015). The consumer makes an initial payment to unlock the system, and then makes periodic payments (typically daily), through mobile money banking (Azuri is an exception as they use a scratchcard system) (Pailman *et al.* 2015). If the customer fails to make payments, the system is locked remotely and will no longer work (Rolffs *et al.* 2015). In some instances, part of the customer's payment goes towards the cost of the system, and after a certain duration of time the customer owns the system. In others, lighting is provided "as a service"—the customer never actually owns the SHS or solar product, but only pre-pays remotely through their cell phone for a certain number of hours of light (Alstone *et al.* 2015; Pailman *et al.* 2015).

Most companies using PAYG models have attempted to tailor payment plans so that the monthly amount is less than what a household would spend on kerosene for equivalent light, whether the person is on a pay-to-own or pay for lighting service plan (Rolffs *et al.* 2015). In addition, all companies offer fairly robust after-sales support, which helps address quality issues (Rolffs *et al.* 2015). However, Rolffs *et al.* 2015 states that at the time of their research in 2013, it was unclear how the PAYG market would develop and whether it would truly reach poorer households, especially because the initial PAYG rates were tailored to match middle class or wealthier families' kerosene expenditures (Rolffs *et al.* 2015). Others are more optimistic about the potential of PAYG business models. In a 2015 Lighting Global Market Research Report about PAYG in Kenya, the authors state "early indications are that PAYG dramatically increases levels of access through consumer markets for off-grid power"

(Alstone *et al.* 2015). They refer to a pilot study by a Kenyan PAYG solar company SunnyMoney where the company evaluated sales of solar study lanterns sold through a school sales campaign. In the study, the company sold some study lanterns using a PAYG financing model and others up front. The company found that 20-50% of the customers introduced to the lanterns through the PAYG program purchased a lantern, compared to 10-15% without PAYG, marking a doubling or tripling in sales for PAYG study lanterns (Alstone *et al.* 2015).

Overall, it's clear that PAYG business models are impacting the SHS and solar lantern sectors in Kenya, and may be opening up these markets to a larger segment of the rural population. However, the published literature in this sector is still preliminary.
Having reviewed and analysed the literature on the development of the SHS and solar lantern sectors in Kenya, and discussed new PAYG business models, the next section goes on to discuss applicable theories and to outline the methodological, analytical, and theoretical frameworks that will be applied in this thesis.

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.

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 this theory can be combined with Painuly's framework to help analyse and understand the drivers and barriers identified in this thesis.

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) 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 4, below.

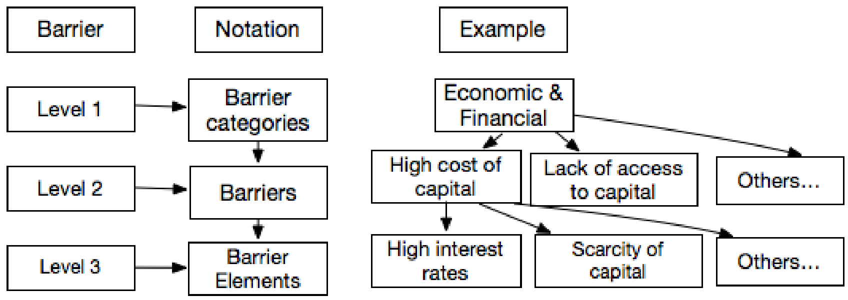

Figure 4. Barrier identification. Source: Painuly (2001) (with amendments).

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 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 co-evolution 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 5, 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."

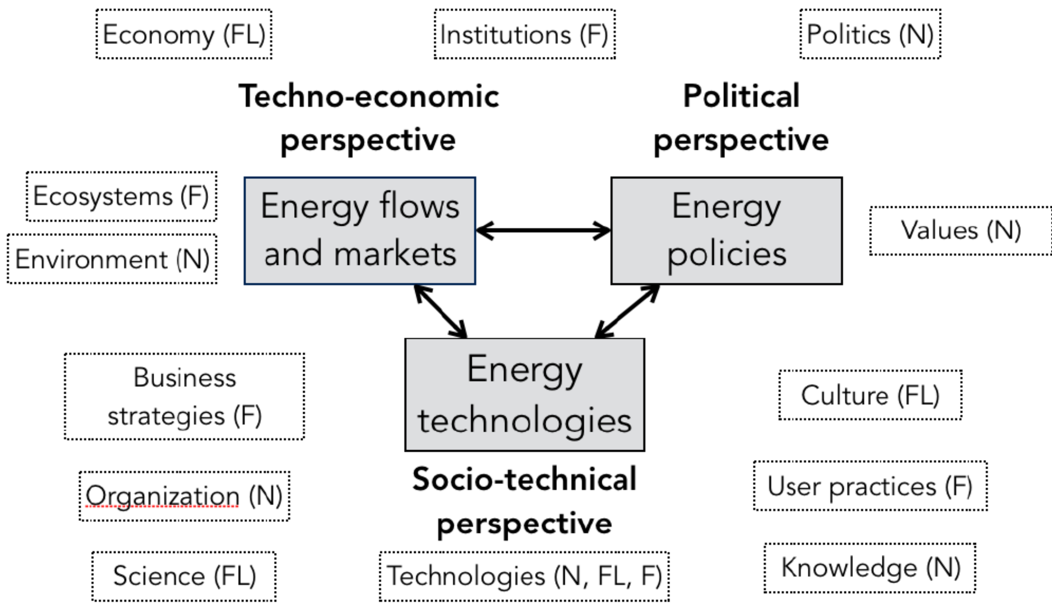

Figure 5. Three perspectives on energy transitions. Source: Cherp *et al.* 2016, incorporating Foxon, 2011, (F); Norgaard, 1994, (N); and Freeman and Louca, 2001, (FL).

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 Kenya. The second thesis focuses on outlining the development of the off-grid solar lighting products sector in Bihar, India. 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 6, below. Yellow indicates a common section.

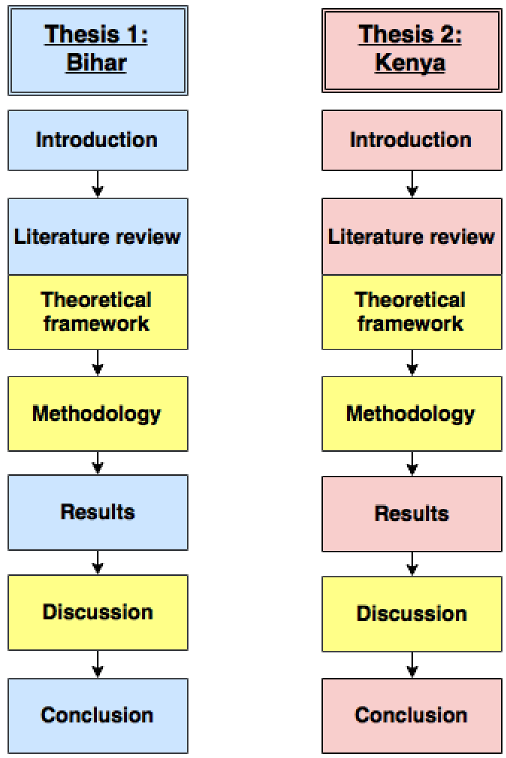

Figure 6. Thesis project structure overview

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:
  - 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 one 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.

Table 4: Interviews solely regarding Bihar

Category	Interviewee
1. Government	Anonymous, Bihar Renewable Energy Development Agency (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
3. Experts	Shreya Jai, Journalist, Business Standard
	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 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 products 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 four off-grid solar lighting product companies in Bihar were also interviewed for the purpose of this research. Finally, three comparative interviews with three 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 off-grid 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 off-grid 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. Results

This chapter summarizes the results from 13 interviews conducted with key stakeholders in the sector, and additional data gathered from reports and other data sources the researcher was referred to in the course of the interviews. It contains a modified timeline of the development of the off-grid solar lighting products sector in Kenya, based on results from the literature review and the interviews, tables setting out additional data procured from the interviews and reports, and an overall presentation of the results and content analysis of the interviews. The companion thesis to this work contains a section with similar interview results from Bihar.

4.1 The Kenyan off-grid solar lighting products sector: A timeline

The first question asked of the interviewees was to describe the history of the off-grid solar lighting products sector in Kenya. All interviewees with pertinent knowledge about the history of the sector either confirmed or confirmed and built on the history described in the literature review. Their contributions are outlined in the timeline in Figure 7, below. One interviewee confirmed information from the literature review that the private SHS sector began in the 1980s. Other interviewees added that the private sector for SHS and solar lanterns as we know it today really began to take off in the 2000s, with several big players such as d.light entering the market and beginning operations around 2005-2007. In addition, the interviews were really able to flesh out the contribution of PAYG business models to the uptake of SHS and solar lanterns following the introduction of these business models in 2011, with seven interviewees pointing to this as a factor.

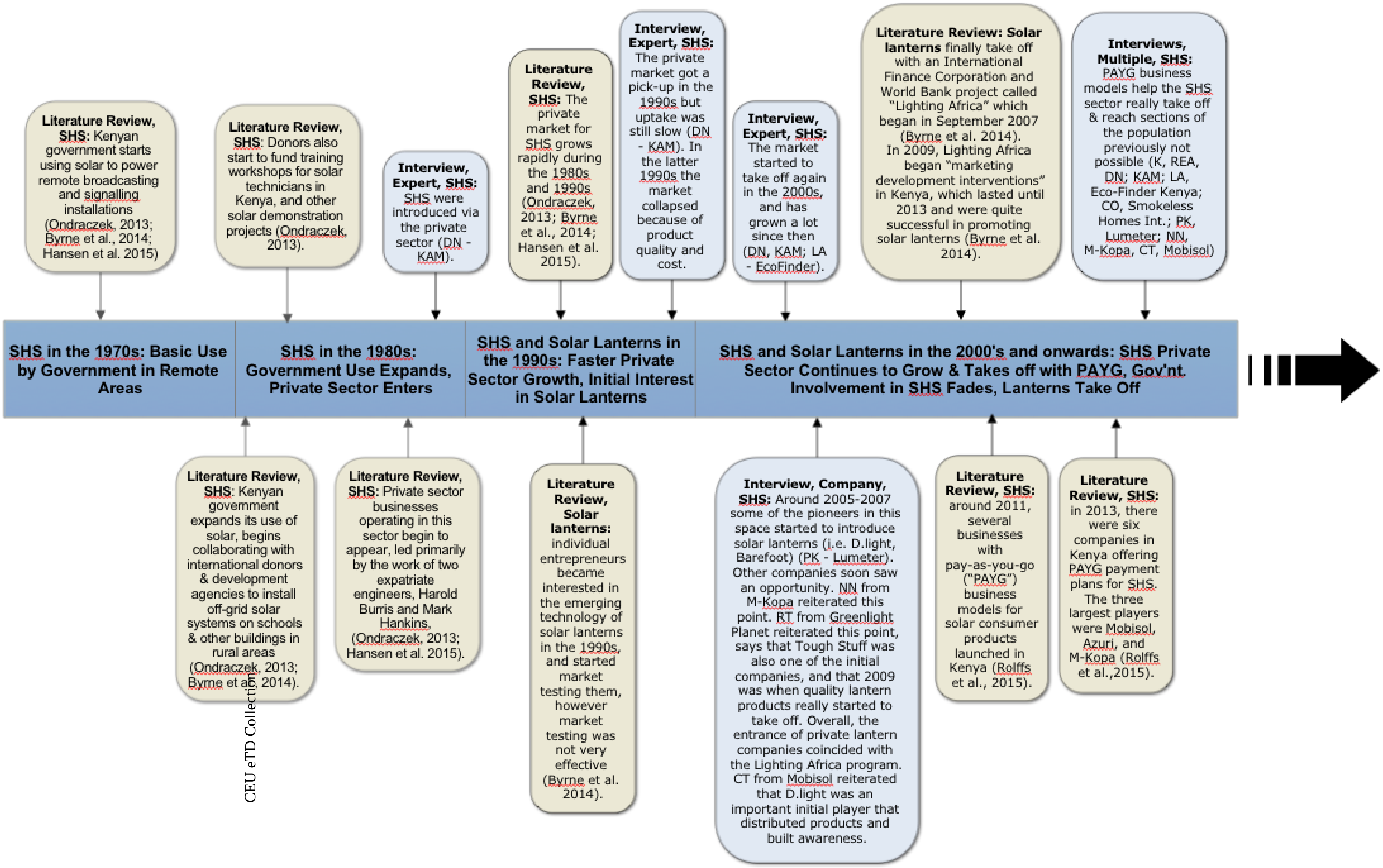

Figure 7. Timeline of the development of the Kenyan off-grid solar lighting products sector

4.2 Additional data: the number of SHS, solar lanterns, and companies

Interviewees were also asked to estimate the total number of SHS and solar lanterns sold and distributed throughout the history of the sector in Kenya. While many interviewees found it difficult to give accurate estimates, one interviewee pointed us to a report by Innovation and Renewable Energy Kenya (IREK), which provides figures for 2015. Another interviewee, who works as director of sales at M-Kopa, a very significant player in the private SHS market in Kenya, provided us with an estimate for SHS and solar lanterns sold and distributed in Kenya. In fact, when we asked the government for estimates of how many SHS and solar lanterns had been sold and distributed in Kenya, they referred us to M-Kopa. Given that the IREK report is from 2015, this paper adopts the M-Kopa representative's estimates as the most up-to-date, valid estimates of the sector. The results are shown in Table 7, below.

Table 7. Number of SHS and solar lanterns sold/distributed in Kenya

Topic	IREK Report (2015)	Nair (2017)
Number of SHS sold/distributed in Kenya	445,000 to 470,000	700,000
Number of solar lanterns sold/distributed in Kenya	1,000,000	2,000,000-3,000,000

Figure 8, below, shows the growth of SHS in Kenya from 1990 to 2017 based on data gathered and presented in the literature review and the estimates from interviewees discussed above.

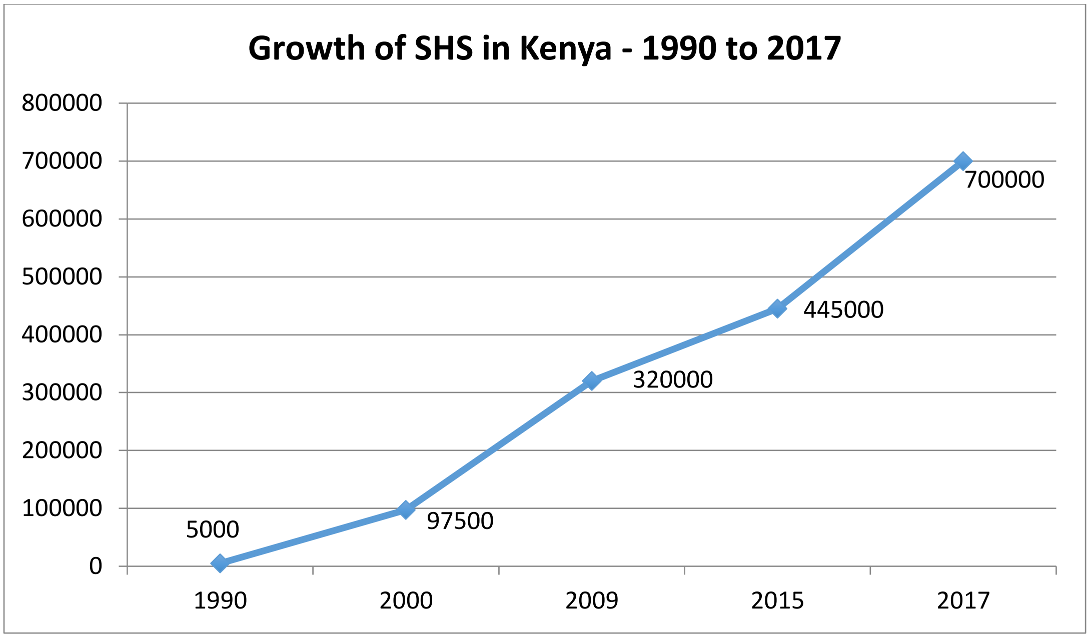

Figure 8. Growth of SHS in Kenya—1990 to 2017. Data source: Ondraczek 2013; Hansen *et al.* 2015; IREK 2015; Nair 2017.

Figure 9, below, shows the growth of solar lanterns in Kenya from 2010 to 2017 based on data gathered in the literature review and the estimates from interviewees discussed above.

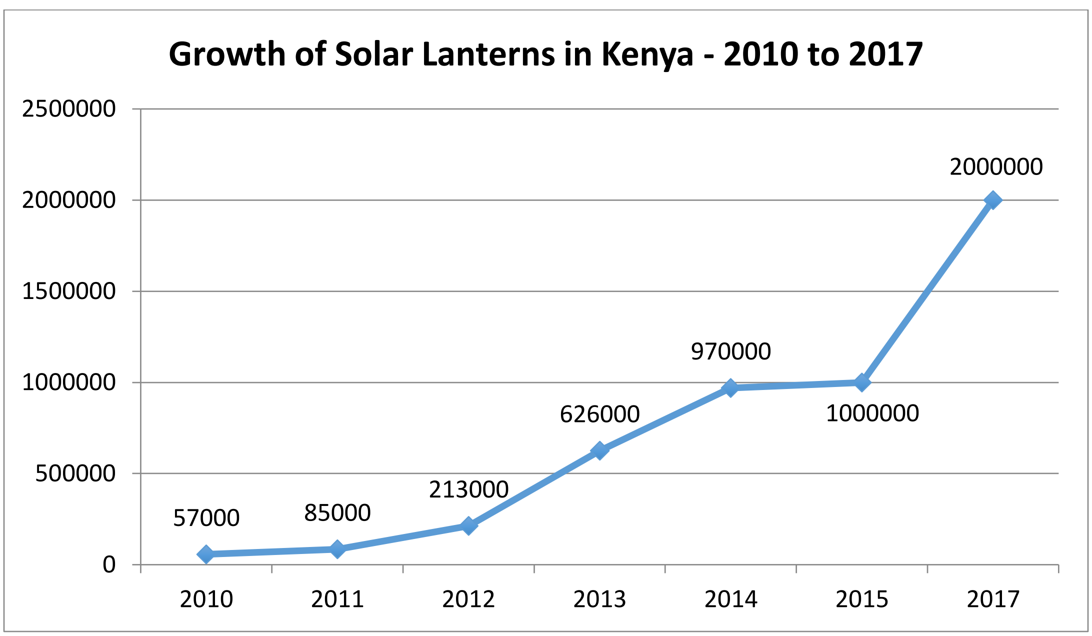

Figure 9. Growth of Solar Lanterns in Kenya – 2010 to 2017. Data Source: IREK 2015; Lighting Global 2016; Nair 2017.

Interviewees were also asked to estimate the number of companies operating in this sector in Kenya selling off-grid solar products, and the number of companies operating as manufacturers. No one was able to give an estimate for the number of companies with confidence, but several interviewees referred us to GOGLA reports. In a GOGLA, Bloomberg & Lighting Global report, as of 2016, there were 15 GOGLA members with a sales presence in Kenya. This means that there were 15 well-established players in the market. There are likely many more informal players in Kenya, as the GOGLA estimate only pertains to large companies, and there was a widespread agreement amongst interviewees that there is a large market selling low quality products in the country.

With respect to manufacturers, two interviewees were able to comment on this, giving a range of one to two manufacturers in Kenya. This differs from the literature review, which described a small but growing manufacturing industry as late as 2009. The interviews collected for this thesis contradict this aspect of the literature review. Manufacturing was described as small and almost non-existent, with almost all products being imported from China. See Table 8 below for a summary of these results.

Table 8. Number of companies and manufacturers operating in Kenya

	Source	
1. Number of companies operating in Kenya	15 GOGLA members with a sales presence (Lighting Global 2016)	
2. Number of manufacturing companies operating in Kenya	2 (Thakkar 2017)	1 (Njugi 2017)

4.3 Drivers and barriers identified in the interviews

With respect to drivers and barriers, interviewees brought up eight main drivers, and four main barriers, each with multiple elements. The eight drivers included (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) factors facilitating company success, (6) cultural factors, (7) government's light touch approach, and (8) international intervention. These results are shown in Table 9, below.

Table 9. Drivers of the growth of the off-grid solar lighting products sector in Kenya

	TOTAL	Govt: EK - REA	Govt: A - REA	Expert: KG, KEREA	Expert: DN, KAM	Expert: JO, Uni. Ham-burg	Expert : LA, Eco-Finder Kenya	Comp: CO, Smoke-less Homes Int.	Comp: PK, Lu-meter	Comp: NN, M-Kopa	Comp: RT, Green-light Planet	Comp: CT, Mobisol	Finance : KB, Safari-com	Finance : VN, AECF
ENHANCED ABILITY OF THE CUSTOMER TO PAY														
PAYG technology & business models	9	1	1		1	1	1	1		1		1	1	
Cost of solar has come down	1				1									
Middle class with disposable income	1					1								
PUSH FROM GOVERNMENT														
VAT exemption	8	1	1	1		1			1		1		1	1
Government creates enabling environment for business & investment	4	1	1	1	1									

ISSUES WITH THE GRID DRIVE CONSUMER DEMAND														
Need for power in areas where it is not available	5	1	1	1			1							1
Expensive grid power	9	1		1	1		1	1	1			1	1	1
Unreliable grid power	7	1					1	1	1			1	1	1
Cust. think grid will never reach	4					1			1	1			1	
CUSTOMER'S PERCEIVED BENEFITS OF SOLAR														
Education & awareness campaigns	7	1		1	1		1	1				1	1	
NGO/international agencies promoting systems	3	1					1						1	
Expensive kerosene	6		1					1	1	1		1	1	
People want power for TV	3					1			1	1				
Technology has improved	2					1	1							
Product tailored to cust. needs	1							1						

FACTORS FACILITATING COMPANY SUCCESS														
Kenyan entrepreneurship	5	1				1	1					1	1	
Sacco and Chamma models	2				1								1	
Availability of financing for companies	3			1			1					1		
More trained technicians	1				1									
Ease of doing business	4	1				1					1		1	
People are aware about solar	1							1						
Development finance from large international organisations	2								1			1		
PAYG overcoming product quality	1									1				
CULTURAL FACTORS														
People ready to take a risk on something new	1					1								

GOVNT- LIGHT TOUCH APPROACH														
Light touch and ex-ante regulation of the government	**3**					1			1	1				
INTL. INTER-VENTION														
The Lighting Africa program	**1**										1			
Challenge fund from AECF	**1**													1

The four barriers included (1) ability of the customer to pay, (2) difficulties faced by companies, (3) issues with product quality, and (4) issues with government policy. Each of these barriers had several elements, listed in Table 10, below.

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

	TOTAL	Govt: EK - REA	Govt: A - REA	Expert: KG, KEREA	Expert: DN, KAM	Expert: JO, Uni. Hamburg	Expert: LA, Eco-Finder Kenya	Comp: CO, Smoke-less Homes Int.	Comp: PK, Lu-meter	Comp: NN, M-Kopa	Comp: RT, Green-light Planet	Comp: CT, Mobisol	Finance: KB, Safari-com	Finance: VN, AECF
ABILITY OF THE CUSTOMER TO PAY														
Initial high cost of solar (1980s and 1990s)	**3**	1											1	1
Customer affordability	**7**		1	1	1	1	1	1						1
Financing for customers (prior to PAYG)	**6**				1	1			1	1		1	1	
DIFFICULTIES FACED BY COMPANIES														
Supply chain and logistics	**1**		1											
Not easy to get the tax exemption	**1**				1									
Infrastructure in Kenya poor in the past	**1**					1								
Financing for companies	**3**					1				1			1	

ISSUES WITH PRODUCT QUALITY														
Quality of products	**10**	1	1	1	1		1	1	1	1		1	1	
People don't know how to maintain the systems	**1**				1									
After sales service	**1**				1									
Initial very poor systems	**1**					1								
ISSUES WITH GOVNT. POLICY														
Lack of local manufacturing	**2**				1			1						
Inconsistent VAT/import duties exemption	**4**						1			1		1		1

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 two sections. 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 two 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's 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 government's "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 0.13–0.17 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 SHS, 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, it's 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 products 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 SHS, 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 wide-ranging 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 seven drivers in greater detail, this section turns to the barriers. According to the criteria set out above, the interviews results highlighted seven 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 use the standard—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 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 echoed 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 sector. They also stated "the regional market is important for any 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 products 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 products 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 that 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 government's 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 a 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 products 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)
5. 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 products 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) 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: Food and 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.

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

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

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. Application fee for a new grid connection in Bihar. Source: NBPDCL 2016.

Type of house	**Amount**
Huts (*kutir)*	Rs. 20.00 (0.28 EUR)
Build houses (*pukka*)	Rs. 75.00 (1.06 EUR)
Larger house	Rs. 200.00 (2.83 EUR)

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

Category		**Charges (1 unit = 1 kilowatt hour)**
Huts (*kutir)*		
	Metered	a) First 30 units at 170 Paisa/ unit (0.02 EUR / unit) b) Remaining units, similar amount charged to the above, but variable
	Non-metered	Rs. 60 (0.85 EUR)/ connection/ per month
Built house (*pukka)*		
	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)

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 off-grid 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 ½ 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 paper 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 joint study was to update knowledge on the growth of the off-grid solar lighting products sector in Kenya, for which a paradigm shift has occurred since 2011 (prior to which most academic literature was written), to fill the knowledge gap regarding the development of the sector in Bihar, and to develop policy recommendations for Bihar based on the Kenya case study. To accomplish this aim, this thesis set out to answer the following research question: **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 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? This thesis forms one part of a two-part joint study. This thesis set out to answer the first sub-question, while the companion thesis answered the second sub-question, and both theses answered the third sub-question jointly.

This thesis accomplished its aim via a literature review and comprehensive interviews with a variety of stakeholders in Bihar, Kenya, and California. These interviews were processed using content analysis and analyzed using Cherp *et al.* (2016)'s three perspectives theory. With respect to the first sub-question, this thesis identified the 7 most significant drivers of and barriers to growth of the off-grid solar lighting products sector in Kenya. These drivers, in order of importance, are: PAYG technology and business models; expensive grid power; the VAT exemption; education and awareness campaigns; unreliable grid power; expensive kerosene; and need for power in areas where it is not available. The barriers, in order of importance, are: quality of products; customer affordability; financing for customers prior to PAYG; the inconsistent VAT/import duties exemption; financing for companies; lack of local manufacturing, and after sales service.

With respect to the second sub-question, the companion thesis to this study determined the 5 most important drivers of and 7 most important barriers to the growth of the off-grid solar lighting products sector in Bihar, India. The 5 drivers, in order of importance, are: unmet electricity demand; unreliable grid power; a post 2005 decrease in solar prices; India's solar mission promoting solar; and the fact that women understand the drawbacks of kerosene and benefits of solar. The 7 barriers, in order of importance, are: the kerosene subsidy disincentivizes customer's purchases; financing for companies; issues with product quality; customers lack awareness of the benefits of solar; a counterproductive MNRE/BREDA subsidy for solar product giveaways; customers think grid power is coming & is cheap, and customer affordability.

One interesting take-away from this research is that when Cherp *et al.* (2016)'s three perspectives framework is used to analyze the drivers and barriers, it becomes clear that with respect to Kenya, techno-economic factors such as expensive and unreliable grid power, expensive kerosene, and the need for power in areas where the grid is not available created the pre-conditions for success of the off-grid solar market, but it was not until a socio-technical force—an innovative business model, PAYG—was introduced in 2011 that the market really took off. The barriers to further growth of the sector in Kenya are also all socio-technical, as opposed to political or techno-economic, suggesting that this perspective represents the area where most attention is required. Another interesting take-away was that the drivers to growth of the sector in Bihar are largely techno-economic, such as unmet electricity demand and unreliable grid power, but they are "out-competed" by serious socio-technical and political barriers such as the kerosene subsidy and issues with product quality, which disincentivize potential customers from purchasing solar lighting products.

With respect to the third sub-question, this joint study set out a series of specific recommendations for addressing the 5 most significant barriers to growth of the sector in Bihar, based on the Kenya case study. The recommendations are: address the harmful kerosene subsidy by eliminating it and redistributing the funds to consumers; establish a challenge fund for Bihar, similar to that in Kenya, to support companies in this sector; pursue further research to tackle quality issues; more awareness campaigns are needed to spread product awareness in Bihar and educate people about the benefits of solar and negative impacts of kerosene; cancel the counterproductive MNRE/BREDA subsidy and redistribute the funds; make grid expansion more predictable and transparent; and that RBI should immediately remove restrictions on mobile money and allow private mobile operators to set up mobile money platforms. If RBI is unwilling to ease the mobile money rules, companies in Bihar could consider adopting a PAYG model similar to Simpa Networks, an Uttar Pradesh company that developed a model allowing them to offer a PAYG style service to customers without mobile money.

The insights generated through this study may help the off-grid solar lighting products sector in Bihar, India's least electrified state, overcome its barriers and bring more clean energy options to the rural poor. It is the first study to examine this issue in Bihar, and thus represents a significant contribution to knowledge. It has also provided an important update to the state of knowledge in Kenya, and enhanced understanding of how pivotal the introduction of PAYG business models was to the growth of the Kenyan off-grid lighting products sector. It was also one of the first pieces of research to comprehensively address the barriers to growth of the sector in Kenya (typically research just focuses on the drivers), and thus the results of this research could also provide insight that helps the Kenyan sector overcome its barriers and grow further.

This research focused on two specific case studies, Kenya and Bihar, thus results, while suggestive for other countries, are not generalizable beyond the two places in question. Fruitful directions for further study include conducting more research on how to address common barriers that both Bihar and Kenya are facing, such as how to overcome the quality issues plaguing both off-grid solar product markets. In addition, this type of study could be expanded beyond Kenya and Bihar to other countries with significant off-grid populations and fledgling off-grid solar lighting products sectors, such as Rwanda and Bangladesh, or to other Indian states that meet the same criteria, such as Uttar Pradesh. Ultimately, additional research along the lines of this study could help further our understanding of what it takes to foster markets for cleaner, renewable energy lighting products in the developing world—and help populations in these areas light their lives without compromising their health or the environment.

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