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**All Together Now:  
Institutional Innovation for Pro-Poor Electricity  
Access in Sub-Saharan Africa**

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A thesis submitted in February 2017 in partial fulfilment of the  
requirements for the degree of:

*Doctor of Philosophy*

**SPRU – Science Policy Research Unit**

**University of Sussex**

I hereby declare that this thesis has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.

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DPhil Science and Technology Policy Studies

All Together Now: Institutional Innovation for Pro-Poor Electricity Access in Sub-Saharan Africa**SUMMARY**

Access to electricity is an important precondition to many aspects of human and economic development. Yet, in rural sub-Saharan Africa in particular, access rates remain very low — at an average of 17% and much lower in some cases. Rural electrification in Kenya, the focus of this thesis, had only reached 7% in 2014. Given the goal of universal electrification by 2030, formulated as part of Sustainable Development Goal 7, scalable and replicable approaches that are able to support productive and non-productive uses are required.

Mini-grids are one promising solution to this problem, alongside grid extension and off-grid approaches such as solar home systems. However, their long-term operational sustainability has historically been a challenge. While the academic literature to date on sustainable energy access has largely been two-dimensional in its analysis of mini-grids (focusing on technology and economics or financing), this thesis contributes to an emerging body of recent contributions to the literature, which have begun to foreground socio-cultural considerations.

Bridging the literature on collective action for common-pool resource (CPR) management and property rights theory, a refined theoretical framework is produced for the purpose of analysing the institutional conditions for sustainable management of rural mini-grids. The utility of this framework and of treating electricity in a mini-grid as a CPR is demonstrated via empirical analysis of three case studies of mini-grids in rural

Kenya and evidence from 24 expert interviews. This yields insights on non-technological approaches to addressing operational challenges relating to sustainable mini-grid management, e.g. fair allocation of limited amounts of electricity to different consumers in ways that are acceptable to the entire community. This thesis develops contributions to the literature on sustainable CPR management and collective action, property rights theory and energy access in developing countries. From these theoretical and empirical insights, it explores a novel institutional structure for sustainable management of pro-poor mini-grids in the form of a community–private property hybrid management platform, thereby opening up opportunities for future research into the implementation of such a platform. The thesis represents the first comprehensive attempt to analyse the institutional aspects of pro-poor mini-grid management as well as the first comprehensive attempt to treat electricity in a mini-grid as a CPR.

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## Abbreviations

A-B-C	-	Anchor-Business-Community
ACTS	-	African Centre for Technology Studies
CBO	-	Community-based Organisation
CPR	-	Common-pool Resource
ERC	-	Energy Regulatory Commission
ETSI	-	Energy Technology Sustainability Index
IEA	-	International Energy Agency
KPLC	-	Kenya Power and Lighting Company
KSH	-	Kenyan Shillings
kW	-	kilowatt (1000 Watts)
kWh	-	kilowatt-hour
kWp	-	peak kilowatt (i.e. maximum power output)
LCEDN	-	Low Carbon Energy for Development Network
LED	-	Light-emitting Diode
MDG	-	Millennium Development Goal
MoE	-	Ministry of Energy

PV	-	Photovoltaic
REA	-	Rural Electrification Agency
SDG	-	Sustainable Development Goal
SE4All	-	Sustainable Energy for All
SHS	-	Solar Home System
SONG	-	Solar Nano-Grids Project
UNDP	-	United Nations Development Program
UNICEF	-	United Nations International Children's Emergency Fund
UNIDO	-	United Nations Industrial Development Organisation
W	-	Watt
WTP	-	Willingness to Pay

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*[...] When a number of individuals have a common or collective interest - when they share a single purpose or objective - individual, unorganized action [...] will either not be able to advance that common interest at all, or will not be able to advance that interest adequately. (Olson, 1965, p. 7)*

## **Chapter 1 - Introduction**

When United Nations Secretary General Ban Ki-Moon launched the Sustainable Energy for All Initiative (SE4All) in 2011 with the goal, among others, to achieve universal electrification by 2030, he opened his speech with a simple statement: ‘energy enables’ (United Nations, 2011). This focus on the importance of energy as an enabler, or a necessary precondition for development, brings attention to the broad spectrum of areas in which access to electricity enables improvements in human development (for example, the improvement of levels of health and education) or economic development (measured by, for example, gross domestic product per capita or poverty rates).

### ***1.1 Electricity as a Precondition to Development***

According to a review of electrification projects in Asia and the Pacific by the United Nations Development Program (UNDP, 2011), electricity access could contribute positively to the achievement of all eight Millennium Development Goals (MDGs). For example, fuel efficiency gains and the productive use of energy can lead to a ‘reduction in extreme poverty and hunger’ (MDG 1) by reducing the expenditure on fuel for lighting (Dutta, 2005). Improved lighting for studying helps to ‘achieve

universal primary education’ (MDG 2), and the opportunity for women to learn new skills, also facilitated by lighting, ‘promotes gender equality and empowers women’ (MDG 3). Replacing traditional sources of light with LED lights promotes the reduction of indoor pollution caused by kerosene lamps and the burning of biomass, which ‘reduces childhood mortality’ (MDG 4) while also ‘improving maternal health’ (MDG 5). The ability to refrigerate medicines and vaccines is critical to ‘combat HIV/AIDS, Malaria and other diseases’ (MDG 6). Reduced consumption of fuelwood and fossil fuels such as kerosene, and the potential to improve access to water through mechanical pumps contribute to ‘ensuring environmental sustainability’ (MDG 7). Furthermore, access to electricity is also crucial for communication, be that in the form of radio, television, telephone or the Internet, as well as access to finance and simple banking facilities, particularly in the case of Africa where mobile telephone banking is very widespread. These benefits help in the ‘promotion of a global partnership for development’ (MDG 8).

The inclusion of ‘access to affordable, reliable, sustainable and modern energy for all’ as goal 7 of the Sustainable Development Goals (SDGs) (United Nations, 2015), which were the successors of the MDGs, made explicit the role of energy access (i.e. access to electricity and clean cooking) in the pursuit of sustainable development and the eradication of poverty. The goal of eradication of poverty also motivated the focus of this thesis on pro-poor rural electrification. In this context, ‘pro-poor’ should be understood to mean that the mini-grid can serve more than the needs of large anchor loads, businesses or the comparatively wealthier households often directly attached to micro and small enterprises in rural areas of sub-Saharan Africa. Rather, the mini-grid is capable of serving all households, including the comparatively poorer ones, whose demand initially may not exceed a single LED light and mobile phone charger. This



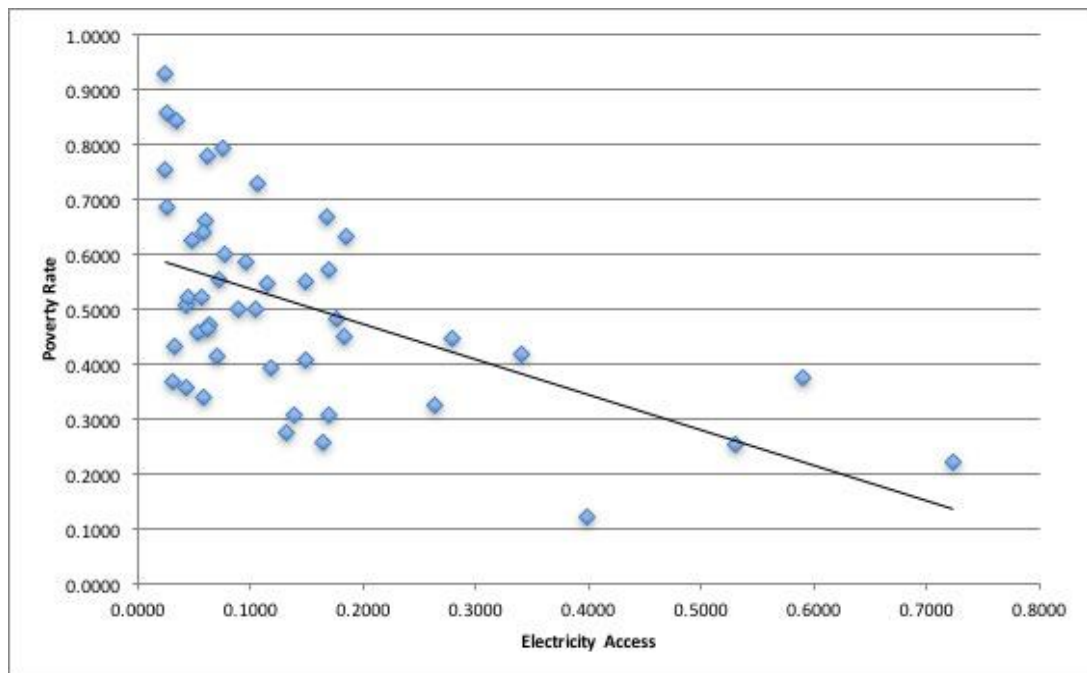
definition is naturally more in flux than a quantitative definition of poor households (e.g. less than \$1.90 per day in 2011 U.S. dollars, which is the poverty line currently set by the World Bank).<sup>1</sup> However, it is more useful in this context as it remains all-inclusive, since electricity demand patterns are expected to change and evolve over time.

However, access to electricity in and of itself is not a guarantor for development. While there is a clear correlation between levels of poverty and access to electricity (See Figure 1.1 for an example based on Kenyan data), causality is not straightforward. These two factors form more of an iterative feedback loop, rather than clearly running from electricity access to reduced levels of poverty. Nevertheless, the data presented in this Figure suggest that access to electricity forms a necessary precondition for development.

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<sup>1</sup> <http://www.worldbank.org/en/topic/poverty/brief/global-poverty-line-faq>

**Figure 1.1 - Poverty Rates vs. Electricity Access in Kenyan Counties in 2009**



*Based on data from the 2009 Kenyan National Census published on [www.opendata.go.ke](http://www.opendata.go.ke); poverty is defined as having less than \$1 per person/day. Each data point represents a Kenyan county.*

## ***1.2 The Current State of Access to Electricity***

The challenge of achieving universal electrification, let alone by 2030 as required by SDG 7 and SE4All, still remains monumental.<sup>2</sup> The overall electrification rate for developing countries reached 78% in 2013, which represented 1.2 billion people, and was considerably higher in urban areas (92%) than in rural areas (67%) (IEA, 2015).

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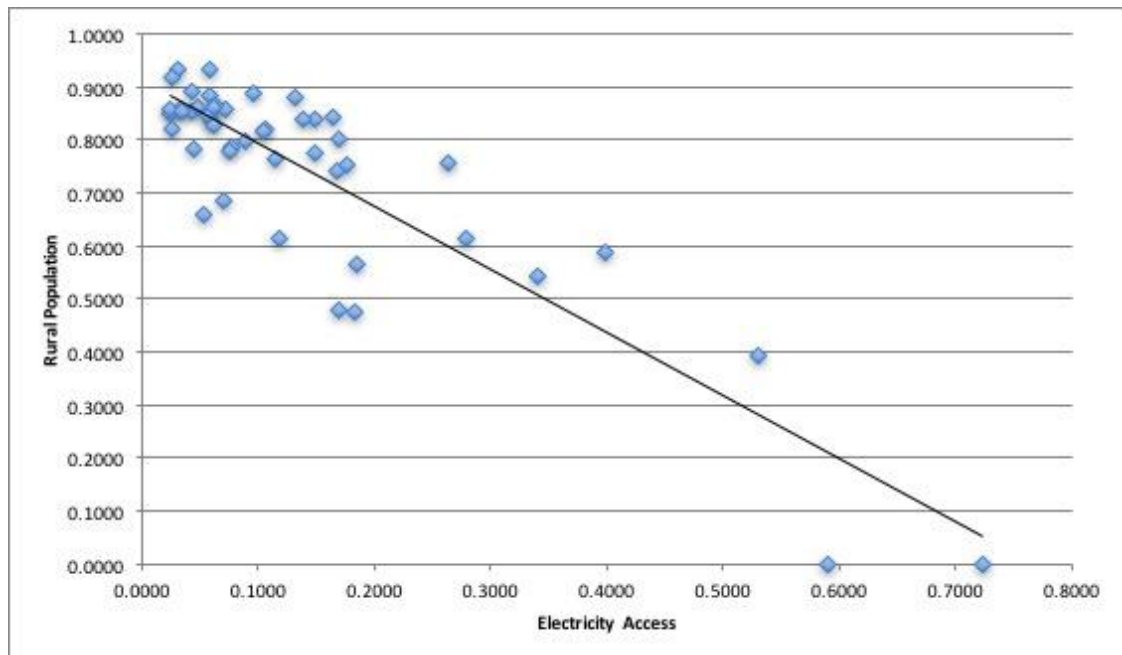
<sup>2</sup> Note: Due to the difficulties involved in collecting reliable and granular data on electrification rates, especially in rural areas, it was difficult to access current data. Most of the data used in this thesis come from the International Energy Agency's 'World Energy Access Database 2015', which included data from 2013, as well as the 'World Energy Access Database 2012, which presented 2012 data. More recent data could not be obtained.

While China has accomplished universal electrification and India has already electrified four-fifths of its population, the situation remains most dire in sub-Saharan Africa. More than half of the total global population currently lacking access to electricity lives in this region, and the overall electrification rate is only 32% (Ibid). Rural areas in particular are underserved, where only 17% of the population have access to electricity (Ibid). In fact, even though this represents a four percentage point improvement from 2010, the total number of people lacking access to electricity in the region increased by 35 million from 2010 to 2013, due to the fact that the overall population growth in sub-Saharan Africa exceeded the rate of new electricity connections (IEA, 2015, 2012).

Kenya provides a good example of this challenge. This sub-Saharan African country is the focus of this thesis and the location of all three case studies that are further described in chapter 3. In 2010, the overall electrification rate in Kenya was at 18%, with an urban rate of 65% and an average rural rate of only 5%, amounting to 34 million people without access to electricity (IEA, 2012). Three years later, the overall rate had reached 20%, while the urban rate had fallen to 60%. The International Energy Agency (IEA) provides no explanation for this drop, but it is likely that the urbanisation of the population proceeded faster than the electrification of those new urban populations. Meanwhile, rural electrification had reached 7% (IEA, 2015). Yet, the population without access to electricity increased by 1 million to a total of 35 million (Ibid). A different way of expressing the chasm between urban and rural electrification rates is shown in Figure 1.2, based on data for all 47 counties in Kenya. The larger the proportion of the population within a county that lives in rural areas, the lower the overall electrification rates for that county. In some of the more remote western and northern counties, electrification rates in 2009 were below 5%. Given the lack of significant progress at the aggregate country level as shown in the IEA data, it is

unlikely that the situation would appear significantly different in those more remote areas of Kenya if a survey were conducted today. With rural electrification rates in 2013 of 4%, 7% and 10% in Tanzania, Uganda and Ethiopia, respectively (IEA, 2015), the situation is not much better for Kenya's regional East African neighbours.

**Figure 1.2 - Proportion of Rural Population vs. Electrification Rates in Kenyan Counties**



Based on data from the 2009 Kenyan National Census published on [www.opendata.go.ke](http://www.opendata.go.ke). Each data point represents a Kenyan county.

### ***1.3 Alternative Approaches for Rural Electrification and the Role of Mini-Grids***

Hence, there exists a promising opportunity and challenge to develop methods to bring access to modern energy services to dispersed rural populations. The extension and expansion of national grids, alongside the addition of centralised electricity generation

capacity, is potentially one way to frame a solution to this problem. While this is often seen as the most promising way to electrify urban and peri-urban areas, it is more difficult to be rendered feasible in rural areas with widely dispersed populations (Zeyringer et al., 2015).

Using East Africa as an example, and assuming fixed costs of USD 22,000 per kilometre of transmission lines and USD 18,000 per kilometre of distribution line, Anderson et al. (2012, p. 4) estimate that grid extension is not economically feasible in areas that would average less than five connections per kilometre of grid extension. Given the fact that over 80%, 65% and 60% of the population live more than 20 kilometres from the nearest substation in Tanzania, Kenya and Uganda, respectively (Eberhard et al., 2011, p. 126), it is unlikely that grid extension is a feasible solution in large parts of rural East Africa. Even though Deichmann et al. (2011) estimate that ‘decentralized power supply is unlikely to be cheaper than grid supplies any time soon’ (p.225), this does not mean that grid connection is an option that households can easily afford, given the fact that most African utilities charge fairly substantial connection fees. In Kenya, for example, the national utility charges each household KSH 34,980–49,080<sup>3</sup> (USD 410–580) in connection fees, an amount that is unaffordable for most rural households. In addition, if the household is further than 600 metres from the furthest substation, it is required to cover the full cost of grid extension.

Furthermore, even taking into account the high capital cost of solar photovoltaics (PV) at USD 7,230 per kilowatt (kW) of installed power, the levelised cost of solar PV

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<sup>3</sup> See the REA NEWS Newsletter Issue 8, Vol. 5, July 2014 by the Kenyan Rural Electrification Authority at:  
[http://www.rea.co.ke/index.php?option=com\\_docman&task=doc\\_download&gid=860&Itemid=505](http://www.rea.co.ke/index.php?option=com_docman&task=doc_download&gid=860&Itemid=505)

mini-grids ‘will generally be competitive with that of grid extension when the extension would imply <10 connections/km’ (Anderson et al., 2012, p. 5). Since Anderson et al. conducted their analysis, the cost of solar PV has roughly halved. Using 2016 data from the U.S. National Renewable Energy Laboratory (NREL)<sup>4</sup>, the cost of PV for installations between 10–100 kilowatts (kW) (the relevant size considered in this thesis) has dropped to just under USD 3,500 per kW installed. This will make solar PV mini-grids even more cost-competitive compared with grid extension, and hence feasible even in less remote areas. In addition, the existing power generation infrastructure is already unable to meet the current levels of demand in many cases, let alone the additional demand created by connecting more rural households to the power grid. Kenya, Uganda and Tanzania already average approximately 80, 70 and 65 days of power outages per year, respectively, and their total installed generation capacity is less than 30 watts (W) per capita, or the equivalent of two typical compact fluorescent light bulbs (Eberhard et al., 2011, pp. 4–8).

One possible solution to this challenge is solar home systems (SHSs), consisting of a small PV cell charging a battery, which can then be used to power a compact fluorescent or LED light bulb or a number of appliances, such as a radio or a refrigerator, depending on the system’s size. These systems have been successfully implemented across the developing world and sub-Saharan Africa, especially in Kenya (Byrne, 2011; Sebitosi et al., 2006). Alternatively, instead of electrifying individual households, it is possible to connect whole communities or villages by constructing a mini-grid, independently of the national grid, that draws its power from one (or in a

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<sup>4</sup> See: [http://www.nrel.gov/analysis/tech\\_lcoe\\_re\\_cost\\_est.html](http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html)

hybrid system two or more) small electric power generation source(s). This approach has been realised very successfully, particularly in East Asia and Latin America, typically relying on small hydro plants or diesel generators as the source of electricity (Casillas and Kammen, 2011). In fact, the IEA (2014, p. 496) expects that in their New Policies Scenario<sup>5</sup> over 140 million people in sub-Saharan Africa will be connected to between 100,000 and 200,000 mini-grids by 2040, amounting to an overall installed generation capacity of 26 million kilowatt-hours (or terawatt-hours, TWh). This is roughly the equivalent of the entire generation capacity of Ireland in 2013 (BP, 2014).

Compared to SHSs, mini-grids offer a number of benefits by their very nature. They generally involve generation capacities that, given proper load management, can be high enough to support economically productive uses, such as pumping water for irrigation or welding, or other economically beneficial uses such as refrigeration, thereby improving the ways in which electrification can catalyse economic development. As demand increases, their generation capacities can be upgraded and their reach expanded relatively easily compared to SHSs, which are typically fixed in size and less modular. Furthermore, mini-grids distribute benefits across the whole community and may include the electrification of households, businesses and public facilities, such as schools and health clinics. Simultaneously, street lights may be installed, which have been shown to significantly increase safety, particularly for women (Iliskog et al., 2005).

At this point, it should be clarified that the term ‘mini-grid’ is not universally defined. Other terms that are also used in the literature, depending on the size of the

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<sup>5</sup> According to the IEA (2014, p. 36) “the New Policies Scenario is the central scenario of WEO-2014. It takes into account the policies and implementing measures affecting energy markets that had been adopted as of mid-2014, together with relevant policy proposals, even though specific measures needed to put them into effect have yet to be fully developed.”

grid, are nano- or micro-grids. However, there are no clear and universal definitions for the sizes of nano-grids versus micro-grids and mini-grids. For the purposes of this thesis, the term ‘mini-grid’ is used exclusively and is defined as a grid-independent (or islanded) electricity grid with between 5 kW and 50 kW peak power and between 10 and 100 connections, which will exhibit the benefits over SHSs described above.

Additionally, if citizens use renewable sources of electricity such as small hydro, wind or solar PV, they can also contribute to environmental sustainability, which is a further requirement for achieving SDG 7. This is a crucial factor, considering that in the most recent Assessment Report the Intergovernmental Panel on Climate Change (IPCC) estimates that in the case of the two scenarios closest to business-as-usual (referred to as RCP 6.0 and RCP 8.5), global warming is likely to exceed 2° Celsius by the end of the century (IPCC, 2014, p. 10). The IPCC also reports that roughly one quarter of total annual CO<sub>2</sub> emissions are contributed by electricity and heat production, which suggests that providing access to electricity to the roughly 20% of the global population that is currently lacking must be achieved through non-fossil forms of electricity generation. However, despite these benefits of rural mini-grids, their long-term operational sustainability has been problematic in the past.

#### ***1.4 Operational Sustainability of Mini-Grids and a Brief History of Mini-Grids in Kenya***

Since operational sustainability of rural mini-grids is one of the central concerns of this thesis, the term ‘operational sustainability’ as it is used in this thesis must be



defined before proceeding with a short overview of the challenges that mini-grids have faced in developing countries in the past, as well as a brief history and overview of the current status of mini-grids in Kenya. Sustainability in this context is less concerned with ecological sustainability, although, as previously mentioned, this is still a potent argument for the deployment of mini-grids using renewable sources for electricity generation. Rather, ‘sustainability’ is defined as the ability of the mini-grid to cover its operating costs and maintain, repair and upgrade the system and, beyond those financial concerns, to understand the needs of the end users in order to avoid and resolve conflict, which may otherwise arise from demand exceeding supply, or a mismatch of supply and demand patterns.

This requires a number of factors. First of all, the mini-grid operations must, at the very least, be capable of earning enough revenue to fully cover the costs of management, operation and maintenance, and to build up small reserves for repairs or eventual upgrades. Ideally, of course, a mini-grid should also offer a return on the capital invested in its construction in order to be capable of attracting sources of capital beyond donor funds or other sources of development aid. However, this is not a requirement for operational sustainability as defined in this thesis, because the focus of this analysis is not on the potential sources of financing (which might require certain returns on investment) but rather on the operational sustainability before interest or debt service is taken into account. The presence of technological capability (for operations, maintenance and repairs) and the ability to source and to afford spare parts, however, are important requirements. Finally, operational sustainability, as defined in this thesis, also includes the ability of the entity operating the mini-grid to avoid conflicts among different end-user groups, whose interests may not be naturally aligned, and resolve those that arise. For example, households that primarily use electricity for lighting,

telephone charging and entertainment, i.e. non-productive uses, and small businesses using electricity for productive purposes may have different requirements. Small businesses will use electricity during the day, which can prevent the batteries of a solar PV mini-grid from fully charging during that time, thereby reducing the amount of electricity available to households for lighting at night.

This operational sustainability, however, has proven challenging in the past, due to the relatively high complexity of operation and maintenance of a mini-grid, compared with SHSs, for example, and the difficulty of charging tariffs that cover costs. For example, in an analysis of 27 community-based mini-grids in Northern Pakistan, Maier (2007) found that after approximately 10 years, a third of the mini-grids were no longer functioning. Similarly, Greacen (2004) found that of the 59 micro hydro mini-grids built in Thailand between 1982 and 2001, fewer than 50% were still operational by 2003. (Both of these author's works are reviewed in more detail in chapter 2.)

While Kenya does not have as long and varied a history of mini-grids for rural electrification as those of Asian countries, such as Indonesia (Schmidt et al., 2013) Nepal (Mainali and Silveira, 2011) and Bangladesh (Alam and Bhattacharyya, 2016; Bhattacharyya, 2015), there is nonetheless a relatively long history of mini-grids for rural electrification in Kenya. There have been at least 10 community-based mini-grids installed in the 2000s. Moreover, according to the author's best estimates based on desk-based research and information gathered during 27<sup>6</sup> interviews with mini-grid experts in Kenya, there were between 20 and 30 privately owned mini-grids in operation in Kenya in 2015, when most of the empirical research for this thesis was

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<sup>6</sup> 24 individuals were interviewed, some of them twice, for a total of 27 interviews.

conducted. This figure disregards the 16 off-grid power stations, which the Kenyan national utility, Kenya Power and Lighting Company (KPLC), is currently operating (SE4All and Kenya MEP, 2016). These will not be considered in this thesis as they are special cases in several respects. First of all, their operation is heavily cross-subsidised through the national uniform tariff that KPLC charges across the country (Kenya MEP, 2016). Secondly, they are currently all diesel-operated (Ibid) and thus their operational sustainability is heavily dependent on diesel prices and the diesel supply chain. Finally, they are considerably larger than what is considered a mini-grid in this thesis, i.e. each of these off-grid stations has a capacity of approximately 1000 kW.

The installation of non-public mini-grids in Kenya began in the early 2000s with mini-hydro<sup>7</sup> mini-grids in the region around Mount Kenya, primarily in Kirinyaga county (the county in the Central province that is closest to Nairobi, yet also includes a part of Mount Kenya). The geology and hydrology of this area is suitable for small-scale hydro power. Even though it is difficult to acquire reliable (much less peer-reviewed) information concerning these early mini-grids, in-depth online searches as well as project documents shared with the author by some of the experts interviewed for this thesis (see chapter 3 for more detail on the interview process) have led to the development of the following overview of the early history of mini-grid development in Kenya.

Throughout the early 2000s, approximately 10 mini-hydro mini-grids were installed by intergovernmental and nongovernmental organisations, often using donor money from multilateral or bilateral organisations such as the UNDP or the European

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<sup>7</sup> Again, the terms ‘pico-’, ‘micro-’ and ‘mini-hydro’ tend to be used interchangeably, but for the purposes of this thesis, ‘mini-hydro’ is meant to include capacities of 1–100 kW.

Commission. These mini-grids had generation capacities ranging from as low as 1 kW for over 60 households up to 100 kW for approximately 200 households. All followed a community-based approach, meaning that after construction and commissioning of the mini-grid, full ownership as well as all operational responsibilities including tariff-setting and collection, maintenance and repairs, were transferred to a community-based organisation established with the assistance of the implementing organisation specifically for this purpose. They also largely used a flat fee tariff structure, i.e. electricity consumption by the end user was not metered; they simply paid a monthly flat fee for their connection to the mini-grid. In many cases, the community either contributed small amounts of capital for the construction, or contributed labour during the construction, also known as ‘sweat equity’. Most of these early community-based mini-grids struggled with financial sustainability, largely due to the flat fee tariff structure, and often relied on repeated donor support. As solar PV became more affordable, more mini-grids using solar PV panels as their main means of electricity generation were installed, yet they still followed the same approach of a community-based ownership model financed with donor money (for example, see two of the case studies described in chapter 3, Kitonyoni and Olosho-Oibor).

As previously mentioned, a few private sector companies began to install and operate (mainly solar PV) mini-grids in rural Kenya as for-profit businesses in recent years, i.e. since 2012, a development that was also facilitated by the reduction in solar PV prices. This development was led by three main companies: SteamaCo ([www.steama.co](http://www.steama.co)), PowerGen ([www.powergen-renewable-energy.com](http://www.powergen-renewable-energy.com)), and Powerhive ([www.powerhive.com](http://www.powerhive.com)), which between them now operate 20–30 mini-grids in rural Kenya. Compared to the early community-based mini-grids, these follow a completely different approach, using prepaid electricity meters and remote monitoring and control

technology, which are discussed further in chapter 4. While the early community-based mini-grids had a clear focus on being pro-poor (as defined above), these mini-grids, by necessity, are largely driven by the requirement to earn a return on their invested capital, albeit a small one compared to other investments bearing similar risk.

Despite these recent developments, replicable approaches for mini-grid-based rural electrification in Kenya that are operationally sustainable in the long-run while also including arrangements to ensure that they can be considered pro-poor, i.e. an enabler for poverty alleviation, remain difficult to find. This thesis argues that the technical and financial aspects of mini-grid operation are comparatively well-researched and understood. Yet, the socio-cultural and, in particular, the institutional aspects are relatively under-researched, even though they hold considerable promise in connecting knowledge gained from both community-based and private-sector mini-grid operation with the development of replicable models for the sustainable management of rural mini-grids. In this specific context of mini-grid operation and thus throughout the rest of this thesis, ‘institutions’ are understood to mean established norms, customs and practices, or ‘the rules of the game’ (North, 1990, p. 4), which are acted upon by local specialised organisational structures for the management of a clearly boundaried resource system. Another area that is also comparatively under-researched, yet not the focus of this thesis, is political and political economy aspects of rural electrification. Ahlborg and Hammar (2014) as well as Newell and Bulkeley (2016) have recently started to place emphasis on these factors in the context of sub-Saharan Africa.

### ***1.5 Limitations in the Literature and the Identification of a Research Question***

The majority of existing literature on energy access in sub-Saharan Africa is characterised by a two-dimensional focus on finance and technology from conventional economic and engineering perspectives. This has led to an important body of knowledge on the nature of the economic and engineering aspects of managing mini-grids. Socio-cultural and political aspects of the energy access problematic have, however, been largely ignored, as canvassed in sections 2.1 and 2.2. This failure to attend to socio-cultural considerations represents a fundamental gap in research on sustainable mini-grid management in particular and sustainable energy access in general. This thesis therefore aims to contribute to a small, emerging body of recent contributions to the sustainable energy access literature, which has begun to foreground socio-cultural considerations, as noted in section 2.3. The key contribution to this recent socio-cultural turn in the emerging literature is to foreground the core role that institutional (understood, as defined above, as rules and norms acted upon by local specialized organisational structures) considerations play in determining critical aspects of both the social and economic operational sustainability of mini-grid management. This includes, for example, how electricity is allocated among users (e.g. avoiding capture of benefits by the more powerful people in the community hierarchies or free-riding); how individuals are prevented from overloading (and thus bringing down) the grid at different times of day (e.g. early morning or evening peak times) and different times of year when the demand for electricity changes (e.g. high demand at harvest time when

disposable household income increases); how revenues are collected; and how maintenance of the grid is managed and funded. This explicit focus on local institutions for boundaried resource management represents a novel aspect of socio-cultural considerations in the literature and thus requires the application of theoretical frameworks that have not yet been comprehensively studied in the context of rural mini-grids.

As elaborated in sections 2.5 to 2.8, there are two fields of academic literature in particular that have foregrounded the role of institutions. Property rights theory provides one of those frameworks, which can be used for the study of institutions, where property rights are understood to be ‘an instrument of society and derive their significance from the fact that they help a man form those expectations which he can reasonably hold in his dealings with others’ (Demsetz, 1967, p. 347). This definition closely aligns with the definition of institutions for the purposes of this thesis, as introduced above. Theories of collective action in the presence of common-pool resources are another area of study that emphasise the role of institutions, as evidenced by the fact that the title of this field’s arguably most seminal and famous work by Elinor Ostrom is *Governing the Commons – The Evolution of Institutions for Collective Action* (Ostrom, 1990). In the past, neither of these theoretical areas have been systematically applied to the context of the operational sustainability of mini-grids in rural areas of the developing world.

Building on the aforementioned emerging socio-cultural literature (for example, Ahlborg and Sjöstedt, 2015; Campbell et al., 2016; Ockwell and Byrne, 2016) this thesis seeks to contribute to the existing literature on pro-poor sustainable energy access, property rights theory and common-pool resource management, especially

focusing on the associated literature on collective action. It aims to achieve this by demonstrating how well-established frameworks from property rights theory and collective action — previously only applied to natural resource management problems as opposed to electricity in a mini-grid — may be refined, revised and combined to assist in analysing the institutional conditions under which long-term operational sustainability of pro-poor rural mini-grids in developing countries can be achieved.

This primary aim leads to the emergence of an overarching research question as well as five sub-questions, which will guide the structure and methodological approach of the thesis. Therefore, the **main research question** asks:

*To what extent can theories of collective action and property rights address challenges affecting the long-term operational sustainability of pro-poor rural mini-grids?*

This research question focuses on the two key guiding concepts of this thesis: (a) the application of theories of collective action and property rights to the novel context of a rural mini-grid and (b) the importance of the concept of operational sustainability as defined above. The following five sub-questions provide a more detailed outline of the analytical approach adopted in this thesis and, therefore, its objective of making an original contribution to knowledge:

- *Sub-Question 1:* What underlying assumptions must be made in order to treat electricity in an isolated rural mini-grid as a common-pool resource?
- *Sub-Question 2:* What are the major operational challenges faced in different types of community-based and private-sector mini-grids in Kenya?



- Sub-Question 3: How does modern demand-side technology, such as prepaid meters and mobile money enabled payment systems, affect the allocation of bundles of property rights in the mini-grid; which operational challenges can thus be overcome and which challenges remain?
- Sub-Question 4: How can the existing theory on enabling conditions for sustainable institutions for common-pool resource management be used to analyse these challenges in mini-grids and develop non-technical institutional responses to them?
- Sub-Question 5: Based on this analysis, what lessons can be learned from community-based and private sector mini-grids in Kenya for the operational sustainability of mini-grids, and how may these two approaches be combined?

The remainder of the thesis is structured as follows: Chapter 2 begins with a review of the existing literature on energy access generally and mini-grids specifically, evidencing the two-dimensional focus of this body of literature on engineering/technology and economics/finance. This leads to the introduction and further development of the theoretical frameworks upon which this thesis is founded, including a more comprehensive introduction to the potential relevance of collective action for common-pool resource management and property rights theory. Chapter 3 outlines the methodology, placing particular emphasis on the description of the three case studies as well as the expert interview process. Chapter 4 analyses the first part of the empirical data, based on the application of property rights theory. In chapter 5, theories of collective action are used to structure the analysis of the second part of the empirical data, which then leads to the discussion in chapter 6. Chapter 6 combines the empirical findings from chapters 4 and 5 in order to propose an innovative institutional

arrangement for mini-grid management as well as a number of original contributions to theory. Chapter 7 concludes and articulates the scope of future research.

## **Chapter 2 - Literature Review and Theory Development**

This chapter begins by providing an overview of the literature on rural electrification in general and the sustainability of mini-grids more specifically, demonstrating and critiquing the two-dimensional focus on technology/engineering and finance/economics of the majority of this literature, as identified by Watson et al. (2012). The focus on these two general topics reflects the fact that in the past, technical and financial challenges, such as an inability to cover operational costs, unsuitable technology or a lack of technological and managerial capabilities, were typically identified as the main reasons for a lack of long-term sustainability, as noted in chapter 1. While there is a recent turn in the literature towards more socio-cultural approaches, this field is still comparatively small and focused on socio-technical frameworks (e.g. Ahlborg and Sjöstedt, 2015; Campbell et al., 2016; Ockwell and Byrne, 2016; Rolffs et al., 2015; Ulsrud et al., 2011, 2015; Winther, 2008). The role of socio-cultural and institutional interventions at the local level in the long-term sustainability of pro-poor mini-grids are shown to be under-researched and it is demonstrated that existing theoretical frameworks commonly used in the study of rural mini-grids are not able to attend to these concerns.

However, there is a large body of literature on the role of local institutions in the management of other boundaried resource systems. This body of literature is mainly concerned with community-based management of common-pool resources, such as pasture for grazing and water for irrigation, and can be drawn upon due to the similarity between the characteristics of electricity in a small and isolated mini-grid and a

common-pool resource. This concept of electricity as a common-pool resource is illustrated using the hydraulic analogy — an educational tool used to teach the basic functionality of electrical circuits at all levels of education.

After demonstrating this similarity, the chapter addresses the widespread belief that a common-pool resource must fall under a common property regime when, in fact, it can be managed under various property rights regimes (Ostrom, 2003). This is followed by a brief introduction to the concept of property rights theory and the concept of bundles of property rights (Schlager and Ostrom, 1992). After discussing the applicability of this concept to the management of water for irrigation, using an example from the literature to demonstrate how this can be done, the analysis then shows how this theoretical framework can be applied to the context of a mini-grid (referring back to the hydraulic analogy) in order to understand the manner in which technology, in the form of modern electricity metering and tariff payment collection technology, affects the allocation of property rights.

The idea of electricity as a common-pool resource is then advanced by introducing the concept of a complex, multiple-use common-pool resource wherein the most important resource management issue is the need to balance multiple interests among different user groups (Steins and Edwards, 1999). This challenge is highly relevant to a mini-grid, in which anchor loads, businesses and households have very different requirements and uses for the limited electrical capacity that is available. It is in this context that the need for more in-depth research into institutional arrangements for long-term operational sustainability becomes particularly relevant.

The study of management institutions in the presence of common-pool resources is the empirical foundation for the development of theories of collective action. After

summarising the key theoretical foundations for collective action, the chapter introduces the central theoretical framework of this thesis: a collection of 33 enabling conditions for collective action drawn from key publications in this field (Agrawal, 2001; Baland and Platteau, 1996; Ostrom, 1990; Wade, 1988).

There is a large body of literature operationalising theories of collective action and the concept of enabling conditions more specifically in the context of the sustainable management of natural resources (fisheries, irrigation, forests, etc.) in order to understand the socio-cultural and institutional arrangements required to facilitate long-term sustainability. However, there is no precedent for a systematic application of this theory to the concept of the management of a mini-grid as a human-made resource system. A search for instances in which electricity has been treated as a common-pool resource in order to analyse the long-term sustainability of mini-grids revealed only three instances (one working paper and two doctoral theses). However, a review of these cases demonstrates that their treatment of the concept is limited, and there remains scope for a much more in-depth and systematic application of this theory to the context of institutions for mini-grid management.

In order to address this gap in the theory, the chapter then takes the first original analytical step of this thesis by refining the framework of enabling conditions for collective action for this novel application. This is achieved by determining the relevance and applicability of each enabling condition to the specific context of socio-cultural, institutional interventions to operational challenges in pro-poor mini-grids. The theory of bundles of property rights and the refined framework on enabling conditions for collective action form the basis for developing the methodology in chapter 3 and structuring the presentation of the empirical findings in chapters 4 and 5.

## ***2.1 Key Concepts from the Literature on Rural Electrification in Developing Countries***

The academic literature on rural electrification in developing countries is, of course, too voluminous to review in its entirety in this chapter. Rather than claiming completeness and replicating the considerable work already done in systematic reviews of rural electrification literature such as Watson et al. (2012), this section illustrates some of the commonly used conceptual approaches using recent publications as examples. In general, there are four groups of factors affecting the long-term sustainability of rural electrification efforts as identified by Watson et al. (2012): financing and economics; technical and engineering; political and institutional; and cultural and social. In particular, the technical and financial factors are very well researched using a number of different conceptual approaches. The most commonly used theoretical approaches employed in this literature are reviewed and demonstrate that these concepts are not well-suited to analyse institutional arrangements to overcome operational challenges, which is the focus of this thesis. It should also be noted that the institutions referred to by Watson et al. are political or civil-society institutions at the national or international level, where institutions are understood to be specialised organisations or laws, policies and regulations. This concept of institutions is shared by most of the literature on rural electrification. This is a slightly broader definition of institutions or institutional arrangements than the one adopted in this thesis, which focuses specifically on the norms and rules of the game for the local management of a clearly boundaried resource system.

### *2.1.1 Insights from Finance and Economics*

In the literature related to the financial or economic considerations involved in rural electrification efforts, three key concepts stand out as being frequently studied: least-cost or cost-benefit analysis for economically focused studies; willingness and ability to pay for financial feasibility analysis of rural electrification efforts; and the role of financing mechanisms in making rural electrification projects financially viable. Levin and Thomas (2014) provide a useful example of the kind of study that relies heavily on least-cost and cost-benefit analysis. After determining the conditions under which SHSs represent the least-cost approach for providing rural electricity access, i.e. areas with low consumption per end user and high costs of grid connection, they then determine what types of financing mechanisms (loan, rental or subsidy) can be employed to maximise the benefit to the rural customer at the lowest cost under various different circumstances. While such an analysis is an important tool for policy-makers and practitioners alike, it does not lend itself to an application beyond the consideration of purely financial factors. Other authors have taken similar approaches, albeit some with a greater focus on least-cost (Nerini et al., 2015, 2016) and some with an emphasis on cost-benefit analysis (Anderson et al., 2012; Lee et al., 2014). There is also a body of literature specifically concerned with cost-benefit analysis in the context of rural mini-grids, which is reviewed separately in section 2.2.1.

Willingness and ability to pay are other important factors in the long-term financial sustainability of any rural electrification effort, regardless of the specific technology being used. Abdullah and Jeanty (2009, 2011) use a survey-based methodology in order to reveal the willingness of households in rural Kenya to pay for electricity provided by

a SHS compared with electricity provided by a national grid and find that, in general, their willingness to pay (WTP) is higher for grid electricity. One important type of WTP study analyses the current expenditure of households on traditional energy sources, such as biomass or kerosene, in order to estimate their revealed WTP for modern energy services, in particular electricity. Bacon et al. (2010) provide a particularly thorough example of this type of study covering nine countries in Asia and Africa. Combining a study of WTP with the type of least-cost analysis previously discussed can also be used to estimate the demand for electricity from different energy sources and at different price points (Alfaro and Miller, 2014). Without a doubt, WTP is thus a critical, well-studied and well-understood factor to consider in rural electrification projects, not only for use in financial planning but also because it can be used to determine end users' preferences for different sources of energy and electricity, as in the case of large revealed preferences studies such as Bacon et al. (2010) or comparative studies such as Abdulla and Jeanty (2011).

As has already been alluded to in relation to the work of Levin and Thomas (2014), there are a variety of different financing mechanisms that may be employed to support the financial viability of rural electrification efforts and make them more affordable to relatively poor rural populations, ranging from donations and subsidies to grants and partnerships, as well as fee-for-service, loan or leasing models and tax reductions. Bhattacharyya (2013) provides a useful overview of these financing mechanisms and emphasises the importance of micro credits, particularly for financing at the end-user level, a conclusion that is shared by UNDP (2011). The necessity of focusing on the demand side of rural electrification is also identified by Monroy and Hernandez (2005) based on an analysis of 185 questionnaire responses from international experts on rural electrification. They found that almost 60% of respondents identified a demand-side



focus as a main parameter influencing the sustainability of electrification projects. They therefore conclude, among other things, that micro-financing and the active support and development of productive uses for electricity are the two factors with the biggest influence on long-term financial sustainability. Nevertheless, the role of other financial mechanisms should not be discounted, based on the studies by Glemarec (2012) and Gujba et al. (2012), which emphasise the importance of public finance in supporting and leveraging private financing of rural electrification in developing countries. Low carbon funding mechanisms and renewable energy funds are identified as important funding sources alongside energy sector subsidy reforms. Finally, Zerriffi (2011) provides an example of a study focused in particular on financing mechanisms and the role of regulation and their effects on both the supply and demand side. He studies producer- and consumer-side financing solutions and concludes that subsidy and regulatory reforms are needed in conjunction with a greater facilitation of financing mechanisms for energy access projects, in order to enable scalable business models which are financially sustainable for the producer and affordable for the consumer.

This overview is by no means exhaustive and cannot cover the entire body of literature using financial and economic theoretical perspectives to study rural electrification options in developing countries. However, it serves to illustrate the types of analyses that a financial or economic focus enables. While such a focus covers important challenges around the financial viability of different electrification approaches and their affordability to the (often very poor) end users, there is less concern for operational challenges unrelated to the economics of the particular approach. The body of literature concerned with technological/engineering approaches addresses some of these other operational challenges, but also largely excludes the role

of institutions and lacks theoretical approaches to attend to them, as the following section shows.

### *2.1.2 Insights from Technology and Engineering*

Theoretical approaches focused on technological or engineering perspectives represent the second dimension of the largely two-dimensional literature on rural electrification. These studies often follow a top-down and prescriptive approach to arrive at recommendations for different technical solutions to the challenges faced in rural electrification in developing countries. Again, there are three thematic groups in particular that emerge: technology selection to determine the most suitable technical configurations for particular environments; technology comparison and the review of different technologies and their advantages and disadvantages; and approaches based on the concept of the energy ladder (albeit often critical) and energy transitions.<sup>8</sup>

Technology selection using a methodology of indexing different alternatives is one of the conceptual approaches commonly found in the literature. Barry et al. (2011), using eight case studies in Malawi, Rwanda and Tanzania, develop and verify thirteen factors that must be considered for sustainable, renewable energy technology selection in Africa. These factors range from ease of maintenance to site selection, government support and financial capacity. This demonstrates that the technical factors involved in rural off-grid electrification exceed the mere selection of suitable technologies and also

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<sup>8</sup> Energy transitions are concerned with the transition from one source of energy (e.g. firewood) to another (e.g. electricity). This is a separate area of study from the socio-technical transitions literature that will be reviewed below.

include the technological capability required to operate and manage them within a certain regulatory, environmental and economic context. A similar concept is the energy technology sustainability index (ETSI) as developed by Brown and Sovacool (2007), which Mainali and Silveira (2015) apply to the context of rural electrification to find that more mature technologies such as micro-hydro and biogas have a higher ESTI than wind and solar PV in the context of rural India. While these approaches thus cover a broad set of factors which are relevant for appropriate technology selection, they all begin from the perspective that selecting the right technology is the deciding factor in determining the long-term sustainability of a particular rural electrification approach, thereby discounting the importance of socio-cultural practices and institutional arrangements.

Rather than selecting a particular technology based on a pre-defined set of criteria, it is also common practice in the academic literature to determine the applicability of a particular technology to a specific context or compare the suitability of a pair of technologies. Azimoh et al. (2016), for example, compare SHSs with mini-grids for rural electrification in two villages in South Africa and arrive at the conclusion that, due to their ability to support productive uses, mini-grids are the preferable option, given the availability of suitable renewable energy sources. However, they do not speak to the significant challenges involved in operating such a mini-grid in a remote and rural place, which frequently arise, as is shown in a separate review of the literature on mini-grids for rural electrification in the following sections. Other examples of such comparative studies include Kishore et al. (2013) and Narula et al. (2012). Kaundinya et al. (2009) provide a comprehensive review of literature comparing stand-alone off-grid electrification with grid extension. A slightly different approach is taken by Sebitosi et al. (2006) who, instead of recommending a technology for rural electrification, look at

existing rural electrification efforts in Kenya and recommend how they may be made more technically efficient, again demonstrating the technocratic nature of this particular body of literature. Yadoo and Cruickshank (2012), on the other hand, demonstrate that a study largely focused on comparing two different technological approaches, namely, biomass and micro-hydro powered rural mini-grids in Kenya, can nevertheless be based on an analysis of other dimensions affecting their sustainability, including the role of institutional frameworks. The institutional frameworks they refer to are, however, chiefly at the regional or national level and considered in connection with the regulatory framework, rather than at the level of a clearly defined and bounded resource system — the focus of this thesis.

Instead of technology selection, other authors have also examined technology adoption, often using the concept of the energy ladder. The concept of the energy ladder posits that as household income increases, energy use moves up the ladder from biomass for firewood, being the lowest rung of the ladder, via other more modern sources of energy, such as LPG and kerosene, all the way to electricity, which is the top rung (Hosier and Dowd, 1987). This implies a linear progression from least sophisticated to most sophisticated source of energy, each replacing its predecessor. Generally speaking, the literature using this theoretical concept finds that the adoption of electricity as a source of energy takes time and is more rapid for higher-income households, yet they also find that the concept of the energy ladder is flawed, as electricity does not fully replace traditional sources of energy such as firewood and kerosene even in the highest-income households (Campbell et al., 2003; Hiemstra-van der Horst and Hovorka, 2008; Murphy, 2001). Hence, the concept of energy transition or fuel stacking is now frequently used in the literature instead, which allows for the simultaneous use of various different types of energy sources. Elias and Victor (2005)

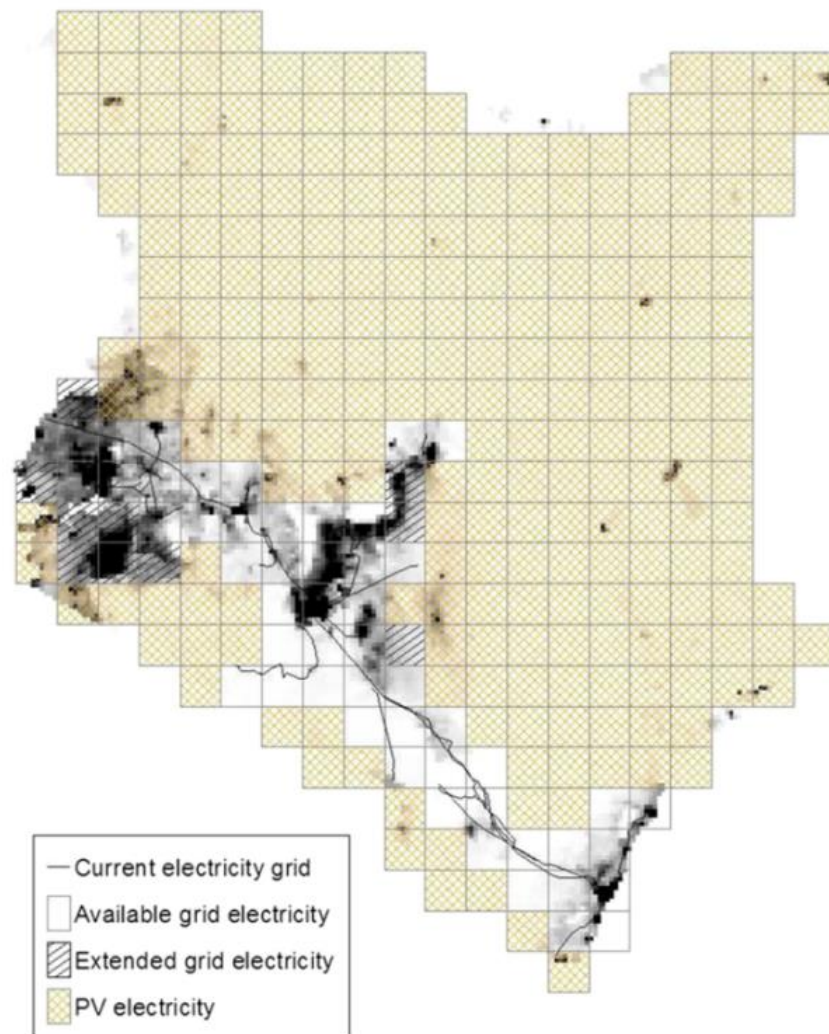
provide a comprehensive overview of the literature on energy transition, both in the context of developed and developing countries, including a review of the causes for and consequences of transitioning away from less efficient, traditional energy sources such as biomass to cleaner (at least at the point of consumption), more modern energy sources such as electricity. They find that while there is a strong correlation between income levels and increased use of modern energy sources, a causal relationship between energy transition and economic development is difficult to establish.

Two additional conceptual approaches are commonly found within the literature, which, while heavily concerned with technology selection, also take other factors into consideration. Nevertheless, they may usefully be reviewed in this section. Bazilian et al. (2012) develop a set of best practice principles for rural electrification from a set of nine case studies in developing countries. Similarly, Terrado et al. (2008) develop a set of best practice recommendations. Both of these publications are examples of a wider body of best practice literature. They develop recommendations that go beyond the selection of technology or the economics of a particular approach, including the role of regulations, the political environment, and, especially in the case of Terrado et al., the importance of sustainable institutions at the community level. However, they provide little guidance as to the design and implementation of such institutions and explicitly identify the need for more research in this area, a call to which this thesis responds.

The other remaining conceptual approach is more technocratic and prescriptive in nature. This approach involves spatial planning or mapping techniques, which model the costs of different electrification options, typically grid extension, mini-grids and SHSs, in order to arrive at the least-cost technologies for a particular geographic context (Deichmann et al., 2011; Ohiare, 2015; Szabó et al., 2011). Specific to the context of

Kenya, Zeyringer et al. (2015, p. 84), using a spatial planning model, find that grid extension is only viable in areas which are already close to the grid and that off-grid solar PV is a viable electrification technology for approximately 17% of the Kenyan population, supporting the relevance of this thesis' focus on mini-grids using solar PV. Figure 2.1 presents the map showing the output of their optimisation model comparing grid extension to solar PV for electrification in Kenya. Thus, the next logical step in this chapter is to review the literature on mini-grids in particular, rather than rural electrification in general, although it should be noted that, predictably, there is considerable overlap between the two bodies of literature.

**Figure 2.1** – Least-Cost Electricity Supply in Kenya



Source: Zeyringer et al. (2015, p.83)

## ***2.2 Key Concepts from the Literature on Rural Mini-Grids in Developing Countries***

Being a subset of the rural electrification literature more broadly, the literature on rural mini-grids in developing countries exhibits a similar two-dimensional focus, as the following two sections demonstrate. Again, as noted in the previous section, this review

cannot claim to exhaustively discuss the entirety of this body of literature. Rather, it provides a mapping overview of recent works to identify the main foci and thus begins to formulate the gap in the academic literature. This thesis aims to address the gap by developing from and augmenting the extensive existing body of knowledge.

### *2.2.1 More Insights from Finance and Economics – Mini-Grid Business Models*

Given the fact that the literature on rural mini-grids is a subset of the rural electrification literature, there exists considerable overlap between the two, as evidenced by the fact that a number of the aforementioned studies concern themselves with mini-grids as well as other electrification options. Lee et al. (2014) have been mentioned previously as an example of a study using a cost-benefit approach. They develop an energy balance algorithm in order to develop a mini-grid sizing strategy, which balances the costs of increasing the mini-grid's generating capacity with the benefits that it provides in the form of greater reliability. Their study is based on the case of a mini-grid in Mali, which frequently experiences overloading of the system due to demand patterns that do not match the supply characteristics of a solar PV mini-grid. Their model suggests an update to the sizing of the grid, which balances the benefits of fewer periods of excess demand with the costs of a system upgrade. However, they do not pursue alternative (i.e. non-technological) ways of rebalancing demand to match supply in order to avoid this 'tragedy of the commons' (the latter is engaged with in more depth further below). Blum et al. (2013) use a similarly cost-focused approach to determine the least-cost electricity generation technology for rural mini-grids in Indonesia, comparing micro-hydro and solar PV to diesel. They conclude that if diesel



subsidies were to be removed, both renewable energy technologies would be cost competitive. While the findings of these studies are important and useful when designing a rural mini-grid, they speak very little to the challenges faced once they are operational. Within the mini-grid literature, however, there is a subset of analyses that is more concerned with these matters, and the business models used to operate the mini-grid in particular.

Knuckles (2016) provides an excellent overview of different business models, comparing 24 cases of mini-grids from developing countries around the world based on factors including: stakeholders in ownership; operation and maintenance of the mini-grid; how tariffs are collected and consumption is measured; what types of end users have been connected; and whether financing exists for end users. He concludes that decisions made across these dimensions are important influences on the sustainability of a mini-grid, defending this statement with 11 observations informed by the empirical data. However, his analysis does not include an in-depth review of different institutional models for ownership, operation and maintenance, only differentiating among community, mini-grid developer or third party roles. Krithika and Palit (2011) provide a similar review based on case studies of different mini-grid business models, comparing cooperative, franchise, fee-for-service, community-based and private sector models. They find that cost recovery is one of the most critical factors in ensuring long-term sustainability regardless of the particular business model, as well as the participation of the community in the institutions operating and managing the mini-grid. This is an important finding, which is echoed by this thesis. However, Krithika and Palit do not provide an explanation rooted in theory for the importance of community participation; they merely state that the mini-grid business models that include more formal structures for community participation have been more sustainable. This therefore indicates the

need for a more in-depth analysis of these institutional arrangements that is more solidly rooted in theory.

Rather than comparing different business models, other studies have focused on the analysis of specific organisational structures, in particular, private sector and community-based. Pigaht and van der Plas (2009) study four private sector micro-hydro mini-grids in Rwanda, showing the importance of private sector approaches for long-term financial sustainability and indicating that local participation is a critical factor. However, their private sector focus means that they do not consider how the local community, in addition to local financing firms and mini-grid developers, could be included in their concept of local participation. Other studies that focused on private sector business models analysed the risk–return profile for private sector investment into rural mini-grids (Schmidt et al., 2013) and the importance of different financing mechanisms, ranging from subsidies to tax incentives, climate finance and preferential lending (Williams et al., 2015). While Williams et al. (2015) discuss different institutional models and the importance of effective institutions, they only refer to institutions at the level of the government or regulator, rather than local management institutions. These local management institutions are more commonly discussed in the literature on community-based mini-grids.

Ferrer-Martí et al. (2012) analyse three community-based mini-grids in rural Peru along technical aspects, socio-economic aspects and the sustainability of the management model. While most of their work focuses on the technical design of the mini-grids, as well as their socio-economic impacts on indicators related to health and education, they also consider the participation of community members in management activities an important factor. However, much like the other literature previously

discussed, they only reference the importance of community involvement and present a quantitative measure in terms of a percentage of families that have partaken in meetings related to management activities in the past. But the authors do not provide a thorough theoretical perspective as to why this level of participation is desirable or which institutional arrangements exist to achieve it. Also building on the literature on rural energy delivery models, Yadoo and Cruickshank (2010) assess the usefulness of cooperatives as institutional models for the ownership and operation of rural mini-grids, using examples from Nepal and Bangladesh. They find that cooperatives ‘can represent a highly favourable delivery mechanism for rural electrification in developing countries’ (Yadoo and Cruickshank, 2010, p. 2946), a finding supported by other studies as well (Iliskog et al., 2005; NRECA, 2009). Yet again, these authors do not analyse this issue using a theoretical and conceptual approach that is particularly well-suited to the study of institutional arrangements, but rather consider cooperatives merely as another energy delivery model alongside private sector investment or public provision of electricity.

Finally, there is a small body of literature concerned with demand-side management technologies and different ways of metering and paying for electricity, in particular the use of prepaid (also known as pay-as-you-go) electricity meters, which falls between the literature on business models and technology and engineering. Pueyo (2013) provides a useful overview of pay-as-you-go technologies, the real-time monitoring opportunities they provide and the business models that are thereby supported. She finds, however, that the evidence of their effectiveness is largely anecdotal and that there is scope for more research into the role these technologies can play in rural electrification. Within this field there are also some studies concerned with the advantages and disadvantages of different technologies for demand-side management (Boait, 2014; Harper, 2013),

which exhibit a much stronger focus on the technologies themselves, rather than their impact on operations. Rolffs et al. (2015) also analyse the role of pay-as-you-go finance models in energy access, albeit it using a socio-technical systems approach rather than focusing on technology or finance. Their work is covered further in section 2.3, when discussing socio-cultural approaches.

### *2.2.2 More Insights from Technology and Engineering – Technologies for Mini-Grids*

Most of the technologically oriented publications concerned with rural mini-grids in developing countries fall under the category of technology comparisons or reviews as presented in section 2.1.2. Dimitriou et al. (2014) is an example of a comprehensive comparison of technologies for mini-grids ranging from solar PV to wind, micro-hydro and biomass, comparing their advantages and disadvantages. Wetz (2012) provides a similar overview of technological options for mini-grids. Many publications, however, select a particular technology for their analysis and typically study either micro-hydro, or solar PV and wind hybrid systems.

Technically minded studies of micro-hydro mini-grids and case studies of their operation, even in the Kenyan context, date back a number of years (e.g. Maher et al., 2003) and the technical difficulties in operating them are therefore well-researched. Kusakana (2014) provides a particularly thorough analysis of technical innovations that may be implemented in order to improve the viability of micro-hydro mini-grids. While other authors have mentioned the importance of community involvement and capacity building at the local level (Murni et al., 2012), they do not explicitly analyse these requirements from an institutional perspective.

A similar pattern can be found in the literature dealing with solar PV or PV/wind hybrid technologies, a particularly thoroughly studied set of technologies. While too numerous to review in its entirety, this body of literature includes studies focused on the risks associated with operating PV hybrid mini-grids (Hazelton et al., 2014); statistical analyses of the operation and load versus electricity production patterns in PV hybrid mini-grids (Louie, 2016; Muñoz et al., 2007); detailed analyses of the benefits of hybridisation compared to relying on just one renewable source of electricity (Mohammed et al., 2014; Neves et al., 2014); as well as studies which determine the most suitable electricity generation technologies for rural mini-grids based on geographic and climatic data, using similar spatial analysis as introduced above (Ranaboldo et al., 2015). Again, while some of these studies (e.g. Hazelton et al., 2014) mention the importance of community participation, they do not offer a theoretical focus on this aspect, but rather consider it a finding that emerges from the study of past cases of mini-grids.

Despite this two-dimensional focus on finance and technology found in the literature on rural electrification more generally, and the mini-grid literature specifically, there has been a turn in the academic literature in recent years towards more socio-culturally focused studies. A number of publications in this area of study use conceptual frameworks concerned with socio-technical transitions to study the long-term sustainability of rural electrification efforts. While some of these socio-technical transition inspired frameworks also study the role of institutions, such as strategic niche management as employed by Ockwell and Byrne (2016) for example, their definition of institutions is slightly broader in scope than the one taken in this thesis. They view institutions as “[...] laws, regulations and policies as well as practices, norms and conventions regarding a particular socio-technical system” (Byrne, 2011, p. 19),

whereas this thesis focuses more specifically on local specialised organisational structures for the management of a boundaried resource system. These socio-culturally focused approaches are reviewed in-depth in the following section and are used to identify the specific gap in current knowledge that this thesis aims to address.

### ***2.3 Socio-cultural Approaches and the Remaining Gaps in the Literature***

In recent years, a small body of literature has begun to foreground socio-cultural considerations, in most cases by operationalising socio-technical approaches. This thesis aims to contribute to this body of socio-culturally focused literature by explicitly analysing the role of local institutions for the management of a boundaried resource system and, for the first time, operationalising and adapting concepts concerned with institutional arrangements for the management of natural resources to the context of rural mini-grids in developing countries. Before introducing and developing this theoretical innovation, however, a review of the existing socio-cultural rural electrification literature is required in order to define the gap in the literature.

One of the earliest examples of a socio-cultural analysis of rural electrification can be found in Winther (2008), who provides an anthropological account of an in-depth ethnographic study of the socio-cultural impacts of rural electrification, using a village on Zanzibar as a case study. While a study of institutional arrangements appears in the form of a discussion of the electricity company in the village, these arrangements do not form the cornerstone of this analysis. Rather, Winther emphasises the difficulty in

predicting the types of social and cultural changes that the introduction of electricity will introduce, and the role of community participation in the success of the electrification project. This focus on the social change brought on by technology has continued to inform a number of other studies, which have applied socio-technical approaches to the study of rural electrification, inspired by the largely Euro-centric socio-technical transitions literature.

Ulsrud et al. (2011) is one of the earlier examples of this body of literature, using a socio-technical perspective to study solar mini-grids in rural India. The authors also find the existing rural electrification literature to be two-dimensional, being centred on economic and technical performance, and hence identify the need for more social science research. They view the mini-grid as a socio-technical system, which, in addition to the technical infrastructure, includes the end users, owners, operators and the local organisations involved in mini-grid operations. Through this lens, they identify five key issues in mini-grid operation: growing demand quickly exceeds supply; operators are a key link in mini-grid sustainability; it may be unclear who is responsible for which activities in mini-grid management; it is challenging to set tariffs that are affordable and economically sustainable; and batteries are a weak link. In particular, the problems of demand growth and responsibility for mini-grid operation are relevant to the focus of this thesis, as becomes evident in the empirical chapters. While Ulsrud et al. identify this challenge, they do not discuss how institutional arrangements to manage and avoid overloading of the system could be developed, thereby leaving an opportunity to augment their findings.

In a later paper, the same authors use a very similar socio-technical perspective to analyse the case of a community-based energy centre in Kenya, which is a central hub

for charging appliances without power lines connecting to other end users (Ulsrud et al., 2015). In this study, they develop and operationalise a five-step analytical framework for village-level energy access, which ranges from the framework conditions (policies, laws, regulations, etc.) to local conditions (geography, demography, etc.) to the quality and reliability of the service provided by the energy centre. However, this framework does not explicitly study the institutions involved in the management and operation of the system either, but rather focuses on the energy centre as a catalyst for socio-technical change.

Müggenburg et al. (2012) also use a socio-technical approach, albeit in a very different context and with a different goal. They study the acceptance of pico PV systems, i.e. solar lanterns, in rural Ethiopia in terms of their technical functioning, as well as the manner in which they interact with the needs and behavioural patterns of their users. Their application of a socio-technical approach is, however, technology-centric in nature in that the explicit goal of the analysis is to develop pico PV systems that are better adapted to the local context and hence more acceptable to their users.

In another example of a socio-technical approach used to study rural electrification, Sovacool (2011) studies barriers which impeded the use of micro-hydro mini-grids for rural electrification in Nepal. In addition to technical, financial and regulatory factors, he finds that there also are socio-cultural barriers: local opposition, particularly against the building of dams and sharing of water resources; unfamiliarity and unrealistic expectations; the presence of social norms against paying for electricity; and the aid dependency of Nepal. While a socio-technical systems approach is useful in identifying these barriers, it does not lend itself to the development of potential institutional



interventions which could overcome some of them. Consequently, Sovacool does not suggest how the development of such solutions could be advanced.

Also operationalising a socio-technical transitions perspective, Ahlborg and Sjöstedt (2015) study the process of economic change in a Tanzanian village after the implementation of a micro-hydro mini-grid by a donor agency, placing particular emphasis on the role of community ownership and collaboration. The authors provide a detailed description of the relationship between the local community and the community-based local utility owning and operating the mini-grid. They show that the relationship can be complicated and that rules, even though they apply equally to all, are not necessarily perceived as fair by all community members. Even though the analysis identifies this local institution as a potential arena for collaboration, the theoretical framing that was used does not lend itself to an analysis of the emergence of institutional arrangements for this type of collaboration, further demonstrating the existence of a gap in the literature around institutions for the sustainable management of rural mini-grids.

In an earlier paper, Ahlborg and Hammar (2014) use a socio-cultural approach to analyse drivers and barriers to rural electrification in Tanzania and Mozambique, comparing grid extension, off-grid and different renewable energy technologies from various perspectives: regulatory, technical, financial, socio-cultural and institutional (understood as policies, laws and regulations at the national level rather than local rules and norms). They find that one of the key barriers to off-grid electrification is ensuring reliability in operation and maintenance, and suggest that income-generating productive uses can improve local management practices.

There is a number of other publications that have taken socio-technical approaches to analysing rural electrification efforts, but none of them explicitly addresses an institutional perspective in the same way and at the same level as the common-pool resource management literature with which this thesis engages. Rolffs et al. (2015) critique the two-dimensional nature of literature on rural electrification so far, then use a socio-technical transitions perspective to analyse the importance of socio-cultural factors in the adoption of pay-as-you-go financing for SHSs. They find that the close alignment of this approach with existing socio-cultural practices of poor women and men in paying for and consuming energy services is an important contributor to its success.

Ockwell and Byrne (2016) also adopt a socio-technical transitions based approach, but extend this perspective by combining it with theoretical insights from the innovation systems literature. They show how an approach based on building a ‘socio-technical innovation system’ can be operationalised in practice to inform ambitious policy programmes such as the United Nation’s Sustainable Energy for All initiative. In particular, the authors use the concept of strategic niche management to study the emergence of the Kenyan solar PV market in order to derive policy conclusions for the deployment of other pro-poor, green technologies. While strategic niche management (and thus Ockwell and Byrne’s analysis) is also concerned with institutions via niche management’s focus on the notion of ‘institutionalisation’ as a core analytical category, it considers them at a different level than the common-pool resource literature. It analyses how rules, norms and conventions that emerge from the development of a socio-technical niche can be widely adopted at the regional or national level into laws, policies and regulations, contributing to niche practices influencing dominant socio-technical regimes. These processes of institutionalisation are just one of a number of

factors that must be analysed. Ockwell and Byrne provide the examples of import taxes and quality standards as the types of institutions that might emerge. This illustrates the somewhat narrower perspective taken in this thesis, which concerns itself with rules, norms and practices exclusively at the local community level in relation to how mini-grids are managed and how they can be operationalised as specialised organisational structures at this level.

Closely linked to the focus on the community level, Campbell et al. (2016) take an explicitly socio-cultural perspective to study the concept of community in the context of rural electrification, using examples from Nicaragua and Nepal. They recast a rural electrification project as a social energy system within a community of interest, thereby taking into consideration ‘existing skill sets, patterns of household interaction and community-level power relations’ (p. 136). They find that this approach provides valuable insights into the social context of energy beyond the mere technological construct of an energy system. By calling for a deeper study of ways in which collaboration within a social energy system can lead to better decision-making, they implicitly call for the type of study presented in this thesis, which focuses specifically on these issues.

This review demonstrates that there has been a recent ‘socio-cultural turn’ in the literature on rural electrification. This development and the resulting body of literature has been a key inspiration for the focus on socio-cultural issues in this thesis, rather than attempting to expand the already large body of literature using technical/engineering or financial/economic approaches. Yet, while many of these recent socio-culturally focussed studies identify institutions at the local community level as an important factor in the long-term sustainability of pro-poor rural electrification in general, and mini-grids

specifically, the theoretical frameworks and conceptual approaches commonly found in the literature are not well-suited to analyse institutions as defined in this thesis. Even though some of the socio-technical approaches used in this literature, which formed a starting point for the theory development of this thesis, such as, for example, strategic niche management considered above, also concern themselves with institutions at the local level, they are not suitable for the analysis of the interaction between: institutions as rules and norms acted upon by specialised organisational structures; a clearly defined and bounded resource system; and the variety of possible end uses and user groups.

This is the gap in current knowledge which this thesis aims to address by drawing on two theoretical frameworks, which have not yet been used systematically in the context of mini-grid management. Firstly, collective action theory provides a framework developed in the context of other instances of local resource management (and particularly common-pool resources), which have been studied through an institutional lens. Secondly, property rights theory provides a theoretical basis for understanding and analysing the relationship between user groups and the resource system. The following sections introduce these theoretical frameworks and explain how they can be applied to the context of the management of rural mini-grids in developing countries.

## ***2.4 How a Common-Pool Resource Perspective Can Contribute to Theoretical Knowledge***

This thesis draws upon two particular areas of work in order to introduce theoretical frameworks to the literature on mini-grids for rural electrification that are suitable for the analysis of institutions, where institutions are defined not specifically as organisations, but rather as norms and ‘rules of the game’ (North, 1990). These institutions are important because they can potentially provide alternative non-technological solutions to such problems as the mismatch between demand and supply patterns (and the resulting ‘tragedy of the commons’) described by Lee et al. (2014). The two relevant areas of study are property rights theory, to analyse the institutional impact of the introduction of certain technologies (i.e. prepaid meters and mobile-enabled cashless payment, which are explored in more depth in chapter 4), and theories of collective action, in order to identify specific factors and conditions that affect the emergence of institutions. Theories of collective action are most commonly associated with the study of long-lasting institutions for the management of common-pool resources. In particular, Ostrom (1990) laid the foundation for her work in showing how common-pool resources can successfully be managed by the people who use them — work that garnered the Nobel Memorial Prize in Economic Sciences in 2009.

In order to describe how these theoretical frameworks may be applied and adapted to the context of rural mini-grids so as to address the gap in the literature identified

above, understanding the relevance of a common-pool resource perspective is the first critical step.

A common-pool resource is defined as being rivalrous (or exhibiting high subtractability), meaning that a resource unit consumed by one resource user can no longer be used by another and that exclusion from access to the resource is difficult (Hess and Ostrom, 2003). This is in contrast to a public good, for example, which is non-rivalrous (e.g. street lighting). These characteristics of a common-pool resource create a number of potential challenges:

*‘Thus common-pool resources are subject to the problems of congestion, overuse, pollution, and potential destruction unless harvesting or use limits are devised and enforced.’* (Hess and Ostrom, 2003, p. 120)

It is important to note that a common-pool resource does not imply open access to all — exclusion is difficult but not impossible. Rather, a common-pool resource may still be associated with a variety of property rights regimes (Ostrom, 2003). This issue is examined in more depth in section 2.5. Typical examples of common-pool resources are fishing grounds, grazing pastures or water for irrigation. In particular, water for irrigation has been studied extensively as a common-pool resource and established as a case in which collective action can be a successful way of managing the resource (Araral, 2009; Bravo and Marelli, 2008; Ostrom, 1990, 1992; Sarker and Itoh, 2001; Theesfeld, 2004). An irrigation example is discussed in more detail in section 2.7 in order to demonstrate how theories of collective action can be applied to the study of long-lasting management institutions in the presence of a common-pool resource. At present, however, it is sufficient to note that water for irrigation is a prototypical common-pool resource and that the operational challenges in its management and the institutions involved in this management have been studied in depth. This is important

because it may be argued that an irrigation system shares a number of characteristics with electricity in a closed system, e.g. a mini-grid.

The analogy between a system of water pipes or canals, such as those used in an irrigation system, and a closed electrical circuit is often used in educational material to help explain the way electricity behaves, since water flowing through pipes can be seen as analogous to electrons flowing through a conductor — the ‘hydraulic analogy’ (Greenslade, 2003). Hence, all the basic characteristics of an electrical circuit can be described using hydraulic analogues. Resistance in the electrical circuit is analogous to friction in the pipes, voltage equates with pressure and current with volume flow.

As a result, a mini-grid that is independent of the grid shares a number of basic characteristics with an irrigation system. First of all, the total amount of water available in an irrigation system depends on the storage capacity of the water reservoir ( $\text{m}^3$ ) and the recharge rate of the reservoir ( $\text{m}^3/\text{s}$ ), whereas the total amount of electricity (or rather electric energy) available in a mini-grid depends on the storage capacity of batteries (kilowatt-hours or kWh), if any, and the power of the generator (kilowatts or kW). A mini-grid with no battery storage would be analogous to an irrigation system with no reservoir, which could be described as a ‘run-of-the-river’ irrigation system. Regardless, the two factors of storage capacity and recharging capacity determine the maximum discharge rate in cubic meters of water per second or joules of electric energy per second.<sup>9</sup>

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<sup>9</sup> One joule per second is one watt (W) and 1000W is 1kW

Given these similarities of resource system characteristics, a mini-grid and an irrigation system, in principle, have certain operational challenges in common. If a farmer who is upstream uses all the water in the irrigation canal, there is no water left for the remaining farmers further downstream. Similarly, if one electricity user with an open-access electricity connection continues to add powerful loads she will eventually demand more than the total electrical capacity available in the system, thereby overloading it, resulting in voltage drops and potentially causing a blackout. In both circumstances, action by one person leads to reduced performance and potential damage to the system (e.g. droughts and blackouts) affecting all users – leading to a potential ‘tragedy of the commons’ (Hardin, 1968), which is discussed in more detail in section 2.5. However, upstream and downstream have no meaning in the case of an electrical circuit because all who are connected have equal access to it. A mini-grid is hence a human-made resource system sharing a number of characteristics with an irrigation system. Therefore, the electricity it transmits (which can generally be conceived of as rivalrous but non-exclusive) is arguably a type of common-pool resource. It is important to point out that the non-exclusivity of electricity depends on the mini-grid and only those consumers connected to it constituting the unit of analysis, without any technical limitations on consumption. This issue is explored further in section 2.5, which considers how different technologies for limiting consumption impact bundles of property rights within a mini-grid and hence impact the nature of the common-pool resource.

It should be noted, however, that there are marked differences between irrigation systems and mini-grids. Most importantly, financial sustainability is usually much less prominent an issue in an irrigation system than in a mini-grid, as the actual common-pool resource — water — has no cost of generation (disregarding the small potential



cost of pumping). Even though community irrigation organisations often charge their members small water tariffs to maintain physical infrastructure such as weirs, canals, gates and pipes, they face considerably less severe financial constraints than mini-grids. Furthermore, a mini-grid is much more technically complex, requiring technical knowledge to manage, maintain and operate.

Nevertheless, electricity in a mini-grid shares certain characteristics with a common-pool resource and thus suggests that analysing the operational challenges and institutions involved in managing a mini-grid from a common-pool resource perspective can yield novel insights. In addition, an important characteristic of a common-pool resource is that it may be managed under various different property rights regimes, meaning that private and common property rights can co-exist within the same resource system. This is an important point to re-emphasise. Common-pool resources need not automatically be associated with common property or any other property rights regime, as has also been observed by Ostrom and Hess (2007). This potential multiplicity of property rights regimes makes it necessary and potentially insightful to introduce the first key theoretical concept used in informing the theoretical and hence methodological approach of this thesis.

## ***2.5 Institutions for the Management of a Common-pool Resource***

### ***Part 1 – Property Rights***

Some of the most important foundations of property rights theory have been articulated by Demsetz (1967). He provides a concise categorisation of property rights

into three types: private, communal (synonymous with common) and state property.

While this is a simplistic view, especially considering the more nuanced property rights theories developed several decades later (e.g. Schlager and Ostrom, 1992), it provides the basis upon which later work on property rights theory has been able to build.

Demsetz paints a rather bleak picture for communal property, arguing that ‘communal property results in great externalities’ (Demsetz, 1967, p. 357) and echoing some of the concerns that his contemporary, Garrett Hardin, famously summarised in *The Tragedy of the Commons* (Hardin, 1968). Hardin presents a particularly pessimistic outlook on the potential of sustainably managing common-pool resources without strong external coercion. This is due to the inherent incentive structure in which the most beneficial short-term behaviour for each resource appropriator is to maximise the consumption of the resource, which in turn will invariably lead to its collapse. Or, as Hardin himself put it, ‘Ruin is the destination to which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons’ (Hardin, 1968, p. 1244).

Section 2.7 returns to the tragedy of the commons as it is important in introducing theories of collective action. With Hardin’s view in mind, one of Demsetz’ arguments against the viability of common property compared to private property is the necessity for everyone that is part of the community to reach agreement on any decision concerning the use of the resource under consideration (e.g. land, water, fisheries, etc.). These concerns already point towards the need for collective action and institutional arrangements for collective action in the management of common property resources, the foundations of which have been significantly shaped by Elinor Ostrom’s research on governing the commons (1990), which is treated in more depth in section 2.7. Beyond her contribution to theories of collective action, however, Ostrom has contributed important theoretical analysis to the conceptualisation of property rights as well.

Schlager and Ostrom (1992) introduced the concept of bundles of property rights and how different positions are associated with them within the resource system. In particular, they define five different property rights, divided into operational-level rights and collective choice rights. The operational-level rights are defined as:

- *‘Access: the right to enter a defined physical area and enjoy non-subtractive benefits (e.g. hike, canoe, sit in the sun).’*
- *‘Withdrawal: the right to obtain resource units or products of a resource system (e.g. catch fish, divert water).’*

(Schlager and Ostrom, 1992, p. 250)

The collective choice rights build upon these, and as a result are more powerful because those who hold collective choice rights have the power to define and control operational-level rights:

- *‘Management: the right to regulate internal use patterns and transform the resource by making improvements.’*
- *‘Exclusion: the right to determine who will have an access right, and how that right may be transferred.’*
- *‘Alienation: the right to sell or lease exclusion, management or withdrawal rights.’*

(Schlager and Ostrom, 1992, p. 251)

Based on these property rights, it is possible to define different positions within the resource system, based on the combination of property rights, or bundle, held. Each property right builds upon the previous one in the order presented above. Schlager and Ostrom (1992) developed a matrix of property rights bundles and associated positions

within the resource system, which they later refined as shown in Table 2.1 (Ostrom and Schlager, 1996).

**Table 2.1** - Bundles of Property Rights Associated with Positions in a resource system

	FULL OWNER	PROPRIETOR	AUTHORISED CLAIMANT	AUTHORISED USER	AUTHORISED ENTRANT
ACCESS	X	X	X	X	X
WITHDRAWAL	X	X	X	X	
MANAGEMENT	X	X	X		
EXCLUSION	X	X			
ALIENATION	X				

Source: Ostrom and Schlager (1996, p. 133)

This framework defines five positions within a resource system. An authorised entrant is allowed to access the resource system, e.g. she can enter the pasture for grazing, but is not allowed to use any of the resource. An authorised user can withdraw from the resource, either through a temporary or a permanent withdrawal right, but they cannot devise their own harvesting (or use) rules and schedules. In other words, they have no authority to change operational rules. That right is reserved to authorised claimants, who have the right to devise operational-level rules, but in turn cannot determine who gains access to the resource or alienate, i.e. sell, their right of management. Proprietors, on the other hand, possess the right to determine who gains access to the resource, but again cannot alienate that right. This right of alienation is reserved for the full owner of the resource system.

This classification of property rights can be used to analyse the effect of the introduction of technology on the allocation of property rights in a resource system. Yandle and Morris (2001) illustrate this using the example of measurement of the volume and flow rate of water being used for irrigation. Initially, when the appropriate

technology for accurately measuring volumes and flow rates was not yet available, use rules may have been developed but access and withdrawal rights would in effect be synonymous. With the introduction of simple metering technology, it becomes easier to differentiate between access and withdrawal rights, because it is possible to monitor and control the flow rate to each user. With more sophisticated metering, rights of exclusion and alienation also become more widely available as water usage rights could be transferred and sold on the market.

Considering the hydraulic analogy and the similarities between a mini-grid and an irrigation system described above, there is considerable scope for the application of this logic to the mini-grid context. However, the theory of bundles of property rights and their associated positions has not yet been applied to a mini-grid or, more generally, to an electrical grid. In a mini-grid, like an irrigation system, modern metering technology facilitates and streamlines the collective choice rights of management and exclusion, compared to less advanced technologies such as unmetered open-access connections or current-limited connections. Furthermore, metering systems allow an easy differentiation between access and withdrawal rights, i.e. they facilitate operational-level property rights allocation. For example, an unmetered connection, by definition, grants access and withdrawal rights at the same time, as the only method of removing the withdrawal rights from a connected authorised user is to disconnect her from the grid entirely, removing both property rights at the same time. However, if a smart, possibly prepaid, meter is used to control the authorised user's connection to the mini-grid, potentially using mobile-enabled technologies allowing for remote control of the meter, withdrawal rights can be temporarily revoked to make her an authorised entrant, without physically removing the access right, i.e. the connection to the grid. Such revocation of withdrawal rights can be useful if the authorised user is, for example, in

arrears on her electricity account or has exhausted her prepaid amount. Technologies, therefore, can make it easier for the full owner or proprietor holding the right of exclusion to exercise that right.

Based on these considerations, Table 2.2 represents a conceptual innovation in the application of property rights theory by analysing how technology, in the form of a prepaid meter in this case, can streamline and automate the allocation of property rights bundles in a mini-grid. In addition, modern metering technology facilitates management of the mini-grid as well, as it allows the full owner, proprietor or authorised claimant holding the right of management to control which end user can withdraw how much power during times of excess demand, prioritising, for example, productive uses during the day and household uses such as lighting and entertainment at night. Chapter 4 will analyse in more depth how prepaid meters, as well as other metering technologies, affect the allocation of property rights.

**Table 2.2** - The Role of Prepaid Meters in the Allocation of Property Rights

	FULL OWNER	PROPRIETOR	AUTHORIZED CLAIMANT	AUTHORIZED USER	AUTHORIZED ENTRANT
ACCESS	X	X	X	X	X
WITHDRAWAL	X	X	X	X	
MANAGEMENT	X	X	X		
EXCLUSION	X	X			
ALIENATION	X				

Remote control instead of physical disconnection

Credit on Meter      No Credit on Meter

Source: Author (developed from original framework by Ostrom and Schlager (1996, p. 133))

This role of technology in the allocation of property rights and the execution of different positions within the resource system leads to the insight that, by changing the

nature of property rights bundles, metering and payment collection technologies may be able to overcome some of the key operational challenges in a mini-grid.

These operational challenges naturally must be identified, which is the first empirical step in chapter 4 of this thesis, followed by empirical testing of the application of this theoretical framework. Following the logic of the analogy of a mini-grid and an irrigation system outlined above, the resulting common-pool resource characteristics of electricity in a mini-grid and the potential for a tragedy of the commons to emerge suggests that there are likely to be other operational challenges that technology cannot easily address, however. There is further evidence pointing towards the need for institutional arrangements beyond property rights, because electricity in a mini-grid not only exhibits certain characteristics of a common-pool resource in general, but more specifically, a complex and multiple-use common-pool resource.

## ***2.6 Electricity as a Complex, Multiple-Use Common-pool Resource***

The analogy between water for irrigation and electricity in a mini-grid can be extended even further by introducing the concept of a complex and multiple-use common-pool resource as developed by Steins and Edwards (1999), rather than a simple common-pool resource as defined above. According to their analysis, a complex common-pool resource is characterised as a resource that is used for different purposes by different stakeholder groups. Critically, a complex common-pool resource requires different interests to be balanced among a variety of user groups, and hence requires platforms that can accommodate these different user groups, as Meinzen-Dick and

Bakker (1999) and Meinzen-Dick and Hoek (2001) demonstrate in the case of irrigation.

Meinzen-Dick and Bakker (1999) not only apply the concept of a complex, multiple-use common-pool resource to the case of water for irrigation in Sri Lanka, but also acknowledge the importance of property rights, since allocation changes with increasing scarcity of the resource. They examine the variety of uses for water beyond agriculture, and hence stakeholders involved, in the context of an irrigation system in south-eastern Sri Lanka. After studying the various organisations involved in the institutional environment of the irrigation system and the rights, including property rights, these different groups hold, they introduce uses for water and the associated user groups other than those primarily focused on field crop production, which range from drinking water for livestock to domestic water uses. They find that creating or expanding an existing institutional arrangement whereby representatives of all user groups have a voice in water allocation is a critical requirement in order to manage trade-offs, as well as identify potential complementarities in the management of water as a multiple-use common-pool resource. Meinzen-Dick and Hoek (2001) expand on this concept and further emphasise the importance of analysing the multiple end uses for water beyond irrigation, drawing on empirical data from the aforementioned Sri Lankan as well as an Indian case study. They find that an assessment of the different uses and user groups will lead to improved allocation of water between users; more productive and sustainable uses; improved social sustainability (i.e. the absence of conflict around the resource); and equitability of management practices and outcomes.

This thesis argues and demonstrates empirically that an issue such as balancing interests among different user groups is an operational challenge that is also found in a



rural mini-grid and that, considering the various potential end uses and user groups, creating institutions to overcome this challenge can have similar benefits as those found in the case of water for irrigation. A useful way of categorising these different user groups according to their electricity requirements is the A-B-C model (Rodríguez Gómez, 2013), which defines three user groups. Rodríguez Gómez introduces the A-B-C model as part of an analysis focused on financial modelling for solar PV mini-grids in East Africa with telecom towers as their anchor tenants. Anchors (A) are large entities, often public or commercial, such as hospitals or cell-phone towers that require a reliable supply of electricity 24 hours per day, seven days per week. Businesses (B) form the second group, including mostly small and micro enterprises in rural areas, which require electricity primarily during the day during normal business hours, but also at night in the case of bars or video halls, for example. Finally, the community (C), i.e. households, require electricity largely at night for lighting, as well as potentially to power radios or televisions. Even if, as is often the case, a mini-grid does not have a single anchor load, balancing the interests within and among these groups, and allocating a limited amount of electric power among them, can be very challenging, as is demonstrated in the empirical chapters of this thesis (see chapters 4 and 5).

Thus, this thesis aims to empirically and analytically test the idea that despite the introduction of modern metering technologies and their ability to facilitate management, institutions for collective action are required to develop fair access rights in mini-grids, as is typical for a complex common-pool resource. According to Steins and Edwards (1999), collective action user platforms for resource use negotiation are needed in order to facilitate this, a concept developed and defined by Röling (1994) in the context of natural resource management:

*“‘Platforms’ involve meetings of farmers who perceive the same problem, realize their interdependence for solving it, and come together to agree.’ (Röling, 1994, p. 129)*

Thus, such platforms have the purpose of developing a collective understanding of the resource base and cooperating to avoid and solve actual and perceived problems (Steins and Edwards, 1999). This concept of a platform for resource use negotiation is revisited at various stages of the thesis and discussed in more depth in the context of a mini-grid, based on the empirical data presented in chapters 4 and 5. This argument further relates to the analogy of an irrigation system, which also involves inevitable trade-offs between uses and user groups, and in which negotiation among the various user groups is also more likely to lead to decisions that are acceptable for all, compared to externally imposed rules (Meinzen-Dick and Bakker, 1999). However, theories of collective action must first be introduced in more detail, given that their application to the case of a rural mini-grid is one of the key theoretical contributions of this thesis.

## ***2.7 Institutions for the Management of a Common-pool Resource***

### ***Part 2 – Collective Action***

The study of collective action in the presence of common-pool resources is largely founded on two seminal works. *The Logic of Collective Action* (Olson, 1965) argued early on that in the presence of public or common goods, self-organised collective action is very unlikely to occur due to the inherent free-rider problem involved if the benefits of the good in question are accessible to everyone, regardless of their participation in collective action. Collective action, according to Olson, would not occur

in the presence of non-excludability. The other critical early analysis of the issue, *The Tragedy of the Commons* (Hardin, 1968), has previously been introduced. Since then, however, there has been a shift in analysis and understanding of collective action in the presence of common-pool resources, chiefly led by Elinor Ostrom's and Robert Wades' numerous assessments of this issue (e.g. Blomquist and Ostrom, 1985; Ostrom, 1990, 1992, Wade, 1987, 1988). Their analysis, as well as that of various other authors (Baland and Platteau, 1996; Schlager et al., 1994) have focused on case studies of authentic, long-lasting collective action institutions which have formed and persisted against all the odds outlined by Olson and Hardin. A large proportion of these case studies are village collectives or cooperatives that have formed to manage pasture or irrigation resources, and in some cases have been able to persist for centuries (e.g. Ostrom 1990: pp. 58-87). Given the hydraulic analogy and the similarities, as well as differences, between water for irrigation and electricity in a mini-grid outlined above, the potential applicability of this theory becomes apparent.

Three seminal publications in particular have laid some of the most widely recognised foundations for understanding and analysing institutional sustainability in the management of common-pool resources. *Village Republics* (Wade, 1988) is the earliest of these three works and is based on the study of several villages in south India, which have created institutions to manage the use of either grazing grounds or water for irrigation. Through the analysis of these case studies, Wade develops 13 conditions regarding the resource system, user group, technology and interactions between them upon which successful collective action depends.

In a similar manner, *Governing the Commons* (Ostrom, 1990) is also based on case studies of collective action institutions. After reviewing the existing literature on the

commons as well as institutional approaches for self-organisation, Ostrom focuses on analysing three different questions using case studies: how and why long-lasting, self-governed and self-organised common-pool resource institutions survive; how self-organised institutions can deal with change; and why common-pool resource institutions fail. Since Elinor Ostrom is, arguably, the most influential scholar on theories of collective action, it is useful to understand the process by which she answers the first question in particular. Ostrom recounts and discusses the history of six different cases of long-enduring and self-organised common-pool resource management — two concerned with pasture and four irrigation cases — and then analyses what similarities exist among these case studies that could explain how they have been able to last for extensive periods of time, in one case, over 750 years. Ostrom (1990) finds that there are noticeable similarities around eight different factors: clearly defined boundaries; rules that match local conditions; institutional arrangements; monitoring; sanctions; conflict resolution; rights to organise; and nested enterprises. These factors become Ostrom's eight design principles for long-enduring, common-pool resource institutions. She defines a design principle as:

*'... an essential element or condition that helps to account for the success of these institutions in sustaining the CPRs and gaining the compliance of generation after generation of appropriators in the rules in use.'* (Ostrom, 1990, p. 90)

The third work, *Halting Degradation of Natural Resources* (Baland and Platteau, 1996), begins with an extensive review of natural resource management and commons theories, including a review of the prisoner's dilemma and game theory in this context. The second part of the book, however, sets out to conduct an empirical assessment of the feasibility of local resource management, similar to those presented in the two

publications introduced above. After an extensive review of empirical analyses on this issue, including Wade's and Ostrom's, as well as an examination of their own empirical work, Baland and Platteau reach eight conclusions regarding conditions for successful collective action.

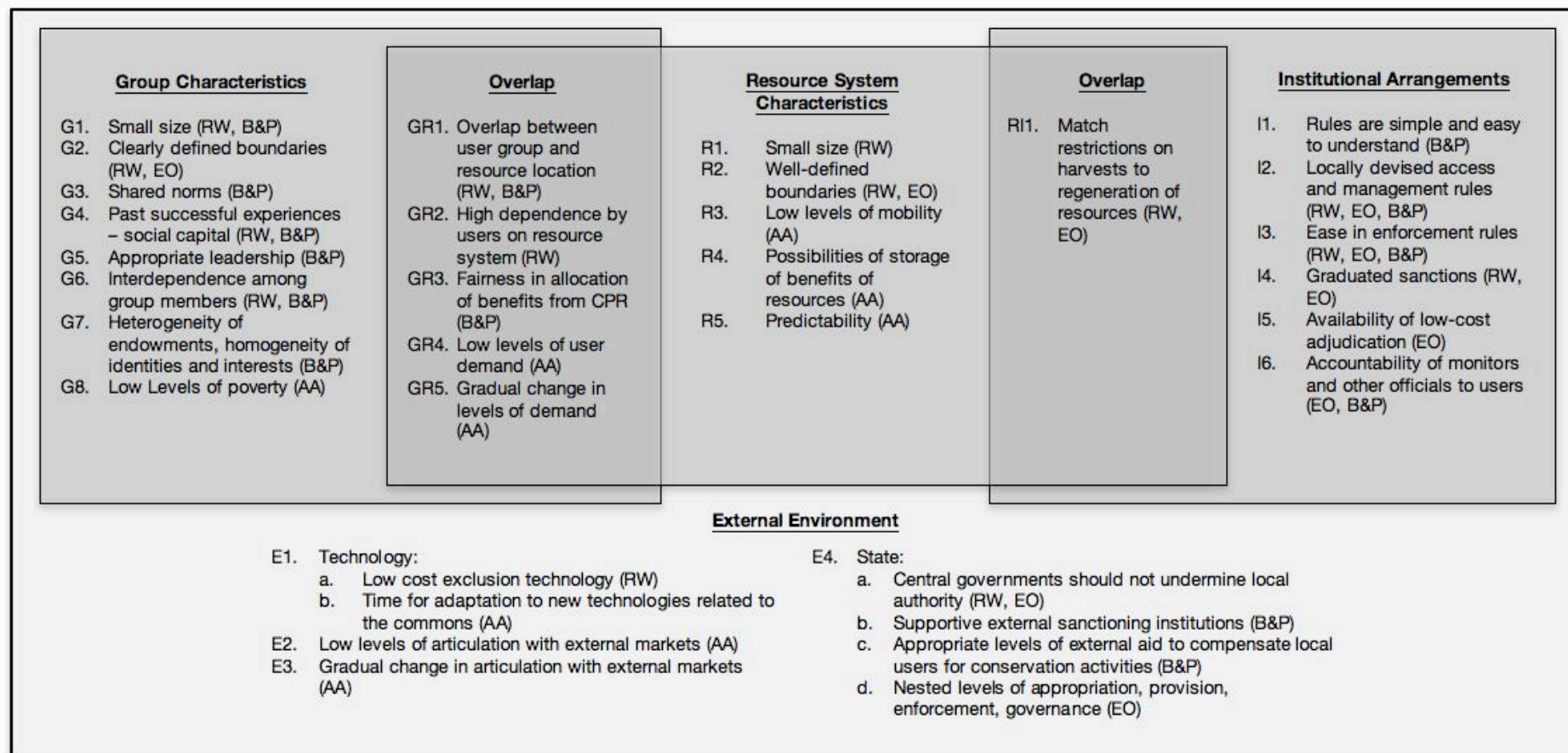
Thus, these three publications share a common thread in that they all study existing cases of successful collective action in order to arrive at enabling conditions, whether they are called design principles, conditions or conclusions. These findings can be used to understand other instances of common-pool resource management and used to explain their success or failure. Sarker and Itoh (2001) provide a good example of how Ostrom's design principles (the methodology would not change if other enabling conditions had been selected) apply to the case of long-lasting irrigation institutions in Japan. They examine each enabling condition in turn and analyse how it applies to the context of Japanese irrigation institutions, a methodological approach and analytical pathway which is used in this thesis as well. They find that the design principles are successful in explaining how the irrigation institutions in question have been able to endure and 'solve the provision and appropriation problems of the Japanese irrigation CPRs' (Sarker and Itoh, 2001, p. 100). Thus, they demonstrate the usefulness of the analytical approach that applies a set of enabling conditions to the context of specific case studies. In principle, this is the opposite approach to that taken by the authors who developed the enabling conditions, who studied existing cases of long-lasting common-pool resource management institutions, looking for similarities that then led to the emergence of enabling conditions. This approach of applying a set of enabling conditions to an existing case of common-pool resource management is widely used in the literature on the following topics: community-based natural resource management (Cox et al., 2010; Fabricius and Collins, 2007; Haller, 2010); forests and wildlife

(Alomao, 2002; Andersson et al., 2014; Blaikie, 2006; Matta and Alavalapati, 2006); several other cases of water for irrigation (Beyene, 2009; Cody et al., 2015; Cox, 2014; Meinzen-Dick, 1997; Nagrah et al., 2016; Tang, 1989); and pasture for grazing (Landolt and Haller, 2015; McCarthy et al., 2004). The next step in the development of theory for this thesis is thus to select the set of enabling conditions most suitable for the application to the case of rural mini-grids.

## ***2.8 Enabling Conditions for Collective Action***

In deciding which set of enabling conditions to use in the analysis, this thesis starts from the most comprehensive set found in the academic literature and then refines that set to those appropriate in the application to rural mini-grids. Recognising similarities across the three key works introduced in the previous section, Agrawal (2001) developed an overarching framework that synthesises the enabling conditions for sustainable management of common-pool resources into 33 enabling conditions grouped under six categories: group characteristics, resource system characteristics, institutional arrangements and external environment as well as two categories including characteristics with relevance to more than one categories (see Figure 2.2).

**Figure 2.2 - Enabling Conditions for Collective Action**



This graphical representation of the 33 enabling conditions for collective action collected and developed by Agrawal (2001) has been developed by the author.

Key: Condition first identified by AA = Agrawal (2001); B&P = Baland & Platteau (1996); EO = Ostrom (1990); RW = Wade (1988).

These include the enabling conditions identified in the three publications reviewed above, as well as nine conditions that Agrawal considered to be lacking from the original set of enabling conditions. These are particularly concerned with the characteristics of the resource itself, and the resource system, as well as the external environment. Agrawal formulates these enabling conditions (noted with ‘AA’ in Figure 2.2) based on a comprehensive literature review of other work in regard to common-pool resource management.

The resulting theoretical framework facilitates analysis of reasons for long-term sustainability, or lack thereof, of existing collective action institutions in the presence of common-pool resources in a more comprehensive manner than the individual subsets developed by the seminal authors above. In particular, Moore and Rodger (2010) provide an example of how an analysis of a common-pool resource management case may be structured using Agrawal’s framework. They define wildlife tourism at Australia’s Ningaloo Reef as a common-pool resource due to the fact that tourists are hard to exclude, their actions affect the experiences of others and they have an adverse impact on wildlife. The authors then consider each of the groups of enabling conditions, discussing their applicability to the case of wildlife tourism, as well as the extent to which they are present in the case study, in order to understand their impact on sustainability. They find that, in particular, institutional arrangements significantly contribute to sustainability and that further research is needed in order to improve the applicability of the enabling conditions to this new context.

Furthermore, a review of 12 common property regimes involving forest, water and pasture in semi-arid Tanzania found that there is no significant difference in the explanatory power of the enabling conditions among different types of common-pool



resources (Quinn et al., 2007). These studies therefore suggest that the application of the enabling conditions to other common property regimes such as a rural mini-grid, for example, would be equally powerful. A systematic application of Agrawal's framework and the underlying theory of enabling conditions for collective action in the management of common-pool resources to rural mini-grids constitute a novel theoretical approach in the academic literature. Therefore, a closer look at the applicability of the framework to this new context is required, in keeping with the need for a refinement of enabling conditions identified by Moore and Rodger (2010) in the context of wildlife tourism in Australia. Before this first analytical step, however, it is necessary to establish that this type of systematic treatment of electricity in a rural mini-grid as a common-pool resource does, in fact, constitute a theoretical innovation.

## ***2.9 The Limitations of Current Literature on Electricity as a Common-pool Resource***

An extensive search for relevant literature only identified three existing publications (two doctoral theses and a working paper) that touch on how electricity in rural mini-grids in developing countries may be treated as a common-pool resource. In a working paper, Maier (2007) explicitly uses a common-pool resource perspective to analyse reasons for successes and failures of 27 community-based micro hydro mini-grids in Northern Pakistan. He finds that communities have established institutions and various rules of use, concluding that they are able to govern the use and ensure the maintenance of the plants in ways that often function better than state- or private-based models. In

most cases, the projects that have failed experienced external pressures, such as the arrival of the national grid. While Maier authored one of the few publications that concern themselves with institutional arrangements in mini-grids, he does not venture beyond treating electricity as a common-pool resource, identifying the attributes of a common-pool resource and describing the resulting challenges faced in its management. There is no systematic application of theories of collective action or reference to overarching enabling conditions for collective action through which institutions and transferable approaches may be developed. Maier's treatment of mini-grids as common-pool resource systems therefore stops well short of operationalising the various seminal contributions to theories of collective action and property rights reviewed above.

In his doctoral thesis, Greacen (2004) also suggests that electricity in community-based micro hydro mini-grids, in this case based on 59 projects in Thailand, can be treated as a common-pool resource. However, rather than elaborating on the manner in which experiences from other instances of collective action could be used to overcome the challenges faced by existing projects, he suggests a technological fix that could be used to address the problems: current limiters, which technically limit the maximum current that can be drawn by each household. Again, there is no attempt at a theoretical expansion of the collective action literature, nor consideration of the sophisticated part of this literature that deals with property rights and the impact of technologies such as current limiters on these property rights, as developed in detail in chapter 4 of this thesis. Furthermore, as this thesis will argue, technical fixes are unable to address several socio-cultural institutional considerations that still persist, such as managing distribution among users during seasonal demand that exceeds generating capacity.

In an analysis of the economic impacts of five community-based micro hydro mini-grids in rural Kenya, Kirubi's (2009) doctoral thesis also studies some aspects of collective action. He focuses on the contested effect of heterogeneity of the group on the sustainability of collective action and finds that heterogeneity of resource users increases chances of long-term success. This analysis only represents one small subsection of a thesis more broadly concerned with the impact of electricity access on rural development (as opposed to how to achieve pro-poor electricity access) and only concerns itself with one of the 33 enabling conditions identified in the theoretical framework in Figure 2.2 (i.e. G7 – heterogeneity of endowments, homogeneity of identities and interest).

There is therefore currently no precedent in the peer-reviewed or grey literature for applying a comprehensive theoretical framework of enabling conditions for collective action to the issue of sustainably managing mini-grids for pro-poor rural electrification. While the common-pool resource characteristics of electricity in an isolated mini-grid have been previously identified by other authors, none of those authors has systematically applied theories of collective action or property rights theory as introduced in section 2.5. Even Maier (2007), who explicitly focuses on institutional arrangements in mini-grids, includes no in-depth discussion of theories of collective action, and the analysis of the existing institutional arrangements is not rooted in this theory (although given the importance of rules he identifies, the use of enabling conditions as an analytical tool would have been appropriate). In addition to this lack of depth and systematic application of the theory, none of the three publications makes an attempt at adapting and further developing the existing theory. Thus, the adaptation of theory presented in the next section of this thesis is the first of several original contributions to knowledge in this area, which this thesis makes.

### ***2.10 Refining the Enabling Conditions for Application to Mini-Grids***

This section refines the enabling conditions in Figure 2.2 based on their applicability and salience in analysing socio-cultural enabling conditions for the sustainable management of pro-poor rural mini-grids. This approach is a direct response to Agrawal's (2001) own critique of the framework's exhaustiveness and the sheer number of potentially relevant enabling conditions. In order to reduce the framework to a more manageable size, and make it as relevant as possible to the context of electricity in a mini-grid, this section systematically examines the enabling conditions and the extent to which, and the ways in which, they relate to the management of electricity as a common-pool resource in the mini-grid context. Each of the categories of characteristics in Agrawal's framework is considered in turn. Enabling conditions with relevance to the socio-cultural aspects of mini-grid management in the resulting refined theoretical framework are represented in Figure 2.3 (note: all codes and enabling conditions mentioned below refer to the codes presented in Figure 2.2). Enabling conditions are excluded from the refined framework due to any of the three following reasons:

- Redundancy: the condition is by definition a characteristic of a rural mini-grid as defined in this thesis.
- Normatively inapplicable: the condition does not match the normative approach of this thesis.
- Substantively inapplicable: the condition does not match the unit of analysis and area of study focused on in this thesis.

Agrawal's 'external environment' (E1-4) category as a whole is therefore not considered, as many of the conditions in this category engage with issues at the regional and national level rather than the local level, which is the focus of this thesis. This category of conditions is thus substantively inapplicable to this analysis. This echoes the arguments made in section 2.3, to the effect that this thesis focuses on institutions at the local level, rather than institutions in the form of laws or regulations, which would fall under Agrawal's external environment conditions. This does not imply that these external environment conditions are irrelevant — they represent a critical area for specific future analysis (see areas for future research articulated in the concluding chapter 7).

### *2.10.1 Group Characteristics*

Several conditions within this category are, by definition, characteristics of all rural mini-grids and can therefore be set aside for the purposes of this analysis due to their redundancy. Neither of Agrawal's two sources (Baland and Platteau, 1996; Wade, 1988) listing small group size (G1) as an enabling condition specify a number that constitutes a small group. It is nevertheless, by definition, a characteristic of mini-grids as they have been defined in chapter 1. Clearly defined boundaries (G2) are also a natural condition of mini-grids. The boundary of the group is defined as the extent of those either directly connected to, or directly interacting in other ways with, the mini-grid, e.g. by paying to charge mobile phones or LED lanterns (incidentally, as has been mentioned before, this is also the unit of analysis of this thesis). The condition of shared norms (G3) does not apply as these are only a requirement if group size is large, according to Baland and Platteau (1996). With regards to mini-grids in contemporary

East Africa, it is unlikely that any significant past successful experience (G4) is to be found with operating mini-grids — as has already been emphasised, most mini-grids in the developing world struggle to operate sustainably. A low level of poverty (G8) is also not a relevant characteristic as the explicit interest of this thesis, and the policy and practitioner efforts it seeks to inform, is in providing access to electricity for poor people via mini-grids. This condition is therefore normatively inapplicable.

Heterogeneity of endowments and homogeneity of identities and interests (G7) as demonstrated by Kirubi (2009) are, however, potentially relevant characteristics. In the context of this analysis, the different sub-groups, among which heterogeneity of endowments and homogeneity of interest may exist, are limited to just the three categories: anchor loads, businesses and households. Of course, there are considerably more granular sub-groups within each of these categories, e.g. households within different income groups, but the analysis does not differentiate within them at that level, due to the exploratory nature of applying this framework to such a novel concept. A related socio-cultural issue, which has not been studied before, is the interdependence among group members (G6), which must be understood in the specific context of each mini-grid. Entrepreneurs exploiting the resource for economically productive uses upon which other users depend might, for example, act as facilitators of collective action, by increasing interdependence within the group. In this context the degree of complexity and specialisation of the local village economy and the extent to which people depend upon each other's goods and services will therefore be considered a proxy measure for group interdependence. However, this also creates a risk of elite control or capture, which can be problematic, especially if appropriate leadership (G5) is lacking. It should be noted that appropriate leadership is defined as being 'young, familiar with changing external environments, and connected to local traditional elite' (Agrawal, 2001, p.

1654). As the empirical data will show, this definition of appropriate leadership is very specific and does not necessarily fit with the reality found in rural Kenyan communities. In fact, an appropriate leader according to this definition might be impossible to find in the context of a rural mini-grid. Especially the requirement for being young (in itself not a clearly defined term) is difficult to achieve and not necessarily useful in communities, in which village elders have been granted official roles by the government in the form of village councils as part of the decentralisation of Kenyan government.<sup>10</sup>

### *2.10.2 Resource System Characteristics*

In a mini-grid, resource system characteristics are relatively straightforward to define. Small system size (R1) and well-defined boundaries (R2) are both given, for reasons analogous to those outlined regarding group characteristics. Low levels of mobility (R3) of the resource are also present by definition, as electricity cannot leave the resource system (i.e. the mini-grid). R1, R2 and R3 are therefore excluded from the refined framework due to their redundancy. The possibility of storage of resource benefits (R4) depends on the particular mini-grid design and whether batteries are present. The final characteristic concerned with predictability (R5) — meaning predictability of supply in this case — is again a function of the energy source used (solar/ hydro/gen-set/other). Since conditions R4 and R5 relate to specific supply-side technological considerations, neither of them is included in the refined framework, as

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<sup>10</sup> See: <http://www.tikenya.org/index.php/press-releases/322-decentralised-units-at-the-county-level>

the aim is to focus on socio-cultural aspects of mini-grid management and these two conditions are substantively inapplicable.

### *2.10.3 Group and Resource System Overlap*

In a mini-grid, the location of the resource system and user group (GR1) is identical. This condition can therefore be disregarded as being redundant. Low levels of user demand (GR4) are to be expected initially, as it takes time for communities to adapt to the use of electricity and build up demand. This build-up, however, will lead to a gradual change in levels of demand (GR5). The importance of this change, and how it interacts with the initially low levels of demand, can be a significant consideration as rising demand must be met by expensive system upgrades. In this context, high dependency by users on the resource system (GR2) relates to the manner in which different uses can increase dependency on the system and also potentially help generate the income streams necessary to maintain the system in the long term. This, however, requires fairness in allocation of benefits (GR3), pointing to the potential importance of the resolution of conflict between household uses (e.g. lighting and mobile phone charging) and productive uses (e.g. refrigeration or agricultural processing) in particular. As a result, conditions GR2–5 warrant closer analysis in this context.

### *2.10.4 Institutional Arrangements*

Institutional arrangements are key to the types of socio-cultural issues with which this thesis seeks to engage; they may potentially play a crucial role in the sustainability of mini-grids, offering opportunities to create enabling conditions from the outset. Rules



(I1) must be simple and easy to understand, requiring members of the community to be able to comprehend them and their rationale. This is similar to the argument for requiring locally devised access and management rules (I2), which in the mini-grid context concerns the extent and nature of community participation in the formulation of rules, especially when there is no metering. The extent to which rules are easy to enforce (I3) is also relevant and relates to the degree of mutual oversight within the community. Graduated sanctions (I4) beyond simple disconnection have, to date, not been described in the literature on mini-grids, yet more analysis on their potential role could yield useful insights. Similarly, as sanctioning processes become more and more refined, the availability of low-cost adjudication (I5) takes on greater importance. Finally, and crucially, monitors and other officials must be accountable to electricity consumers (I6) in order to minimise, for example, the chances for elite capture and squandering of revenues. All of the institutional arrangements are therefore included in the refined framework.

#### *2.10.5 Resource System and Institutional Overlap*

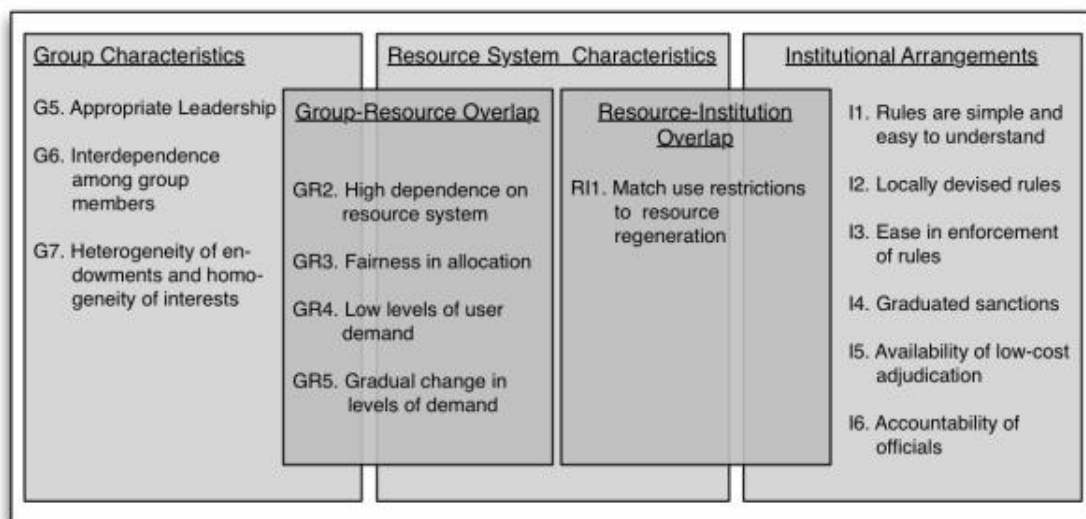
Matching the use restrictions to regeneration of resource (RI1), i.e. matching supply and demand within the mini-grid, is one of the central challenges of managing any electricity network and hence must be included in the refined framework.

#### *2.10.6 The Refined Framework*

This refinement of Agrawal's framework to the context of rural mini-grids hence leads to a set of 14 enabling conditions for collective action in mini-grid management

(see Figure 2.3), which must be considered in more depth based on empirical findings from the field visits and interviews described in chapter 3. These conditions are largely focused on the group characteristics, the overlap between group and resource characteristics, and the institutional arrangements governing the interactions between the group and the resource, as well as within the group itself. The group in this case comprises all those end users connected to the mini-grid (i.e. all authorized entrants, using the terminology defined in Table 2.1).

**Figure 2.3 - Refined Theoretical Framework**



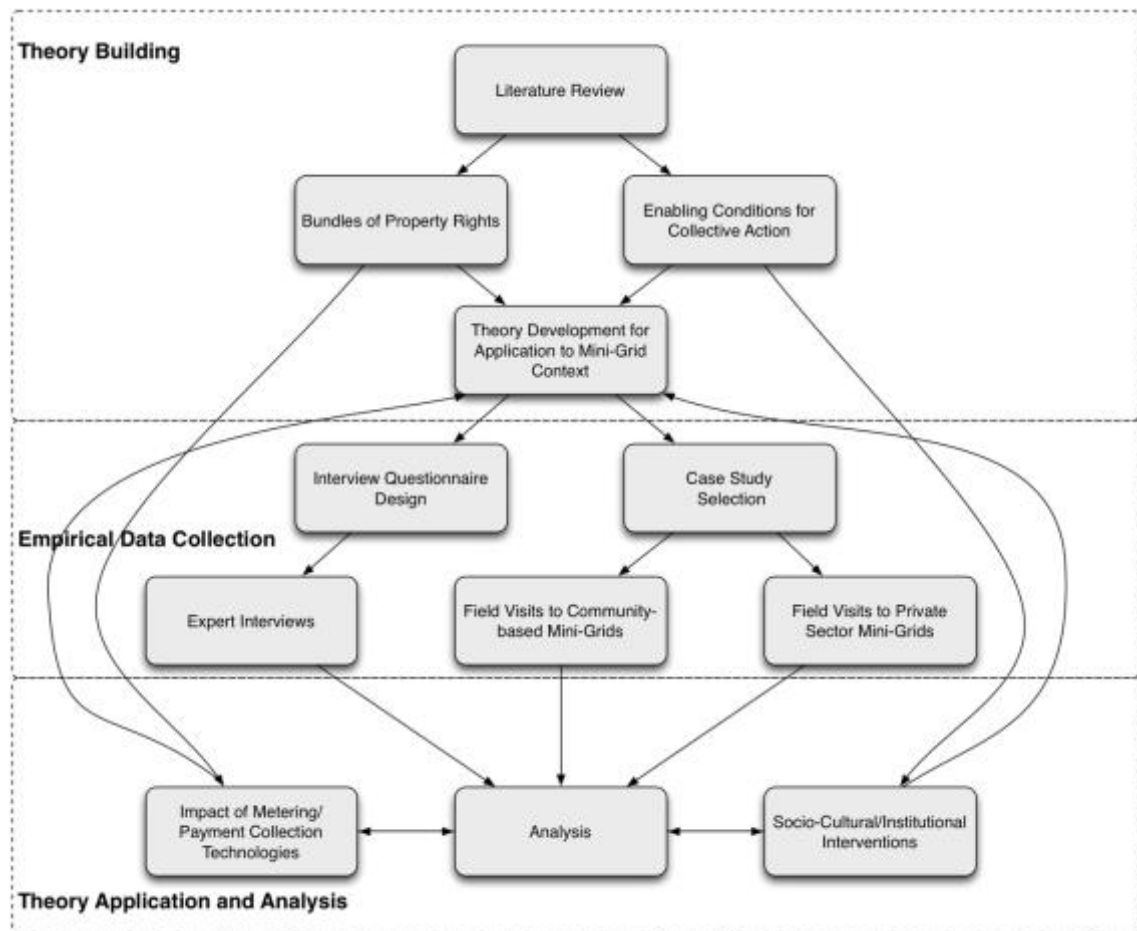
Source: Author (developed based on framework by Agrawal (2001, pg. 1659))

The theoretical foundation formulated in this chapter is now operationalised in the methodology in chapter 3 and the following empirical chapters. This methodology, the following two empirical chapters (4 and 5) and the discussion (chapter 6) are directly motivated by and follow the structure of the research question and its five sub-questions formulated in section 1.5.

## Chapter 3 - Methodology

The methodology underpinning the original research and analysis conducted for this thesis is based on three distinct but related phases, which involved a combination of theory building, empirical data collection and theory application and analysis, where the results of the theory application phase in particular fed back into theory development. Figure 3.1 presents a flow chart outlining the three phases, the empirical and analytical steps taken in each of them, and how they build upon and relate to each other.

**Figure 3.1 - Research Design and Methodology in Three Phases**



The first phase focused on theory development, identifying the gap in the literature as well as suitable theoretical frameworks to fill this gap. These theoretical frameworks were then developed further and refined in order to render them applicable in analysing the socio-cultural factors that contribute to sustainable management of pro-poor mini-grids. These segments were completed in Chapter 2. This theory then informed the research design of the second, empirical phase, which took the form of semi-structured interview questionnaires rooted in the theoretical frameworks and the selection of three Kenyan mini-grids to be investigated via field visits.

The empirical data collection took place during two separate trips to Kenya in May, 2014, and January to early March, 2015. During these visits, 27 interviews with 24 experts in the field of mini-grids for rural electrification in Kenya were conducted in Nairobi and Kisumu (some were interviewed twice), including representatives from the private sector, inter-governmental organisations, the public sector and various types of not-for-profit organisations active in the area of rural electrification in Kenya and the East African region more generally. Additional details concerning interviewee selection are provided in section 3.2.4. The three mini-grids were selected due to three key factors: at the time of the field visit they had all been operational for over one year; they included community-based as well as private sector ownership models; and while they were similar in terms of the source of electricity (all involving some combination of solar PV, wind and diesel backup), the metering and payment collection technologies differed greatly among them. Section 3.2 provides a more in-depth introduction to the case studies as well as the rationale for choosing Kenya as the target country.

In the final theory application phase of the methodology, the empirical data collected in the second phase was analysed through the lens of the two theoretical frameworks developed in phase one and presented in chapter 2 above. Namely, enabling conditions for collective action and bundles of property rights were identified in order to determine the role of modern metering and payment technologies in the sustainable management of mini-grids, as well as the scope of non-technical, socio-cultural institutional interventions in addressing operational challenges. The results of applying this theory led to further theory development. Each of these three methodological phases is described in more depth below.

### ***3.1 Phase 1 – Theory Building***

The first phase of the research conducted in the preparation of this thesis consisted of the literature review as well as theory selection and development or refinement presented in chapter 2. After identifying the socio-cultural gap in the literature and identifying the common-pool resource characteristics of electricity in a mini-grid, a thorough review of property rights theory and theories of collective action was conducted in order to arrive at suitable theoretical frameworks for the analysis of factors affecting the sustainable management of pro-poor mini-grids in rural Kenya.

In a first analytical step, the theory of bundles of property rights was applied to the context of isolated mini-grids, specifically taking into consideration the effect of prepaid meters and tariff collection technology using mobile money on the allocation of property rights and hence the assumption of roles within the mini-grid. Hypothesising

that these technologies can only solve some, but not all, of the operational-level challenges, the theory of enabling conditions for collective action as collated by Agrawal (2001) was chosen as a suitable theoretical framework in order to determine the possibility of non-technical socio-cultural or institutional interventions to address major operational challenges.

The refinement of this theoretical framework of enabling conditions for collective action in the presence of a common-pool resource for the application to the context of sustainable management of pro-poor mini-grids in a developing country represents the first major contribution and analytical step presented in this thesis. For the first time in the academic literature, each enabling condition listed in Agrawal's (2001) framework has been systematically considered in order to determine its applicability to the context of operational challenges in a rural mini-grid. The resulting refined framework of those enabling conditions most applicable to the analytical focus of this thesis presents an original contribution to theory building. This theory was then used to inform the research design for the second phase on empirical data collection.

### ***3.2 Phase 2 – Empirical Data Collection***

The empirical data for this thesis was collected in Kenya during two separate field trips between May, 2014, and March, 2015, over a total period of 10 weeks. Kenya was selected as the target country for this analysis due to three key factors. First of all, Kenya has been a leader in East Africa in developing its solar PV market, ahead of Tanzania and Uganda, for example, and can generally be seen as taking a leading rather

than lagging role in developing energy policy in the area (Hansen et al., 2015; Ondraczek, 2013). This means that there not only exists a relatively large number of experts with many years of experience in rural electrification in Kenya, but also that electrification models that have been shown to work in Kenya may also be capable of adaptation to other contexts in East African countries. Secondly, Kenya has experienced a rapid and widespread deployment of SHSs in the last five to seven years, leading to a wealth of learning on the deployment of solar PV in Kenya (see e.g. Byrne, 2011; Byrne et al., 2014), and a comparatively well-developed domestic market for solar PV (Hansen et al., 2014). Finally, Kenya has over a decade of experience with rural mini-grids, originally in the form of community-based mini-grids for the most part (i.e. donor-funded and owned and operated by the community), which have experienced varying degrees of success and sustainability (Kirubi, 2009; Maher et al., 2003; Yadoo, 2012). These three factors further strengthen the case for Kenya as a target country, because there are a number of relevant cases of successful and failed rural electrification projects based on mini-grids, and hence a solid base of experienced experts from which to sample interviewees. Furthermore, Kenya has seen an acceleration of the involvement of the private sector in the financing, deployment and operation of rural mini-grids in recent years, and there now are an estimated 20 to 30 privately-owned, rural mini-grids in operation in Kenya (as has been detailed in chapter 1). These private sector mini-grids all rely on advances in metering and payment collection technologies for their energy delivery models. Kenya therefore has a uniquely deep and broad history of mini-grid development in East Africa, if not sub-Saharan Africa as a whole, and therefore is the ideal target country for this analysis. The potential pool of expert interviewees and case studies, from which to sample for the empirical research conducted for this thesis, is large enough that a sample that is representative of the entire pool, can be selected

without having to contact every relevant interviewee and visit every potentially relevant case study site.

A 10-week period of field work was conducted, including time spent in Nairobi (hosted by the African Centre for Technology Studies (ACTS)) and in Kisumu in Western Kenya. Three field trips were also made to three different operational mini-grids. Table 3.1 provides a description of the key characteristics of each mini-grid. This included two visits made during a separate period of field-based research in collaboration with, and with logistical support from, the Solar Nano-grids (SONG) project, a research project funded by the the UK Engineering and Physical Sciences Research Council and led by the University of Loughborough in partnership with Grameen Shakti, Caribsave-Intasave and the United International University in Bangladesh (Khan and Brown, 2014).



**Table 3.1 - Case Study Characteristics**

<b>Name</b>	<b>Kitonyoni</b>
Location	Makueni County, Eastern Province
Operational since	2012
Owner	Cooperative, donor-funded
Operator	Cooperative and University of Southampton E4D
Generation technology	Solar PV with diesel backup generator
Generation Capacity	14 kWp PV and 37 kW diesel (diesel never run at time of visit)
Metering technology	Post-paid meters and prepaid meters using scratch cards
Types of customers	Public facilities (e.g. clinic and school) and small businesses
<b>Name</b>	<b>Mageta Island</b>
Location	Lake Victoria, Siaya County, Nyanza Province
Operational since	2013
Owner	Private company
Operator	Private company with local employee
Generation technology	Solar PV, single wind turbine, diesel backup generator
Generation Capacity	5 kWp
Metering technology	Prepaid meters with mobile-enabled payment
Types of customers	Small businesses, some with households attached
<b>Name</b>	<b>Olosho-Oibor</b>
Location	Ngong, Kajiado County, Rift Valley Province
Operational since	2009
Owner	Community-based organisation, donor-funded
Operator	Community-based organisation
Generation technology	Solar PV, single wind turbine, diesel backup generator
Generation Capacity	10 kWp wind and solar, 10 kW diesel backup
Metering technology	flat fee, unmetered
Types of customers	Public facilities (e.g. clinic and school) and small businesses

Source: author

As can be seen from their key characteristics, the three mini-grids visited are quite similar in size as well as the electricity generation technology used. However, they demonstrate a broad variety of institutional setups (community-based organisation, cooperative and private operator), as well as a range of metering and tariff collection technologies. Given the focus of this thesis on the role of metering and payment collection technology and the institutional arrangements within the mini-grid, these three case studies represent a useful sample of mini-grid based energy delivery models currently in operation in Kenya. This is because they exhibit the kind of contrasting and deliberate comparisons that Yin et al. (2006) suggest as one of the possible criteria for multiple case study selection, for example, between metering technologies used or ownership structures. During the visits to the three mini-grids, detailed hand-written notes were taken throughout the day, which were later used to compose more detailed memoranda. The following sections provide more background information on each of the systems, informed by these memos. Figure 3.2 shows the location of all three mini-grids.

**Figure 3.2 - Map of Field Visit Locations**

Map Data © 2016 Google

### 3.2.1 Kitonyoni

The Kitonyoni community-based mini-grid is located approximately four hours southeast of Nairobi in Makueni county. It was installed in 2012 by the University of Southampton as the first implementation site for the Energy for Development (E4D) project. The power generation consists of 56 solar PV panels for a total of 14 kilowatt peak (kWp) of generating capacity and a battery bank of 24 batteries, as well as a 37 kW diesel backup generator. Figure 3.3 shows pictures of the central installation site. The PV panels are located on the roof, which is also used to collect rainwater in a cistern. The container on the left contains the battery bank, load control equipment and the diesel backup generator. The container on the right contains the office of the management committee as well as a charging station. It has been built on land that has

been set aside by the community and registered with the county in the name of the cooperative. The mini-grid extends to the school, charging station, dispensary, market, church and some businesses (tailoring and ironing, barber shop, hardware store, etc.) within a radius of 200 metres, but does not include any households. As part of the community engagement process, Southampton helped the community establish a cooperative which is tasked with the operation of the mini-grid. The cooperative currently has 190 members, a management committee and a supervisory committee. The management committee is tasked with organising the day-to-day maintenance of the mini-grid (mainly cleaning the PV panels), selling the prepaid scratch cards used to load credit on to the prepaid meters located in the businesses, collecting the tariffs from public facilities that are connected through post-paid rather than prepaid meters, such as the dispensary and church, and operating the central charging stations where small portable appliances such as mobile phones and LED lanterns may be charged for a fee.

**Figure 3.3** – Central Installation in Kitonyoni



Source: author

At the time of the visit, however, the actual load control and balancing of supply and demand in the system was done remotely by the University of Southampton using mobile network data transmission. The plan was to slowly transfer management to the cooperative as management capacity increases. Interestingly, the national grid was extended past the community shortly after project completion. Figure 3.4 shows a picture of the national grid running past the mini-grid. Yet the community decided against connecting to the national grid, because they expected the mini-grid to be more reliable than the national grid and they felt a certain sense of community pride in their system. Furthermore, the fee to connect to the national grid of approximately 35,000 Kenyan Shillings (KSH) proved to be unaffordable for most community members. At the time of the visit, no member of the community had been connected to the national grid.

**Figure 3.4 – National Grid Passing Kitonyoni Mini-Grid**



Source: author

### 3.2.2 *Olosho-Oibor*

The Olosho-Oibor community-based mini-grid is located in Ngong county, approximately two hours southwest of Nairobi. The mini-grid was constructed in June, 2009, by the United Nations Industrial Development Organisation (UNIDO) in order to electrify the dispensary, which serves approximately 8,000 people in the area, the school with 400 students and the church, a focal point for the local community, which is quite dispersed due to the pastoral nature of their livelihood. The system originally consisted of 3 kWp of PV with a battery bank, a 3 kW wind turbine with a separate battery bank and a 10 kW diesel generator, which can charge both battery banks. At a later stage, the UNDP contributed another 4 kWp of solar panels to the system. The community contributed approximately KSH 60,000 ( USD 580) in capital as well as ‘sweat equity’ (i.e. manual labour) by helping to bury the distribution lines underground, for example. Figure 3.5 shows a picture of the wind turbine on the left as well as the two buildings housing the mini-grid components on the right. The building in the centre of the image houses the shop and charging station and the second stage of 4 kWp on the roof. The building on the right contains the battery bank, load control equipment, diesel backup generator and the office of the manager, as well as the first stage of 3 kWp on the roof.

The mini-grid is owned and operated by a community-based organisation that was set up for this purpose with the help of UNIDO at the time the mini-grid was constructed. The community-based organisation employs a dedicated local manager, who is tasked with collecting the tariffs and conducting basic maintenance and repairs. The main income streams to the community-based organisation are from electricity

sales to a small shop, a barber shop, as well as the public facilities in the village such as the school, church, dispensary and a rescue centre for girls escaping their communities to avoid female genital mutilation. All of these connections are unmetered and pay a flat fee per month. In addition, the mini-grid also supplies a charging station, where customers can charge their telephones or LED lanterns for a flat fee.

**Figure 3.5** – Central installation at Olosho-Oibor



Source: author

The general reliability of the system, as well as its suitability to the environment, appears to be very good. Strong winds at night, coupled with sunshine during the day for most of the year, mean that the diesel generator is rarely needed. The local manager estimates that repairs are only required two to three times per year and that on average it takes between one to five days to have an expert arrive to perform the repair. A major problem, however, is that no one in the community knows the fair price for these repairs and the income stream from the mini-grid operation barely covers such operating costs.

As a result, the community-based organisation has repeatedly been obliged to find further donor money in order to finance repairs of the wind turbine, for example. At the time of the visit, the community-based organisation was in discussions with the United Nations International Children's Emergency Fund (UNICEF) to install a further PV bank to be used for pumping water, together with meters in order to improve the revenue stream. Despite these problems, the community-based organisation has shown considerable resilience in operating the mini-grid continuously since 2009.

### *3.2.3 Mageta Island*

Mageta is an island in Lake Victoria, approximately five kilometres off the Kenyan coast and just east of the Ugandan border. SteamaCo, then called Access:Energy, electrified one of the fishing villages on Mageta in 2013 as a pilot for a privately owned and operated mini-grid in rural Kenya. This private ownership stands in contrast to the community ownership of the previous two case studies, and therefore will serve to illustrate the institutional differences between these two approaches in the empirical analysis of chapters 4 and 5 and the subsequent discussion in chapter 6.

The system consists of approximately 5 kWp solar PV as well as a small (~0.5 kW) wind turbine and a diesel backup generator. All connections are metered and prepaid using the widespread Kenyan mobile payment system M-Pesa, enabling customers to top up their prepaid electricity meters by transferring funds via SMS. All the meters are centrally located, with an individual wire running to each end user in order to prevent any tampering with the meters. The system is monitored remotely, using an SMS-based data transfer protocol, yet SteamaCo also employs a local manager who is responsible for routine maintenance such as cleaning the PV panels, as well as acting as a first point



of contact for its customers. Figure 3.6 shows the central generation installation on the left, the centrally located prepaid meters in the centre and the individual wires running to each customer on the right.

**Figure 3.6** – Central Installation at Mageta Island



Source: author

The Mageta system has approximately 50 customers, almost all of whom are small businesses, such as telephone charging stations, bars, a video hall, a barber shop and a small grocery store. Only a few households are connected to the grid, yet it should be noted that most businesses are attached directly to households, so wherever a business is connected, the adjacent household also has access to electricity. Demand for electricity is strong, and SteamaCo has expanded the system since its construction in 2013. Even so, with 50 connections sharing a total of approximately 40 kWh of generation capacity on a sunny day, electricity is relatively scarce and as a result, quite expensive.

According to the manager, the typical business pays 200 KSH (approximately USD

2.00) per day and the few connected households pay approximately 400 KSH per week. By comparison, there is a 600 KSH flat fee per month in Olosho-Oibor, for example. As a result, however, the Mageta mini-grid is able to finance all of its operating costs out of its revenue stream, as well as any repairs that have been necessary. Nevertheless, despite complaints, even by the manager himself, that electricity currently is too expensive, it is clearly apparent that the availability of reliable electricity has presented new business opportunities for the local community in addition to the traditional economic activity, which is dominated by fishing.

#### *3.2.4 Interviewee selection and interviews*

In addition to these field visits of operational mini-grids in rural areas of Kenya, 27 expert interviews lasting 45–60 minutes were conducted in Nairobi and Kisumu. The interviewees were selected based on their experience with all aspects of designing, financing, deploying, operating and owning rural mini-grids. The initial set of potential interviewees was contacted, then further expanded using a guided (or exponential discriminative) snowball sampling technique. During the first field visit in May, 2014, which also included the field visits to Kitonyoni and Olosho-Oibor, nine interviews were conducted with a focus on interviewee familiarity with those two projects as well as the history of community-based mini-grids in Kenya. During the second field trip, which included the visit to Mageta in early 2015, a further 18 interviews were conducted, which, in addition to the same topics as in the first round of interviews, also focused on the role of the private sector in rural mini-grid deployment in Kenya. Table 3.2 describes the professional background of each of the 24 anonymised interviewees (three interviewees were interviewed twice due to their familiarity with several of the

case study sites as well as relevant experience in the community-based and private sectors).

**Table 3.2** – Interviewees and types of organisations

<b>Interviewee 1</b>	Private sector energy consultancy	<b>Interviewee 13</b>	Private sector, off-grid electricity developer
<b>Interviewee 2</b>	Non-profit organisation, energy access focus	<b>Interviewee 14</b>	Private sector, off-grid electricity developer
<b>Interviewee 3</b>	Non-profit organisation, energy access focus	<b>Interviewee 15</b>	Donor agency
<b>Interviewee 4</b>	Academia	<b>Interviewee 16</b>	Private sector, off-grid electricity developer
<b>Interviewee 5</b>	Private sector provider of mini-grid technology	<b>Interviewee 17</b>	Non-profit organisation, rural development focus
<b>Interviewee 6</b>	Private sector, finance	<b>Interviewee 18</b>	Intergovernmental organisation
<b>Interviewee 7</b>	Private sector, solar PV technology provider, formerly public sector	<b>Interviewee 19</b>	Private sector, off-grid electricity developer
<b>Interviewee 8</b>	Private sector energy consultancy	<b>Interviewee 20</b>	Private sector, energy consultancy
<b>Interviewee 9</b>	Private sector, finance	<b>Interviewee 21</b>	Private sector, off-grid electricity developer
<b>Interviewee 10</b>	Non-profit organisation, rural development focus	<b>Interviewee 22</b>	Non-profit organisation, energy access focus
<b>Interviewee 11</b>	Non-profit organisation, energy access focus	<b>Interviewee 23</b>	Non-profit organisation, rural development focus
<b>Interviewee 12</b>	Non-profit organisation, energy access focus	<b>Interviewee 24</b>	Public sector

The interviews were conducted using a semi-structured approach in the form of ‘depth interviews’ (Oppenheim, 2000), in which conversation was permitted to flow within a clearly defined range of topics guided by a catalogue of questions. This catalogue of questions was directly informed by the theoretical frameworks. This meant

that the interviews aimed to elicit first hand experiences with different institutional arrangements in mini-grids, technical as well as non-technical responses to operational challenges and the role of different metering and payment collection technologies, in addition to questions concerning the interviewee's professional background and experiences with rural electrification in Kenya and questions regarding the major operational challenges faced in rural mini-grids. The catalogue of interview questions comprised 34 questions, presented in Annex 1, from the following seven topics:

1. General Background (current professional role, past experience with electrification and mini-grids)
2. General factors affecting long-term sustainability of mini-grids (key operational challenges, ways of balancing supply and demand, advantages and disadvantages of community-based and private business models)
3. Challenges specific to community-based mini-grids (successful or unsuccessful cases and their institutional setups, conditions in community affecting chances for long-term sustainability)
4. Challenges specific to private sector mini-grids (successful or unsuccessful cases, interaction with the community)
5. Institutional interventions to challenges (the role of rules, how they are determined, monitored, enforced and sanctioned, and how they evolve over time)
6. Technical interventions to challenges (the role of current limiters, post-paid and prepaid meters and mobile money, their impact on interaction and relationship between mini-grid operator and end user)

7. The A-B-C (Anchor, Business, Community) of consumer groups (challenges of serving each consumer group and their influence on the long-term sustainability of the mini-grid)

Of course, as these were guiding questions for semi-structured interviews, not every interviewee was asked each of the 34 questions from the catalogue. However, it was ensured that each interview included questions from each of the seven subsections. The only exceptions were the two sections specific to private sector and community-based mini-grids. If an interviewee was only familiar with one of those ownership models and had no significant experience with the other, the questions from the section on the unfamiliar ownership model were discarded.

When explicit consent was given (26 out of 27 times), the interviews were recorded and detailed notes taken immediately after the interview. The recordings and notes were also shared with the interviewees, in order to provide them the opportunity to review what had been said and, if necessary, make changes. None of the interviewees, however, requested that the notes be changed or for sections of the recordings to be discarded. In a final step, the interviews were transcribed for later analysis.

### ***3.3 Phase 3 – Data Analysis***

In the first analytical step, the key operational challenges faced in rural mini-grids in Kenya were determined based on first-hand observations during the field visits and evidence collected during the interviews. The theory of bundles of property rights was then used to determine the effect of prepaid metering technology on the allocation of

property rights in a mini-grid and how this technology provides potential solutions to certain operational challenges. The next analytical step determined which operational challenges still remained despite these technologies. In addition to interview evidence, the fact that Olosho-Oibor is an unmetered system, Kitonyoni uses prepaid meters with locally sold scratch cards and Mageta uses prepaid meters with mobile-enabled payment greatly aided in determining which operational challenges are difficult to address using these technologies.

In the next stage of the empirical data analysis, the refined theoretical framework of enabling conditions for collective action was operationalised in a coding methodology in order to determine to what extent this theory can provide a basis for the development of non-technological institutional responses to the remaining operational challenges. In order to achieve this the enabling conditions for collective action presented in the refined framework in Figure 2.3 have been used as codes for a thorough analysis of the interview transcriptions. This process allowed the extraction of relevant quotes from the interviews for each of the enabling conditions, which will be discussed in detail in chapter 5. As an example this coding process identified nine quotes relating to the code ‘simple and locally devised rules’ and seven quotes relating to the code ‘gradual changes in demand’. This step of the methodology therefore used an initial coding technique with a focus on descriptive coding, which assigns topics to text passages (Saldaña et al., 2013).

In a final step, the findings from the application of the two theoretical frameworks were consolidated, and it was determined how the two frameworks interact, to what extent they can inform the development of local management institutions and what

additions and augmentations to the theoretical frameworks are supported by the empirical evidence.

### ***3.4 Limitations and Potential Weaknesses of Methodological Approach***

Due to the financial and temporal constraints of independent doctoral research, the methodological approach taken in this thesis inevitably has some limitations and potential weaknesses. First and foremost among these is the limited number of case studies visited. This is largely due to time and cost limitations, as well as difficulties in obtaining detailed information concerning operating mini-grids. It proved particularly challenging to identify people familiar with certain mini-grids that appeared in the literature or project reports. As a result, it was often not possible to gain simple, yet reliable and specific information that would be required to organise a visit to the mini-grid. In some cases, simply being informed of a reliable location and description of how to get there proved very difficult. Hence, the mini-grids visited cannot be claimed to be representative of the whole mini-grid sector in Kenya, let alone rural East Africa in general. Nevertheless, given their characteristics, they provide useful data to test the applicability and usefulness of the two theoretical frameworks operationalised in this thesis in this new context of rural mini-grids. In addition, the expert interviews allowed the insights generated from the field visits to be compared against and supplemented by experiences with other community-based and private sector mini-grids in the country.

In addition to these sampling difficulties, the visits to the two community-based mini-grids, which were organised together with the SONG project, were planned long in advance and in close collaboration with the local management. The managers and operators as well as the community members were aware of the timing of the visit, and the management provided a guided tour of both grids. This means that the conditions observed during the visits may not have been fully representative of everyday operation. The conversations with local management and some community members, however, still provided rich information concerning operational challenges. In the case of Mageta Island, this limitation was less relevant as the visit was organised at short notice, i.e. the management learned of the visit on the same day. The visit was guided by the local operating manager, who spoke very openly concerning the limitations of the system. Observation of normal everyday operation and short conversations with some community members regarding their experiences with the mini-grid were also possible without the manager as a permanently present guide. Due to monetary and time constraints, it was also not possible to conduct household surveys. Since the intention was not to gather ethnographic data or statistically significant survey outcomes, but to explore the usefulness of the two theoretical frameworks, the empirical evidence gathered on mini-grid operation proved sufficient to fulfil the primarily theoretically oriented goal of the thesis.

The biggest limitation of the interview process is the almost complete lack of interviewees from the government or the state utilities. Despite repeated attempts to establish contact with officials at the Kenya Rural Electrification Agency (REA), the Energy Regulatory Commission (ERC) and the Ministry of Energy (MoE), it proved to be very difficult to get a representative from any of these organisations to agree to an interview. This omission, however, is not a significant concern in relation to the focus



of the thesis on the local operational challenges that relate to mini-grids, as opposed to the broader policy environment. This is reflected in the exclusion of the external environment from the theoretical framework of enabling conditions. The focus of this thesis is on mini-grid-level operational challenges and methods of overcoming them, rather than those created, for example, by a lack of regulatory clarity.

Generally speaking, the interviewee selection was based primarily on research of current and past mini-grid projects in Kenya as well as organisations involved in all stages of their implementation, but it also relied on snowballing. This means that any selection bias introduced in the original selection of interviewees tends to be perpetuated. However, by interviewing experts from a variety of sectors, including private developers, non-governmental and inter-governmental organisations, donors, development consultancies and think tanks, it was still possible to triangulate among different points of view and experiences in order to arrive at conclusions that are less likely to be biased towards one particular point of view than if fewer individuals from less diverse backgrounds had been interviewed.

Another problem inherent in an interview-based research design is that it tends to be difficult to encourage interviewees to discuss failure. Yet often the most interesting lessons can be learned from failure. Nevertheless, useful information regarding failed as well as successful Kenyan mini-grids could be gathered by guaranteeing the interviewees' anonymity, allowing conversation to flow freely and building trust throughout the interview. Interviewees were then directly encouraged at the later stages of the interviews to discuss failures that they had witnessed in the mini-grid sectors. However, it should be noted that interviewees limited their willingness to discuss failures to former rather than current employers or projects in most cases.

Finally, interviewing local practitioners and experts, i.e. foreign elites, as a white, western researcher brings with it a certain positionality. In most cases the interviewer is seen as an outsider and thus the information provided to the interviewer might be self-censored in order to project a particular image from the inside onto the outside world. However, as for example Herod (1999) has noted, being an outsider can also “provide the opportunity for small-talk at the beginning of an interview which can operate as an ice-breaker, or it may mean that people feel less threatened than if they were dealing with a local researcher and they may therefore be more forthcoming with sensitive information and the like” (pg. 325). While this positionality is unavoidable when conducting expert interviews it is important to keep it in mind when analysing the research findings.

All of these methodological limitations, in particular those concerned with the depth and breadth of the data collected during the field visits to existing mini-grids, do not fundamentally impact the value of the research presented in this thesis, however. The emphasis of this thesis is very much on exploring the potential relevance of the new application of property rights and common-pool resource management theory to mini-grid management, as opposed to providing a definitive, empirically-based assessment of the specific challenges of mini-grid management in relation to specific case studies. This theoretical testing is therefore what defines the methodological emphasis on interviews with individuals with broader experience of mini-grid management, as opposed to an emphasis on detailed case studies or embedded ethnographic observation. Moreover, the work undertaken in this thesis provides a solid basis for studies that can use the theory developed and preliminarily tested in this thesis to design more

empirically-focused studies in future (as outlined in more detail in the concluding chapter of this thesis).

## **Chapter 4 - The Allocation of Property Rights in Mini-Grids**

This chapter examines the allocation of bundles of property rights within mini-grids by discussing the impact of different types of metering and payment collection technologies that are currently being used on the major routine operational challenges. This will be followed by a consideration of the effect of these technologies on the allocation of property rights to different entities (for example private companies or community-based organisations) and the resulting property rights regimes within mini-grids. This analysis is underpinned by empirical data from the three case studies and expert interviews. Based on these data, the analysis provides the first evidence of the potential usefulness of a management platform as introduced in section 2.6. This could, for example, bring together the private owner/proprietor and the community represented by a community-based organisation, a novel concept that is discussed in considerably more depth in chapter 6. The analysis concludes by suggesting that there are remaining operational challenges that cannot easily be solved through technological interventions, but rather require a careful and systematic application of theories of collective action in order to arrive at innovative institutional arrangements to overcome them. The chapter begins by considering some of the advantages and disadvantages of different metering and payment collection technologies and their impact on the operational sustainability of mini-grids, based on evidence from case studies and interviews.

#### ***4.1 Technical Developments and their Impact on Operations***

The focus of this section is on the issue of metering and payment collection, rather than focusing on the technical challenges of mini-grid operation related to the generation technology, its suitability to the context or its maintenance and repair, which has been studied in detail (see chapter 2). This focus is important for a number of reasons. The challenge of metering and tariff collection was repeatedly identified as a critical factor by a number of interviewees and, as identified in section 2.2.1, the impact of modern metering and payment collection technologies on operations requires more research. Furthermore, the three case studies differ in their technical setup for metering and payment collection, thus allowing for a comparative analysis of the impacts that different technologies have on routine operations. First, the different metering and payment collection technologies are introduced in more detail.

In a mini-grid, as is the case with every other type of electrical grid (at least in theory), there are a number of ways in which customers can be charged for the electricity they use. The technologically simplest approach is one in which the amount of electricity used, i.e. the number of kWh, is not measured at all. Instead, customers pay a fixed weekly or monthly fee for their connection to the grid. In this simplest form there is no limit to the power they can draw from the system, other than the technical limitations of the grid itself. In order to avoid excessive consumption, current limiters (also known as power limiters) may be introduced, which limit the maximum power that is drawn by each connection. The most common technical setup worldwide, however, are post-paid meters, which measure the number of kWh consumed in a

certain time period. These meters are then read either in person or remotely and a bill is issued to the customer accordingly. Finally, a utility can decide to install prepaid meters, on to which a customer may load a certain number of kWh that can then be used at will, similar to minutes purchased on a prepaid mobile phone contract.

These prepaid meters have become increasingly commonplace in Kenya over the last few years, and even the national utility KPLC is changing most of their household meters to prepaid.<sup>11</sup> Furthermore, there are two ways in which credit can be loaded on to the prepaid meter. A consumer can purchase a scratch card at a shop with a code that is then used to add credit to the meter. Alternatively, however, the customer can use mobile-enabled payment systems to add credit directly to the prepaid meter without the necessity of leaving home to purchase a scratch card. In Kenya, SMS-based mobile-enabled payment is widespread and many who own a mobile phone, which as of 2013 was almost 80% of Kenyans (Malack et al., 2015), also have a mobile money account. By far the most widespread system in use in Kenya is called M-Pesa, and is owned and operated by mobile network provider Safaricom, which is the leading provider by market share. M-Pesa kiosks, where it is possible to add funds to an M-Pesa account, can be found even in the more remote areas of Kenya and were present at every site that was visited during the empirical data collection for this thesis.

Many of the donor-funded, community-based mini-grids established approximately 5 to 10 years ago in Kenya (e.g. Olosho-Oibor [one of the three case study sites for this thesis] and several micro-hydro mini-grids in the Mount Kenya region) were designed as unmetered systems with either open access or current limiters. There are some

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<sup>11</sup> [http://kplc.co.ke/img/full/4F8rkuaFUtAD\\_KENYA%20POWER%20USER%20GUIDE.PDF](http://kplc.co.ke/img/full/4F8rkuaFUtAD_KENYA%20POWER%20USER%20GUIDE.PDF)

advantages to this, such as reduced upfront cost (Interviewee 7) and straightforward financial forecasting due to the fixed amount paid by each customer in each period:

*‘It makes the business case easier. Everyone’s paying a fixed amount of money. In a franchisee type model where the entrepreneur is a local this works very well . . .’* (Interviewee 7)

However, the challenges associated with unmetered systems outweigh the benefits by far. The biggest challenge in an unmetered system is in effect the ‘tragedy of the commons’ as introduced in chapter 2. When paying a flat fee for electricity, there is no incentive to save electricity, but rather to use as much as possible in order to achieve the best price per unit consumed. Because of this implicit incentivisation for overconsumption, it is challenging to make an unmetered open-access system financially viable. Interviewee 15 provided the following example of an unidentified project:

*‘There was a case of a community project that was basically open access with a flat rate. . . . But after one year and a half the project was not realizing anything so they had to go back to their pockets to even have money to repair the system. So a donor had to come in and instead of being able to expand the capacity [they] had to introduce meters. It was very clear that if they had introduced meters from the beginning they would have gotten the right amount of revenue.’*  
(Interviewee 15)

In the case of Olosho-Oibor the situation is similar, although meters have not been retrofitted there. The local technician, who is employed by the community-based organisation, reported that in the past, whenever there was a technical fault and

consequently a repair needed, the community-based organisation approached the original donor, in this case UNIDO, to receive a donation to cover the cost of repairs. This was because the revenue from the flat fees was not enough to cover the operational costs and also set up a reserve. Raising the flat fee was also not an option, as this requires agreement among the members of the community-based organisation, who are themselves customers of the mini-grid. Thus, users were not willing to pay the full levelised cost of the electricity, including maintenance and repairs, even though they were only paying flat fees for a theoretically unlimited (from their point of view) electricity supply.

Introducing current limiters, even though they improve the excludability of electricity as a resource (which is discussed in more depth in section 4.2), does not assist in resolving this issue. In fact, according to a number of interviewees (Interviewees 2, 5, 7 and 11), current or power limiters add more problems for the most part. First of all, current or power limiters constrain users to low-power appliances, which is in tension with the aspirations associated with electricity supply:

*‘... when you introduce electricity to a rural setting the people might start very low — 3 bulbs and stuff like that — but after some time they start acquiring appliances and it becomes very difficult to keep replacing the load limiter every time somebody buys an appliance.’*  
(Interviewee 11)

Such continual upgrades to the current limiters would be costly as well as extremely inconvenient for the customer, who must wait for their current limiter to be upgraded if they wish to use more energy-intensive appliances and must also plan for step changes in their electrical expenditure, as current limiter upgrades are accompanied by higher



flat fees (Interviewee 7). While some limitation on electricity usage would certainly be necessary in a system in which supply cannot always meet demand, there are other less binary solutions, which are discussed below. In addition to the inconvenience, it is likely that some businesses would not be able to operate at all with the limitations imposed by current limiters. One such example is a hairdressing business, which is popular in rural villages but also energy intensive. A typical hairdryer will draw approximately 1000 W of power, whereas the typical current limiter used in a mini-grid would only allow approximately 100 W (Harper, 2013). One interviewee observes:

*'A lot of businesses that do exist in these communities like hairdressing, which is very energy intensive. Having some sort of current limiter would mean they wouldn't be able to run their business. You really need to know the profile of the businesses that will be connected to the grid.'* (Interviewee 2)

This demonstrates the difficulty of operating the mini-grid in such a way that it can technically and financially sustain itself, while also keeping in mind the goal of pro-poor sustainable electricity access. Evidently, current limiters are not well-suited to support this goal, as they can hamper economic activity and development if used indiscriminately and across all types of end users. Finally, relating to the issue of financial sustainability, current limiters do not support a viable business plan, as Interviewee 5 observed in comparing current limiters to post-paid meters:

*'If you are trying to make something financially self-sustaining, effectively you are trying to sell your product, which is power. So current limiting is not a very good idea. Why would you limit people from buying your product?'* (Interviewee 5)

Because a current limiter with a flat fee limits the total amount a customer can consume in a given period of time it not only ensures that the customer does not use more than she paid for, but also limits the customer to this maximum amount, even if she is willing to pay for the ability to consume more. In this sense, post-paid meters have an advantage, as they do not limit consumption, but encourage people to consume more of the product that is being sold, i.e. electricity. Customers are able to consume as much electricity as they wish at the time when they need it, provided total demand does not exceed the total capacity of the mini-grids. Post-paid meters thereby provide convenience compared to current limiters. One interviewee stated:

*‘One of the advantages is encouraging the customers to use electricity. From the business point of view this is very good. [...] After they have consumed some people then find it difficult to pay. So you sometimes have many people defaulting.’ (Interviewee 7)*

This introduces the obvious disadvantage of post-paid meters. Collecting the money from every customer at the end of the month is not just costly and labour intensive, but people often find it difficult to pay for the electricity they have consumed. Even without the additional costs incurred by following up with customers who are in arrears, a post-paid meter must be read by a person who goes from door to door, and some homes or businesses may be unoccupied at the time of the visit. This applies in particular to withdrawal, which must be accomplished through physical disconnection from the mini-grid. Furthermore, if a post-paid meter is read monthly, this means that the operation of the mini-grid must be financed upfront for the billing period plus the period allowed for the payment to be processed, which is typically a period of approximately six weeks in total (Interviewee 7). While this is not a problem unique to rural mini-

grids, the difficulty of collecting payments from customers, especially those in arrears, is exacerbated in this context, according to Interviewee 2:

*'If it is your sister or friend you charge them 10ct per kWh whereas the agreed level was 45ct a kWh and because you have that relationship it might be more difficult to collect debt compared to having a computer that says you can't have electricity . '* (Interviewee 2)

This alludes to the fact that prepaid meters, especially in combination with mobile-enabled payment systems such as M-Pesa in Kenya, can overcome many of these challenges by reducing or even completely removing the opportunity for these types of conflicts of interest within the community. Furthermore, there are major logistical and operational advantages to using prepaid meters, which Interviewee 22 summarised as follows:

*'Prepaid meters with mobile money are a bit of a game changer especially for mini-grids because it takes cash collection out of the system which is a huge issue. . . . Collecting 10-20 USD a month from 100 households each month would be a lot of money for an operator who maybe makes 200 USD a month. The logistics of moving the money around and depositing the money can be very challenging. The bank might be 20 km away. Prepaid mobile money avoids a lot of that hassle. '* (Interviewee 22)

Interviewee 7 also illustrated how this lack of financial infrastructure not only affects the mini-grid owner/proprietor, but also the customer. In this case, the interviewee's father-in-law lived 30 km from the nearest town with a bank, meaning that saving money to pay at the end of the billing period was very difficult and involved

saving cash at home, where safekeeping the money may be challenging. As a result of this lack of financial infrastructure, it would be more customary to spend money as it is earned, a point that is raised again in relation to the seasonality of income. However, a post-paid metering system does not align with this spending pattern.

In addition to eliminating the need for collecting payments in person and the associated costs, the combination of prepaid meters with mobile money is desirable to both the owner/proprietor and the customer because it eliminates the need for financial infrastructure such as a bank. This has, however, been replaced by the need for mobile network coverage and the presence of M-Pesa agents in the communities. Yet, in areas with poor network coverage these problems can be overcome by installing systems where customers use mobile money to pay for their electricity while they are in areas with good network coverage. Customers receive a code they can then use to add the credit to their prepaid meter, which is outside the network coverage area (Interviewee 22). A further advantage of cashless transactions, according to Interviewee 5, is that they greatly reduce opportunities for theft. Cashless transactions using mobile money are therefore considerably more desirable than the ‘second-best solution’ (Interviewee 22) involving scratch cards sold for cash. Compared to meters that can be directly prepaid using mobile money, scratch cards involve a number of problems regardless of the type of monetary transaction involved in purchasing them, particularly if the goal is to scale and replicate the business model:

*‘Trying to get scratch cards to the agents can be incredibly difficult. . . . There is a credit issue as well because you typically have to give it to the agents on credit and then trying to reclaim that cash from maybe 100 agents is a nightmare.’ (Interviewee 2)*

Prepaid meters are also flexible and allow users to choose when they have money available to buy electricity. This exhibits a closer fit with the seasonal nature of the income pattern of much of the population in rural areas, especially in communities in which agriculture is one of the major economic activities. Prepaid meters provide customers an opportunity to purchase electricity in advance, when they have disposable income, but does not commit them to a monthly contract like flat-fee business models:

*‘People’s income here is very seasonal. If they are catching fish they have money. [...] Being able to buy power when you have the money and not buy power when you don’t have it just makes sense.’*

(Interviewee 5, referring to Mageta Island)

As has been mentioned above, saving up for future expenses is difficult, especially in rural areas where financial infrastructure is lacking. For example, both Olosho-Oibor and Kitonyoni are several hours’ walk from the nearest bank and there is no bank on Mageta Island.

Finally, prepaid meters that return usage data to the mini-grid operator via remote monitoring systems allow for more flexible business models and provide a much better understanding of the demand patterns within the community, according to Interviewee 20. These significant impacts of prepaid meters, combined with mobile-enabled payment on the operations of a rural mini-grid, also affect the allocation of bundles of property rights among the different stakeholders. The next section therefore analyses how these different technologies can be analysed from the perspective of property rights theory, before the final section of this chapter considers the operational implications of this analysis.

## 4.2 *Metering Technologies and the Allocation of Bundles of Property Rights*

In order to analyse how different metering technologies affect the allocation of bundles of property rights within a mini-grid based on the empirical data presented above, it is important to reconsider the concept of a common-pool resource and associated concept of bundles of property rights. First of all, a common-pool resource, as introduced in section 2.5, does not need to be associated with a particular property rights regime, such as public, common or private property. In fact, as Ostrom and Hess (2007) argue

*‘... the world of property rights is far more complex than simply government, private and common property. These terms better reflect the status and organization of the holder of a particular right than the bundle of property rights held.’* (Ostrom and Hess, 2007, p. 15)

Instead of the somewhat simplistic view of property rights as being private, public or common, Ostrom and Hess therefore argue for the classification of the five different property rights and associated positions for actors within a resource system set out in Table 4.1 below.

**Table 4.1** - Bundles of Property Rights Associated with Positions within a Resource System

	FULL OWNER	PROPRIETOR	AUTHORISED CLAIMANT	AUTHORISED USER	AUTHORISED ENTRANT
ACCESS	X	X	X	X	X
WITHDRAWAL	X	X	X	X	
MANAGEMENT	X	X	X		
EXCLUSION	X	X			
ALIENATION	X				

Source: Ostrom and Schlager (1996, p. 133)

Different actors or groups of actors (including a private person or company, a community-based organisation or the public sector) can hold different bundles of property rights and thus different positions within the same resource system. In addition, it should be noted that these property rights can be related to the resource system itself (i.e. the physical infrastructure of a mini-grid, such as solar panels, wires, meters, etc.) as well as the flow of resource units (i.e. the supply and consumption of electricity).

There are therefore two operational dimensions along which the allocation of property rights within a mini-grid can be considered based on the delineation of different property rights into operational level rights (access and withdrawal) and collective choice rights (management, exclusion and alienation) as defined by Ostrom and Schlager (1996). The impact of different metering technologies is an operational level consideration, whereas the allocation of management, exclusion and alienation rights held by different actors is a consideration at the collective choice level. The impact of the different metering technologies discussed in the previous section is considered first.

An open access system such as the one in Olosho-Oibor does not differentiate between access and withdrawal rights, meaning the authorised entrant and authorised user positions are identical. This basic allocation of property rights is not affected by the introduction of current limiters. The current limiter only limits the maximum resource flow rate from the resource system to the authorised user, i.e. the maximum electrical power that an end user can draw. Nor can a post-paid meter, although in effect privatising the resource (which is covered in more depth in section 6.1), affect the

allocation of bundles of property rights in and of itself. As long as an end user is connected to the mini-grid and is thereby an authorised entrant, she is also an authorised user, so long as she pays her electricity bills on time. This is equally true for post-paid meters as well as flat fee tariffs. Only if the end user fails to pay the tariffs is he or she physically disconnected from the mini-grid by a technician, meaning that the access and withdrawal rights are simultaneously revoked.

With the introduction of prepaid meters (as is the case in Kitonyoni and on Mageta Island), this allocation of property rights becomes more sophisticated, as previously discussed in section 2.5. Whether a customer connected to the grid is an authorised entrant with access rights or an authorised user with withdrawal rights becomes dependent on the credit on their meter. Once their credit is exhausted, their withdrawal rights are automatically revoked until they have loaded additional credit on the meter. However, even if their withdrawal rights are revoked, their access rights remain, as they are not physically disconnected from the grid. They can load credit on to the prepaid meter and thus regain their withdrawal rights, without having to re-establish their access rights to the mini-grid. With the introduction of mobile-enabled payment systems such as M-Pesa, this process becomes even simpler, as the end user can regain withdrawal rights without even leaving their home or business to buy credit in the form of scratch cards. This automation of the allocation of withdrawal rights also means that exclusion (of the privatised resource electricity) in the case of prepaid meters is not controlled by a proprietor, who may favour relatives or friends within the community despite the fact that they are in arrears, but is an automatic process that is straightforward to understand.

Furthermore, management, being the right (or in this context, the ability) to devise operational level rules, is also positively affected by the introduction of prepaid meters,



especially due to the availability of highly granular demand data and the ability to quickly react to this information. Thus, prepaid meters also facilitate the responsibilities of the authorised claimant, a position within the mini-grid that may possibly be held by a variety of different actors. This relates to the second dimension along which property rights theory can be used to understand mini-grid operations — the allocation of rights at the collective choice level.

The institutional setup of the mini-grid is the major determinant of the allocation of collective choice level property rights. The operational-level rights of access and withdrawal are, by definition, always allocated to the end users, i.e. the anchors, businesses or households which form the different user groups for the purposes of this thesis. Meanwhile, collective choice level rights can be held by different entities. In Kenya, there are currently three different models in operation: public, private and community-based. In each case, all collective choice level rights are typically held by one single entity. The Kenyan utility KPLC, which is majority-owned by the Kenyan state, is the full owner, proprietor and authorised claimant of public mini-grids, which are not the focus of this study, as established in chapter 1. The allocation of property rights within each of the latter two categories (private and community-based) can, however, be illustrated based on the case study mini-grids.

Mageta Island is a privately owned and operated mini-grid, meaning that the full owner, a Kenyan private company, is also the proprietor and authorised claimant of the system. In this position, the private owner decides who holds access and withdrawal rights based on their ability to consume electricity and pay for it, and not based on community consensus as might be the case in a community-based model. In this case, the authorised users are merely clients and any superior property right is held by an

entirely separate private entity. In the case of Mageta, the owner has decided to hire a local manager to represent it as authorised claimant. In addition to basic maintenance such as cleaning the solar PV panels, he can, for example, decide to start the backup diesel generator or limit the amount of power available to the grid based on the state of charge of the battery bank. Arguably, since he is hired by the private owner and could be dismissed, the right of management still rests with the full owner of the system. There hence is a clear dividing line in the Mageta Island grid, where everything below withdrawal rights in Table 4.1 is held by a private company that is exogenous to the community.

In this respect, Olosho-Oibor is diametrically opposed to Mageta Island in that a community-based organisation is the full owner and proprietor of the mini-grid and employs a manager who represents it as the authorised claimant. Because the authorised users are also involved in the management, exclusion and alienation process through their representatives in the community-based organisation, there exists a certain degree of overlap between those holding collective choice level rights and those holding operational level rights. Importantly, as has been mentioned when introducing this case study in section 3.2.2, in reality, the manager is only an authorised claimant because any decision of exclusion must be passed through the community-based organisation. Thus, Olosho-Oibor represents the prototypical allocation of property rights for a community-based mini-grid, just as Mageta Island is a prototypical example of a private sector mini-grid.

Kitonyoni, while also a community-based mini-grid, exhibits a slightly more complex allocation of property rights. To review, Kitonyoni is fully owned by a cooperative with a supervisory committee, which is elected by the members of the

cooperative every three years and in effect holds the position of proprietor. The authorised claimant managing and operating the mini-grid is a management committee, which is established by the proprietor in the form of the supervisory committee. They are responsible for running the battery-charging hub, selling prepaid credit to the connected customers and maintaining the mini-grid. The University of Southampton, which holds the principal investigator role in the project, donated and built the Kitonyoni mini-grid. Through remote load management using SMS-based remote monitoring technology described earlier, the University also holds some of the authorised claimant rights. At the time of the site visit for this research, only approximately 1.5 kW of the available 14 kW capacity had been made available for consumption within the mini-grid, with the aim of slowly making this capacity available as demand in the community grows. Clearly, compared to Mageta Island or Olosho-Oibor, the institutional arrangement in Kitonyoni is more complex, involving a nested structure of entities holding different bundles of property rights. In particular, the position of the authorised claimant is in effect held by two entities: the management committee formed of community members and the University of Southampton through its ability to remotely control the amount of electricity made available for consumption.

Mageta Island and Olosho-Oibor hence sit at opposite ends of the spectrum of allocating bundles of property rights to the community or a private entity. While as a private property regime Mageta Island has the advantage of timely and straightforward management, the community is simply a customer and hence it does not seem to enjoy the same level of local support as Olosho-Oibor, a common property regime. Kitonyoni, however, shows that different positions within the property rights regime of the mini-grid system can be held simultaneously by different types of actors — a finding that becomes important throughout the remainder of this thesis.

The cooperative in Kitonyoni and the community-based organisation in Olosho-Oibor can be considered institutions for collective action in the presence of a common-pool resource, similar to community-based irrigation management institutions that have formed the basis for much of collective action theory (Bravo and Marelli, 2008; Ostrom, 1990, 1992; Sarker and Itoh, 2001; Tang, 1989). The sense of ownership and support that this instils can be illustrated by the fact that in Kitonyoni the community remained committed to their own mini-grid, despite the arrival of the national grid, because they see its direct benefits and it gives them a certain sense of pride. By contrast, a member of the community in Mageta set up a small diesel-powered mini-grid as a private enterprise, which is now in direct competition with the other grid (see section 5.2. for a more detailed discussion of this).

Three factors therefore provide the first indication that there may be benefits in combining private sector with community-based approaches to achieve sustainable mini-grid management models. First, the case of Kitonyoni shows that it is possible for more than one entity to occupy the position of authorised claimant. Second, the case of Mageta Island, as well as the interviewee evidence presented so far, demonstrates the benefits of a private sector owner, proprietor and authorised claimant (a private property regime) with the necessary technical and financial capabilities for sustainable mini-grid operation (this is revisited in chapters 5 and 6). Third, the resilience of the Olosho-Oibor system (a common property regime), despite its financial and technical struggles, demonstrates the benefits of community involvement, which is further supported by interview evidence:

*‘Working with them [the community] to find out what they want and how much they are going to use is important. In this case they might not know the product very well. They know of the product but they*

*don't know how to use it productively. . . . It absolutely has to be with the community because you can't dictate what they are going to do and how they will do it. ' (Interviewee 9)*

*'From the conceptualization of the project you can help train people. Give them awareness skills. Let them understand what this system is. They didn't call you and tell you that they want you to build a solar system in their community. You're coming in to do it. So you must also explain to them the advantages of this system over what they are using right now. Don't just assume that "it's electricity, they will love it." No. Make them aware what you introduce to them. You are introducing change in a community, basically. ' (Interviewee 15)*

On the basis of this more sophisticated conceptualisation of bundles of property rights informed by insights from the literature on common-pool resource management, it becomes possible to consider a carefully designed approach where the position of authorised claimant is held by a combination of community-based and private sector entities as a means of combining the advantages of both of these models.

### ***4.3 Combining Private and Common Property Regimes***

The analysis in the previous section suggests that within the theory of bundles of property rights, the role of the authorised claimant could be held by a management platform similar to the platform for resource use negotiation suggested by Steins and Edwards (1999) in the context of a complex common-pool resource (introduced in section 2.6). In the context of a mini-grid, such a management platform could bring

together the private sector owner/proprietor and the community represented by a community-based organisation. In such a model, the community, through a representative entity, would be involved in some aspects of the management and operation of the mini-grid, thereby providing a platform not only for interaction between the private owner of the mini-grid and the community, but also for essential aspects of building capacity and aligning expectations. A few initial findings from this chapter can be used to formulate some of the possible benefits, while chapter 6 develops the role and property rights position held by such a platform in more depth, and chapter 5 determines in much more detail which operational challenges it could help to overcome.

In direct response to the interview evidence presented at the end of section 4.2, a community-based organisation could be responsible for initiating stakeholder meetings with the community in which the private owner and proprietor could explain the plans for mini-grid-based electrification in the community, including the potential opportunities and, importantly, the limitations of the system. In return, the private company could gain a better understanding of how community members wish to use the electricity. An important advantage of such a platform for interaction between the private owner and the community, however, would be that the process of community engagement, which is currently typically only done once during the project development stage for a rural mini-grid (e.g. Franz et al., 2014) would not be a one-time snapshot of intentions for electricity use in the community. Rather, it could become a continuous and dynamic process in which the operator can adapt to the changing needs of the community. If the interaction between the community and the private owner is frequent and regular, this could allow the private company to proactively avoid operational

challenges by working with the community, rather than reacting to problems after they have developed. Interviewee 3 makes the following observation:

*‘ . . . So the bottom line is, I think, the systems can complement each other. I think the sustainability of the private sector approach and the strength of the community approach where everybody is actually involved, when the two are married you have a better model. ’*

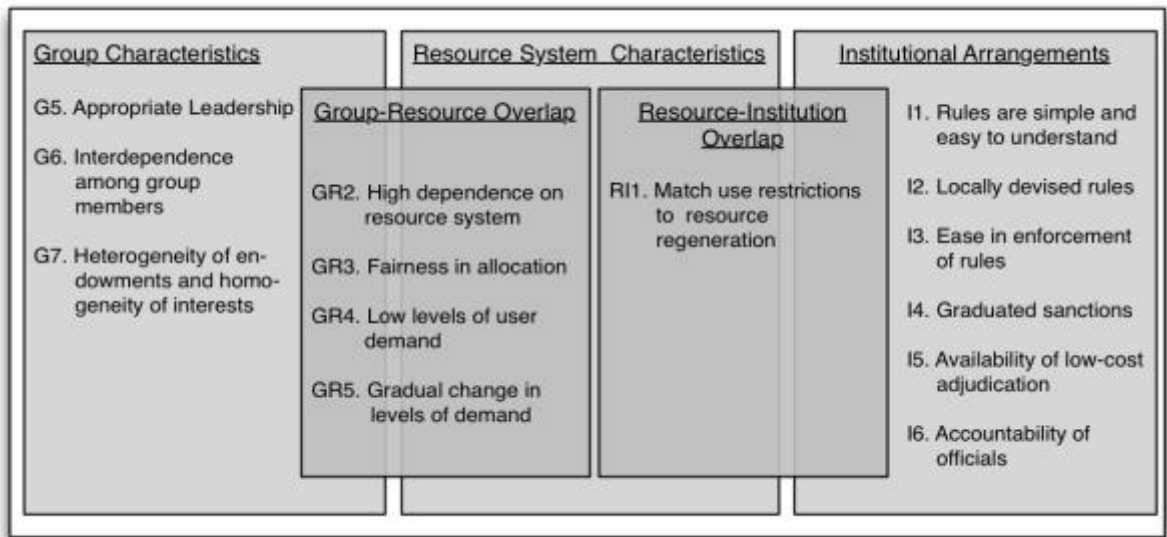
The need for interaction among different stakeholder groups is emphasised by this conception of a management platform which combines aspects of private and common property rights regimes. This relates to the argument made in section 2.4 that electricity in a mini-grid exhibits the characteristics of a complex common-pool resource and that useful lessons can therefore be learned from applying theories of collective action to the problem of electricity as a resource in a closed mini-grid system. This is particularly true for those operational challenges that remain despite the use of prepaid meters and mobile-enabled payment systems and their many advantages. Chapter 5 introduces these persistent operational challenges. By systematically applying the refined theoretical framework of enabling conditions for successful common-pool resource management developed in section 2.10, this thesis demonstrates how useful non-technical institutional responses can be developed by drawing on the set of enabling conditions for collective actions that are typically used in the context of other common-pool resources, such as water for irrigation. In doing so, it also further explores the ways in which a management platform may be able to positively affect the operational sustainability of a mini-grid.

## **Chapter 5 - Enabling Conditions for Collective Action in Mini-Grids**

This chapter represents the second empirical section of this thesis, and demonstrates how the refined theoretical framework presented in section 2.10.6 and in Figure 5.1 can usefully be applied to structure the analysis of these empirical data and therefore structure consideration of sustainable operation of rural mini-grids more broadly. In order to achieve this, the chapter considers each of the enabling conditions identified in the refined framework, thus demonstrating their relevance to the sustainable management of rural mini-grids, and provides examples from the case studies and expert interviews to illustrate the importance of each enabling condition for collective action. This facilitates a subsequent discussion of factors influencing the long-term operational sustainability of mini-grids.

Throughout this chapter, it becomes clear that the two key operational challenges faced by rural mini-grids relying largely on renewable energy sources and, in particular, solar PV (as is the case in all three case studies), are centred around seasonal variations in supply and demand as well as the difficulties involved in serving a variety of different consumer groups from a supply of electricity that is much more limited than that of a national electricity grid. These challenges differ from the operational challenges related to metering and tariff collection because even in the presence of prepaid meters, these challenges may remain and thus, arguably, require institutional mechanisms to overcome them.



**Figure 5.1** - Refined Theoretical Framework

Source: Author (developed based on framework by Agrawal (2001, pg. 1659))

Essentially, the challenges are centred on matching supply and demand. One of the overarching enabling conditions to consider throughout the chapter is therefore:

RI1: Match use restrictions to resource regeneration

Whilst this need to balance supply and demand is common to all electricity grids, seasonal fluctuations of supply and demand are particularly challenging in a rural mini-grid depending largely on solar PV, wind or both for electricity generation. The mini-grid in Olosho-Oibor has historically struggled with this balancing act. The local manager recounted that at times it has been necessary to shut off entire segments of the mini-grid in order to avoid draining the batteries too quickly and being required to run the diesel generator — a costly backup solution, the operating expenses of which could not be covered by the low tariffs charged. During the rainy seasons in particular, it was often not possible to fully recharge the battery banks during the day, necessitating such load-shedding measures after sunset. The difficulty of load management was further exacerbated by a lack of technical understanding of the mini-grid. This is evidenced by

the fact that the community bought an electric welder, which they were never able to use as the mini-grid cannot supply the power required to operate it. In summary, Olosho-Oibor evidently struggles with this enabling condition.

In Kitonyoni, on the other hand, load management is achieved through two different measures. First of all, the system has large amounts of excess generation capacity, i.e. it could support considerably more load than is currently demanded by the local businesses connected to the mini-grid. While this is a highly effective way to avoid overloading and minimise the need for load management, it is also very expensive and thus challenging to scale and replicate. This approach can only work in the context of a not-for-profit, donor-supported pilot project. Secondly, a team of researchers at the University of Southampton remotely control how much of the available electricity supply is released for consumption by local businesses, public facilities and the charging kiosk. The potential benefits and drawbacks of this arrangement are discussed below in relation to conditions GR5 (gradual change in levels of demand) and I1 (rules are simple and easy to understand).

In terms of capacity utilisation, the grid in Mageta Island operates in a different mode than Kitonyoni; as demand for electricity grew, the private owner of the mini-grid added additional generation capacity to meet demand. However, this capacity was only added once it had become clear from detailed data on electricity usage that the demand for this additional capacity really existed. In general, the grid in Mageta Island is based on a highly technology- and data-driven approach that collects detailed and highly granular demand data for each connection.

Further evidence of the challenges associated with load balancing, especially on the demand side, can be drawn from the interviews. Seasonal variations in demand are

greatest in areas in which agriculture dominates the village economy. During the harvest season, for example, there is considerably higher demand than usual, as people need to mill and grind their crops and have more income to spend on electricity. On the other hand, during the dry season, especially in January, demand tends to be lower as people are cash-strapped, and the seasonality is further exacerbated by the need to pay school fees at the beginning of the year. In the majority-Muslim northeast of the country, much lower demand occurs during Ramadan, as noted by one interviewee:

*‘For example, in the Northeast most of the people there are Muslim. So demand during Ramadan is normally very low compared to the other months . . . When the school begins that also affects almost all the payments. Or after the holidays when people spend a lot they then struggle in January.’* (Interviewee 7)

Furthermore, demand varies throughout the day, with household demand peaking after sunset as demand for lighting increases. An interviewee notes that this peak is exacerbated by traditional practices in agricultural areas:

*‘. . . there are challenges because traditionally people tend to do processing in the afternoon and in the evening so the time of day affects balancing your power load as well.’* (Interviewee 1)

Keeping these challenges in mind, the remainder of this chapter reviews in succession each of the enabling conditions of the refined framework developed in section 2.10 and reproduced in Figure 5.1, and presents evidence from the case studies as well as interviews that speaks to each enabling condition. The subsequent discussion in chapter 6 then analyses how this conceptual framework can contribute to understanding the role of socio-cultural institutional innovation in the management of mini-grids.

## ***5.1 Group Characteristics***

### G5: Appropriate Leadership

The importance of appropriate leadership — defined by Agrawal as being young, familiar with changing external environments and connected to the local elite — in the management of a rural mini-grid and the impact on its long-term sustainability and the chances for successful collective action becomes evident in a number of empirical examples. Again, it should be noted that this definition of appropriate leadership does not necessarily fit the reality on the ground. In Olosho-Oibor, for example, the community-based organisation officially overseeing the management of the mini-grid is comprised of village elders, rather than a young leader, who are respected by the community but lack the technical and financial capacity required to operate it effectively. This is evidenced by the fact that the community-based organisation could not agree on a tariff that would cover the operating and maintenance costs and allow for a small reserve for repairs and unplanned maintenance to be accrued. Furthermore, according to the local manager, even though there have been customers in arrears, those failures to pay have never resulted in permanent or even temporary disconnection. Despite these problems, at the time of the visit the local manager had been able to keep the mini-grid operational for six years by attracting further donor funding from UNIDO and UNICEF. Appropriate leadership is clearly not fulfilling all the requirements within the community-based organisation in Olosho-Oibor, as the committee itself is not young and their familiarity with the external environment is unclear. However, this case illustrates that Agrawal's definition of appropriate leadership is flawed in this context

and shows that a well-trained local manager is equally important and can supplement the leadership.

In the case of Kitonyoni, the research group affiliated with the University of Southampton assisted the community in creating and registering a cooperative, which owns the mini-grid. This cooperative employs a dedicated management committee, which is comprised of three community members. The members include two women who have been trained in cooperative management as well as simple day-to-day maintenance, such as cleaning the PV panels from dust, as well as operating the kiosk in which prepaid scratch cards to load credit on to the meters are sold and where small appliances may be charged for a fixed fee. The management board of the cooperative is elected by the members of the cooperative every three years, ensuring accountability of the leadership as well (see also condition I6 – accountability of officials). This speaks once again to the importance of local, dedicated management, further supported by evidence from the interviews:

*‘He [the local technician] is the first point of contact to the management. Most of the time when you have an issue a wire came loose or very basic things so a technical person doesn’t need to go there. . . . You need a leader in the community that understands a little bit of the system and makes sense of it.’* (Interviewee 19)

The case of Mageta Island emphasises this point even further. The private owner/proprietor employs a local technician who is the first point of contact for customers and deals with simple maintenance and repair requests. He also alerts the operator of any major repairs that are required. At the time of the visit, for example, two of the PV panels had been damaged in a storm and the technician had already ordered replacement panels from the owner. This is in stark contrast to Olosho-Oibor, where the

local manager complained that, especially in the first few years of operating the mini-grid, he never knew who to contact in case of a technical fault such as a broken wind vane on the wind turbine or poorly performing batteries. It should be noted that appropriate leadership, as understood in the enabling conditions for collective action, is less concerned with the technological capability of the leadership, but rather the legitimacy of the process in which the leadership is selected and their connection to the community. In this sense, appropriate leadership is present in all three case studies, albeit in most situations in the form of a local manager (or management committee) who is connected to the community and an organisation (the University of Southampton for Kitonyoni and the private owner for Mageta Island) that is familiar with the changing external environment. Only in Olosho-Oibor is the appropriateness of this latter entity unclear. The requirement for appropriate leadership to be young is simply not realistic in this context.

This therefore emphasises that appropriate leadership may comprise two entities: local management together with a specialised organisation that owns and operates the mini-grid. That the specialised organisation has the appropriate technological capability as well was a factor that was also raised in the interviews (see also condition I6 – accountability of officials):

*‘Having a specialized organization that is looking after several of these sites and has the industry know-how is integral. Otherwise it is like a classroom being built and then used as a chicken pen. You are just building the infrastructure and not creating the ecosystem around it.’ (Interviewee 2)*

The importance of a dedicated and specialised organisation in achieving appropriate leadership also becomes evident when considering a key challenge in managing a mini-

grid: tariff setting. There are two potential pitfalls when determining tariffs with the direct involvement of the community rather than with a view to financial long-term sustainability and viability. In Kitonyoni, for example, tariffs were set based on community surveys. According to the village chief, community members were asked to predict what they would be able to pay for electricity based on current expenditure on other sources of energy (a typical stated preferences approach). They did not want to appear poor, so they overstated their ability to pay, resulting in initial tariff levels considerably higher than anything the community had previously spent on energy. In order to ensure the viability of the system, tariffs quickly had to be lowered to accurately reflect the ability to pay i.e. their stated preferences did not match their revealed preferences. The other issue with locally-determined tariffs is potential for elite capture and conflict, as noted by one interviewee and already mentioned in chapter 4 in relation to the benefits of prepaid meters over post-paid meters:

*‘There are mini-grids around that have followed an entirely community-based approach particularly for tariff collection and tariff setting. But they run into a number of issues because if it is your sister or friend you charge them 10ct per kWh whereas the agreed level was 45ct and then because you have that relationship it is more difficult to have debt.’ (Interviewee 4)*

This experience suggests direct peer-to-peer involvement in tariff payment collection could lead to operational difficulties and potential conflicts. Such dynamics seemed problematic within the community at Olosho-Oibor, where, as previously mentioned, disconnection due to failure to pay had not been enforced in practice. In summary, considering the enabling condition G5 (appropriate leadership) has highlighted the importance of dedicated management with a local presence and a

specialised organisation operating the mini-grid. Together, these two entities represent one viable way to achieve appropriate leadership as defined in the enabling conditions.

#### G6: Interdependence Among Group Members

Interdependence among group members is considered an enabling condition in collective action theory because it increases the likelihood that members will collaborate in order to avoid resource depletion and its negative associated effects. The empirical evidence in relation to mini-grids with regards to this condition is mixed. In Olosho-Oibor the interdependence between group members is more difficult to assess and observe due to the largely pastoral nature of the livelihoods in the area than in the other case study communities. A less collaborative village economy around electricity was observed than was seen in Kitonyoni and Mageta, which are based heavily on agriculture and fishing, respectively. It could be hypothesised that if there is indeed a comparatively lower degree of interdependence within the community, this could be one of the explanatory factors in the community-based organisation's struggle to develop the types of collective action institutions discussed in this thesis. Such institutions allow for collaborative uses of a limited amount of electricity and, in turn, create opportunities for productive uses. Aside from a small shop, a charging kiosk and some of the computers originally donated by UNIDO that are still operational in the school, little new activity beyond lighting, least of all economic activity, has developed in the community. Nevertheless, other factors related to the group may have aided in keeping the grid operational despite all the challenges faced (see also condition G7 – heterogeneity of endowments and homogeneity of interests).



In this respect, Kitonyoni is a much more active village economy with a variety of end uses for electricity ranging from sewing to electronics repair and a hair salon. According to the logic of this enabling condition, the community should thus be more likely to succeed in acting collectively towards the benefit of the mini-grid. They are not only subsistence farmers; rather, they are a complex village economy depending on each other for products and services. Mageta Island is quite similar in structure in that there is a variety of different end uses, such as electronics shops, bars and a music hall. Despite the fact that most of the men in the village are fishermen and the vast majority of their income is derived from fishing, some of them have developed side businesses. The local manager is a good example of this phenomenon. He still goes fishing and also operates a small kiosk selling small electronic appliances. Thus, the community members depend on each other and the use of electricity, which, according to the logic of the enabling condition, makes them more likely to form collective action institutions in order to sustainably manage the mini-grid. Generally speaking though, interdependence of group members (condition G6) is closely related to heterogeneity of endowments and homogeneity of interests (condition G7).

#### G7: Heterogeneity of endowments and homogeneity of interests

As previously mentioned, Kirubi (2009) has considered this particular enabling condition in the context of electricity in a mini-grid as a common-pool resource using three case studies in Kenya. He found that, in the case of the mini-grids studied for his thesis, heterogeneity of interests is positively correlated with the likelihood of successful collective action since those with the highest interest in the operation of the mini-grid are motivated to encourage collective action to improve long-term operational

sustainability. However, most of the evidence from the empirical data collected for this analysis points in the opposite direction, in that homogeneity of interest is positively correlated with collective action, as suggested by the enabling condition. One example of this is pre-existing organisations, which provide a focal point for the community. These can be in the form of a faith-based organisation, an agricultural cooperative or a similar group, which can, to some extent, form the basis of new institutional arrangements around electricity as a resource. According to one interviewee:

*‘I think the best characteristic of a community is actually, in order to make these projects more successful, the setting of the community. I found out that if there is some kind of structure in the community and not just the political structure, if there is a community that is focused on an institution like school or is built around a school or a church and there are clear structures there that could really support the working of the project.’ (Interviewee 1)*

A good example of such an organisation is the Girls’ Rescue Centre in Olosho-Oibor, which has helped to create a real sense of community in an otherwise relatively dispersed pastoral community and is therefore also linked to condition G6 (interdependence among group members). As has been previously suggested, this helps to partially explain the fact that this mini-grid has survived for so many years in spite of almost constant financial and technical difficulties. Of course there is no guarantee that such an organisation will create homogeneity of interest, as community members can still pursue different interests in their individual uses for electricity. However, it is important to recognise that a pre-existing organisation in the community can foster cohesion and create at least some shared interests, which, according to the logic of this enabling condition, can help to facilitate the emergence of collective action. In Kitonyoni and Mageta Island, such a structure fostering community cohesion and

shared interests does not exist. Without conducting a household survey, which was beyond the methodological scope of this thesis, it is generally difficult to assess the heterogeneity of endowments (in this case understood as different levels of income and wealth) as well as the homogeneity of interests. Nevertheless, the interdependence among group members, as mentioned under condition G6 above, suggests a certain degree of homogeneity of interests in the mini-grids that were the subject of field visits and exhibited characteristics of successful management.

Condition G7 (heterogeneity of endowments and homogeneity of interests) was also raised in several interviews, in particular in the context of the overarching challenge of serving different consumer groups, namely, anchors (A), businesses (B) and the community (C), as defined in the literature discussed in chapter 2. In particular, over-reliance on one anchor load can be problematic due to the misalignment of interests between the anchor load and the other consumer groups. One interviewee observes:

*‘If you put in an anchor [load] of course the anchor will consume 60% of the generation. Then you have 40% which the business people have to fight over together with the consumers on the ground to get it. So what do you really want to do?’* (Interviewee 15)

Interviewee 7, referring to a community-based mini-grid in north-eastern Kenya called Mpeketoni, described how this can be a particular problem if the anchor is a ‘sensitive’ load such as a hospital. In this case, there was an agreement with the community that the hospital’s surgeon would inform the mini-grid operator when critical surgery was scheduled to be performed so that the operator could ensure all other loads that could cause blackouts would be disconnected during that time, thereby guaranteeing the power supply during the surgery. This level of heterogeneity of

interests is clearly problematic, including if other users depend on the electricity for economically productive purposes. This therefore suggests that homogeneity of interests is indeed an enabling condition for collective action in a mini-grid. The role of the heterogeneity of endowments, however, remains unclear, suggesting that the practical relevance of this particular enabling condition (G7) is potentially confounded in the context of mini-grids. This raises further questions that may warrant additional research in relation to the management of other types of common-pool resources that are assumed to be subject to this and other enabling conditions assessed in this thesis.

## ***5.2 Group and Resource System Characteristics***

### **GR2: High Dependence on the Resource System**

The condition of high dependence on the resource system is closely related to conditions G6 (interdependence among group members) and G7 (heterogeneity of endowments and homogeneity of interests) and highlights a significant empirical finding: the importance of small businesses in forming the backbone of the long-term financial sustainability of the mini-grid and the creation of economic opportunities in the community. As Interviewee 5 stated,

*‘For us, businesses is where it’s at. They use more power, they generate good income, the income they can generate by having power is significantly higher than without. . . . You are essentially giving people the ability to pay your bills.’*

However, this demand from businesses does not inevitably appear as soon as electricity becomes available. In fact, creating supplementary businesses, such as charging stations, agro-processing enterprises, water pumps or even television broadcasts of major sporting events, can help generate revenue from productive uses that is required for the financial sustainability of the mini-grid, to foster economic development in the community, or to create demand during daylight hours:

*‘If you diversify your productivity – irrigation, water pumping, commercial – it’s better for the existence of the mini-grid. You are producing power but you also need someone to take the power in.’ (Interviewee 15)*

This idea of diversified productive uses relates to the concept of a complex and multiple-use common-pool resource which was introduced in chapter 2. Electricity, in fact, should therefore be considered a multiple-use common-pool resource because it can ideally (in terms of its contribution to human and economic development) be used for a diversified portfolio of activities. This, in turn, helps create increased dependence on the resource, which is an enabling condition for collective action. It could therefore be argued that the homogeneity of interests in condition G7 (heterogeneity of endowments and homogeneity of interests) should be augmented with heterogeneity of uses as an enabling condition for collective action in the context of a mini-grid. This is discussed further in chapter 6. Furthermore, such diversification of uses can also help to alleviate some of the challenges around seasonality mentioned above, as explained by one interviewee:

*‘The fact that some communities are agro-based and they get paid at certain times of the month is a really big challenge. What I have seen [is] most of the mini-grids are in a place that has some form of regular cash flow. It is probably a trading centre so that in addition to the revenues in agriculture there is also*

*revenues in trade or there is a government institution there or a training institution and that attracts a certain amount of businesses or people who have regular income. And those are the places where you would find these mini-grids being successful.’ (Interviewee 1)*

Kitonyoni is a good example of a customer base that is diversified beyond agro-based economic activities and highly dependent on electricity. All of the end users connected to the mini-grid, apart from the public facilities (school, church and dispensary) use the electricity for productive purposes and are therefore financially dependent on it being available and reliable. On Mageta Island, the customer base is similarly diversified, although some households are also connected to the mini-grid in addition to businesses. One factor that could negatively affect the Mageta mini-grid in this context is the emergence of a competing mini-grid in the community. A local entrepreneur sells connections to a diesel generator at a fixed, unmetered, daily tariff. Even though he only provides electricity during daytime hours, as opposed to 24-hour availability of electricity through the mini-grid in the case study, this reduces the community’s dependence on the case study mini-grid. On the other hand, competition between two electricity providers could be beneficial for the community. The long-term effect of this competition remains to be seen, as the diesel-based mini-grid had only been installed a few weeks prior to the time of the visit and it appeared it was already struggling with reliability.

While there are many fewer productive uses for electricity in Olosho-Oibor, high dependence on the system is still a relevant condition due to the importance of electricity for the operation of the community facilities such as the school, dispensary and especially the rescue centre for girls. Once more, this also relates to the homogeneity of interests discussed as part of condition G7 (heterogeneity of

endowments and homogeneity of interests). Generally speaking, it can be concluded that high dependence on the resource is an enabling condition present in all three case study mini-grids, and a factor that was generally considered to be critical by several interviewees, especially in relation to the presence of small businesses and productive uses for electricity. Thus, collective action, if necessary, would also be supported by this factor.

In this context, it should be noted that the evidence presented so far also suggests that the dependence of households on electricity is much less important to sustainable management of the mini-grid than the dependence of productive uses (i.e. micro and small businesses) or socially valuable uses (e.g. hospitals or the Girls' Rescue Centre). The households therefore depend on the other loads to make the operation of the mini-grid sustainable, a point that closely relates to condition G6 (interdependence among group members) and that is revisited in the discussion in chapter 6.

### GR3: Fairness in Allocation

The perception of fairness in allocation of electricity is a critical factor, in particular in those cases where demand for electricity exceeds the available generation capacity. In this context, fairness is not an absolute term, meaning that every single user gets exactly the same amount, but rather it refers to the perception of fairness in the context of the particular community structure, something that Agrawal (2001) also notes. Of the three mini-grids visited, the problem of excess demand is most pronounced in Olosho-Oibor where, as has been previously mentioned, branches of the mini-grid must at times be switched off in favour of others. However, since this allocation is decided upon by the

community-based organisation, which is respected by the community (although its demographic representativeness of the entire community is unclear), it appears to be considered by the community as fair. This overlaps with the issues respecting condition G5 (appropriate leadership) and the issues of its legitimacy as well as condition G7 (heterogeneity of endowments and homogeneity of interests) and its relation to pre-existing organisations, in the form of the Girls' Rescue Centre in the case of Olosho-Oibor. Interviewee 23, who was closely familiar with the project, described the allocation process as follows:

*'... during the day they give priority especially to where they were charging the telephones and where they have the computers because in the school they don't need lighting during the day. Then they have some computers in the staff room for school. So as their day goes by maybe in the evening the priority will be given even to the hospital because they have one refrigerator they were using and they give it priority. So in the evening they want to be using the mobile phone charging unit then they also give priority to the rescue centre for the lights and maybe some of the students stay for one hour when they need it.'* (Interviewee 23)

This demonstrates a clear, needs-based allocation approach, which prioritises those uses that are most dependent on electricity for their planned activities at any given point, relating back to condition GR2 (high dependence by users on resource system).

On Mageta Island, the allocation is based on a purely for-profit model, i.e. electricity is allocated simply to those who can pay for it. While the simplicity of this, of course, makes management of the mini-grid straightforward, especially when combined with prepaid meters and mobile money, it is not a system that necessarily results in fair allocation, or rather allocation that is perceived as being fair. This was evidenced by the fact that even the local mini-grid manager himself complained that



electricity was too expensive. Thus it becomes clear that, given the pro-poor focus of this thesis, allocation of electricity should not be based purely on the ability to pay, but also take into consideration the needs of different end-users. This is not only true if electricity is a scarce resource, as in the case of Olosho-Oibor, but also when deciding who to connect to the mini-grid. In Kitonyoni only small businesses and community facilities have been connected but no households, as they were mostly located too far from the location chosen for the solar PV array. While this is a perfectly reasonable decision to make in order to save on the very high costs (both financially and in terms of technical losses) of extending a mini-grid by several hundred metres, those community members spoken to, including members of the cooperative management committee, expressed frustration with this decision, leading to the impression that the allocation was not perceived as fair by all community members in Kitonyoni.

In the allocation of a limited amount of electrical power, this issue of balancing financial or economic considerations with actual and perceived fairness in allocation is particularly challenging, given the different types of end users:

*‘The challenge is basically the amount of power and how much you can give each of these categories [anchors, businesses, households] for them to be happy. The anchor takes a bigger portion. This is your main consumer. The businesses will take second and then the consumer with their basic needs will come third.’*  
(Interviewee 15)

This allocation schedule, if an anchor load is present, is entirely rational from a business management perspective, in that those customers who can consume the most and hence create the most revenue for the mini-grid get the highest allocation priority. However, a lack of perceived fairness in allocation can create problems:

*'You can even talk to the anchor load and tell them 'please on this date can you reduce your consumption so we avoid disrupting people. Because when you disrupt many people they can be dissatisfied. But this one customer you can have a deal with. . . . So you want to take care of those who are bringing in a lot of money [the anchors] but also those who can make a lot of noise [the households].'* (Interviewee 7)

Thus, fairness in allocation is an important enabling condition in mini-grids. This is not only the case when electricity is scarce, but also in relation to determining who can be connected to the mini-grid and who, for various reasons, might not be able to be connected. If either or both of those aspects of allocation are considered unfair by any end-user group, it can create conflict and hence make collective action in resource management less likely to succeed.

#### GR4 and GR5: Initial Low Levels of Demand and Gradual Changes in Levels of Demand

Clearly, these two conditions are closely related and are important in the context of mini-grids because shocks in demand or step changes in demand patterns can cause sudden under-supply, which can overload the mini-grid infrastructure, cause blackouts and potentially permanently damage the system. If demand increases more gradually there is time to react to those changes and develop load management solutions (see conditions I1 [rules are simple and easy to understand] and I2 [locally devised access and management rules] below). Furthermore, beyond short-term variations, seasonality can also create step changes in demand, e.g. due to increases in disposable income during the harvest season or large increases in demand for electricity for agro-

processing. If these are not anticipated and load management measures developed in advance, they can also cause disruptions to the electricity supply. Gradual change thus relates not merely to the issue of how electricity usage changes over time, but also the predictability of this change (this is also suggested by Agrawal (2001)). If the demand changes are not distributed over long periods of time, i.e. several months, they must at least be predictable.

Olosho-Oibor is an example of demand changes that were gradual enough that the local management had time to develop the load management schedules mentioned above under condition GR3 (fairness in allocation of benefits from common-pool resource) in collaboration with the community, despite the fact that the grid never earned enough money to invest in system expansion itself. That is, due to the initially low levels of demand and gradual rise in demand for electricity in a community that had had little to no previous experience with electricity before the installation of the mini-grid (and hence would not have been able to accurately predict future demand patterns), there was enough time for collective action to emerge and develop institutional arrangements to overcome the challenges.

Kitonyoni has pre-empted this problem in a considerably more expensive but highly effective manner, by building in large excess capacity and controlling remotely how much of this capacity is available for consumption in the mini-grid. In a way, this arrangement ensured through outside intervention that initial demand in Kitonyoni was low and would only be able to grow slowly, as more capacity was made available. Given the importance of low initial levels and gradual change in levels of demand, this arrangement is likely to be highly effective in supporting long-term sustainability, at

least until demand levels reach the maximum capacity available in the mini-grid. How long that may take is difficult to estimate.

Mageta Island serves as a good example of the difficulty in forecasting demand growth. After the initial hub had been installed, which allowed approximately 30 individual connections, demand for more connections grew faster than anticipated and it was necessary to install a second hub with another 20 connections. Yet, even with those two hubs there appears to be large excess demand in the community, as evidenced by the diesel-based mini-grid set up by a local entrepreneur. Thus, on Mageta Island, demand grew rapidly, leading to competition in electricity suppliers rather than the emergence of collective action, which, in fact, was not encouraged by the private sector institutional arrangement of the mini-grid.

However, demand growing more quickly than initially anticipated is not an unusual challenge to encounter, as testified in the interviews in relation to other private sector mini-grids in Kenya:

*'I couldn't believe how quickly they figured out to use 2.5 kW . . . Much quicker than expected. A question of 6 months.'* (Interviewee 21)

*'In the first one year the growth is very high and then it goes to about 5%. . . . When you have a private investor they don't want to over-invest. . . . When that growth comes they [the private sector] might not be able to meet the demand. . . . When the demand goes up and you are not matching it the quality of supply goes down so the customers complain a lot.'* (Interviewee 7)

In addition to the challenges concerning rapid demand growth, the seasonality of demand can create step changes in demand as has previously been discussed with

respect to condition RII (match use restrictions to regeneration capacity). Smoothing those step changes is highly desirable to avoid grid overloading and customer dissatisfaction. One potential solution, as suggested by one of the interviewees, may be to focus on trading centres, i.e. market towns that are a focal point of economic activity in an area where demand may be less seasonal. However, since 70% of Kenya's rural population directly depend on agriculture for food and income (USAID, 2013, p. 5), this approach is likely to only have limited reach, particularly in light of the goal of universal electrification. Thus, there is a clear benefit from gradual changes in demand and, as is the case with many of these enabling conditions when considered in the context of a rural mini-grid, the relationship between enabling condition and collective action is reciprocal — a gradual change in levels of demand reduces the opportunities for dissatisfaction and conflict by allowing time for collective action institutions to emerge. But the presence of collective action institutions can also assist in the creation of other arrangements, which encourage gradual changes in demand through usage rules, another important enabling condition and one with a bi-directional relationship to collective action.

### ***5.3 Institutional Arrangements***

Institutional arrangements — where institutions are defined loosely, not just as specialised organisational structures but also rules, norms and commonly understood and accepted practices — are another key area in which concepts borrowed and adapted from theories of collective action can be a useful tool in overcoming the types of operational challenges faced by mini-grids that are discussed in this thesis. This is

particularly true for enabling conditions I1 (rules are simple and easy to understand) and I2 (locally devised access and management rules).

### I1 and I2: Simple and Easy to Understand, Locally Devised Rules

Use rules in a mini-grid can be, for example, in the form of type-of-use rules, e.g. prohibiting the use of particularly power intensive appliances such as kettles or irons, or time-of-day rules, e.g. preventing either certain customers from using power at certain times of day, or preventing certain end uses at specified times of day. Such use rules are also an important tool in helping the community in understanding the limitations of the mini-grid, as Interviewee 15 recounted in relation to a donor-financed, community-based mini-grid in the Turkana region of Kenya:

*‘We want people to understand that it is not that we don’t want them to use power but we want everyone to have access to this power and that you have their very basic needs covered within this. Through community awareness people need to understand that it’s a smaller system, there is also room to expand it, but it wouldn’t now be very prudent to start using heavy machinery that . . . shuts the entire system down. . . . Each and every household will already know exactly what they will use the power for . . . You will be given an amount of power based on your lot.’ (Interviewee 15)*

Based on this understanding, the consumers can begin to appreciate the challenges of matching supply and demand in a mini-grid. As a result, their expectations are more closely aligned with the limitations of the mini-grid and they are more likely to accept that occasionally the system can only support basic needs. This also relates to condition GR3 (fairness in allocation of benefits from common-pool resource). Through type-of-

use rules, the limited electricity supply available in a small mini-grid can benefit a larger number of people than it could without those rules. One example was described by Interviewee 18 in relation to an older community-based micro hydro mini-grid (Kathamba in the Central province of Kenya), confirming that such rules are being implemented in practice:

*'I went once to a village where they had something like 1 kW and were doing it from a small hydro. These guys had connected 41 homes and I was totally surprised. 1 kW, how do you divide that? But they were missing load limiters so you went to the houses and found this guy can only use 1 bulb or this guy can only use 2 bulbs.'* (Interviewee 18)

Such rules thus can also ensure each community member has access to a similar amount of electricity, e.g. by determining that each household must at least be able to light their home. Time-of-day rules can also be fairly simple: businesses or community facilities are encouraged to operate during the daytime hours, when household electricity demand is very low, and discouraged to operate after sunset, when electricity is required for household lighting and entertainment and high-power end uses would quickly drain and unduly strain the battery banks (Interviewees 5, 9 and 23). More generally, these simple rules can be used to inform consumer behaviour that is in accordance with the technical specifications of the grid, as noted by one interviewee:

*'... you can spread the load out throughout the day which major utilities around the world are trying to do but in this context you can make a direct message to people who don't yet have electricity consumption habits so they don't have to start with bad ones.'* (Interviewee 9)

This demonstrates a clear advantage of mini-grids over larger national grids if electricity is scarce and demand exceeds supply at times. While it is very difficult in large national grids to coordinate collective action and enforce use rules, the small group size of a mini-grid enables the development of use rules and makes enforcement easier (see conditions I3–I5 respecting rule enforcement and sanctioning).

Consequently, load management and the smoothing of demand peaks can be more easily achieved. An overarching consideration, however, is the importance of not only ensuring that condition I1 (simple rules) is met, but also that these rules are locally devised in collaboration with the community, in accordance with condition I2 (locally devised access and management rules):

*‘ . . . And also the community members, like the business people who require to do business after sunset, you also bring them on board to understand the role they are going to play in this particular project. . . . You go there one day and find that they have come up with their own set of rules to run that facility that you didn't even imagine. ’* (Interviewee 3)

Despite this inference of the potential usefulness, applicability and practicability of simple, locally devised use rules in cases where demand exceeds supply during certain times of day or seasons, there is very little evidence of such rules in the case study mini-grids. The only concrete example of such a rule can be found in Olosho-Oibor, in the form of the aforementioned deactivation of branches of the mini-grid during times of low supply. While this is a locally devised rule, which appears to be accepted by the community, it is relatively crude compared to the more complex type-of-use and time-of-day rules that could be further devised. Why the development of such rules has not been attempted in Olosho-Oibor is unclear, though it can be hypothesised that the rules are implicit rather than explicit, in that the rescue centre, school and dispensary are



prioritised in the electricity supply and the two businesses (charging station and shop) that are directly connected to the mini-grid only operate during the day.

In the cases of Kitonyoni and Mageta Island, the absence of use rules is due to structural and technical factors. Use rules simply are not necessary in Kitonyoni due to the large excess capacity built into the system. Nevertheless, the importance of local involvement in the design of any rules becomes clear when revisiting the fact that the University of Southampton only releases limited capacity for consumption according to a schedule, which has not been clearly communicated to the cooperative. While the cooperative is aware of the fact that this remotely-controlled capacity schedule is being implemented, they are unaware of the rules or the rationale for their development. The local village chief, who was available for conversation during the visit, expressed frustration with this situation and acknowledged that they had to contend with these limitations due to the fact that the mini-grid was ‘a research’. In Mageta Island, use rules are in effect communicated through price. That is, electricity is cheaper during the day and more expensive at night. However, while this sounds like a simple solution, it is, in fact, not particularly straightforward. Since the only other example of prepaid consumption that most community members have experienced is the mobile phone, which does not have different prices depending on the time of day, such intraday variations in the price of electricity can come as a surprise to consumers and hence cause frustration, according to Interviewee 5.

Overall, it seems likely that simple and locally devised use rules could be a useful type of institutional arrangement in mini-grids, which struggle with load management at times. However, the fact that they must be locally devised means that the involvement of the community in designing them is absolutely critical. While this level of

community involvement might be daunting initially, there also are clear potential benefits, in particular for a private sector owner/proprietor. This again raises the potential for a management platform, along the lines of the platforms suggested by Steins and Edwards (1999), bringing together the owner/proprietor and the community as a potential institutional arrangement to design such use rules, among other things. Chapter 6 includes a more in-depth discussion of the potential role of such a platform.

I3, I4, I5: Ease in enforcement of rules, graduated sanctions and low-cost adjudication

Technological developments, such as the introduction of prepaid meters using mobile payment systems, are increasingly ‘a game changer’ (Interviewee 5) when it comes to tariff collection and the enforcement of payment. They eliminate the need for cash collection, reduce the need for conflict adjudication and reduce the risk of elite capture. There is, however, still a role for community involvement in the various aspects of enforcement of rules. In particular, enforcement of the type-of-use and time-of-day rules previously mentioned can be conducted effectively in a peer-to-peer setting:

*‘There is the idea of two bulbs per household at night but again in the village when you buy a fridge your neighbour will know that you have a fridge. Or when you buy a TV your neighbour will know.’ (Interviewee 3)*

*‘...the best way of looking at managing the loads at any one time is by actually controlling the appliances used by members. They’ve got a limited number of people and they know what they are using - it is basically a very close-knit community. So when one line disconnects they actually find out who was the*

*cause for that and that means there is a new appliance that has come into effect or something like that.* ' (Interviewee 11)

An additional benefit of this level of community involvement is that it discourages theft through bypassing the meter. Several interviewees mentioned that despite expectations of theft becoming a problem it did not transpire in practice to the degree they feared (Interviewees 5, 19 and 21). This suggests that if enough people benefit locally or are dependent on the resource (GR2), a mutual understanding develops that tampering with the system could affect everyone — an attitude typical of successful collective action.

These enabling conditions are worth considering in more detail in the context of the case study mini-grids, particularly in relation to tariff collection. In Olosho-Oibor, access is unmetered and the flat-fee tariffs are collected in cash on a weekly or monthly basis. While rules are in place stating that failure to pay should eventually result in disconnection, according to the local manager disconnection has never actually been enforced. This suggests that while graduated sanctions are present (failure to pay does not result in immediate disconnection), their enforcement and the adjudication of conflict with customers who are in arrears, is challenging. This is likely due in part to the fact that the mini-grid is owned entirely by the community and is seen as having to serve the community members first. Financial sustainability is only a secondary consideration. Arguably, a specialised organisation such as the owner/proprietor would therefore be better at enforcing rules and adjudicating conflict, which refers to the condition of appropriate leadership (condition G5).

In Kitonyoni and Mageta Island, prepaid meters and remote load management in effect enforce the rules. Thus, sanctioning in these cases is not gradual, but binary, as

has been discussed in relation to property rights in the previous chapter. Once prepaid credit on the meter runs out, the customer is essentially disconnected until she buys credit again. Since no other use rules are present, other forms of rule enforcement are not relevant in these two cases.

The conclusions to draw from conditions I3 through I5 are therefore twofold. While community involvement can be a simple and effective way to mutually enforce use rules, the enforcement of tariff collection and the adjudication of conflicts resulting from failure to pay should be handled by a specialised organisation in order to avoid conflicts of interests or elite capture. A specialised organisation, such as the owner/proprietor, also helps advance the achievement of the final enabling condition.

#### I6: Accountability of officials

This enabling condition implies that accountability should be a requirement for any official — in this case anyone who holds management, exclusion or alienation rights — in any organisation involved in the ownership, operation and management of a mini-grid. This would include a private company, a community-based organisation or a type of hybrid management platform (see section 6.4). In Olosho-Oibor, the local manager is employed by the community-based organisation and as such could be dismissed as would any other employee if they were to be found to misappropriate funds or mismanage the mini-grid in some way. In practice, however, it is questionable how feasible this course of action would be because there would be no obvious replacement with similar skills and experience in mini-grid operation. The leadership of the community-based organisation itself is comprised of respected community members but

it is unclear to what extent this is a representative and inclusive group. The leadership has remained constant throughout the existence of the mini-grid, suggesting that it is unlikely officials would indeed be held accountable if mismanagement were to occur, or that the structures needed to remove an official from office are even in place.

In comparison, the management and leadership structure in Kitonyoni is much more transparent. The cooperative management committee is elected every three years by all members of the cooperative, ensuring that dishonest officials may be removed from office. The management committee then employs the actual managers tasked with the operation of the mini-grid itself. Thus, the necessary structures for the accountability of officials are in place in this case. The Mageta Island mini-grid is structured as a private company. The local manager is a direct employee reporting to the management of the owner/proprietor of the mini-grid. One form of accountability and conflict adjudication which the owner/proprietor put in place is a customer service hotline, where customers can report any complaints. However, more direct ways in which customers can hold the management of the mini-grid accountable do not exist, much like any other private company.

Therefore, accountability of officials is a particularly relevant consideration in institutions in which the community is represented by a set of elected officials. One interviewee gave a particularly striking example of the consequences of a failure to establish mechanisms to hold officials accountable. In the case of a micro hydro mini-grid called Thiba in the Central Province of Kenya, the chairman of the community-based organisation owning the mini-grid declared the land upon which the powerhouse had been built as his property, and with it all the assets needed to generate electricity. Because the community had no way to remove the chairman, the situation escalated,

and in the end they burned down his house in protest of his appropriation of the mini-grid assets:

*'I believe they put the house of the chairman on fire. . . . As a form of protest that he appropriated all the assets because the assets were on his land together with his secretary.'* (Interviewee 16)

Accountability of officials therefore is a highly relevant condition, which must be considered when facilitating the establishment of organisations and institutions for the operation and management of a mini-grid, in particular whenever the community is directly involved. Building in mechanisms to hold officials accountable is critical given the fact that both empirical chapters of this thesis have highlighted the importance of community involvement in mini-grid management, ideally in the form of a management platform bringing together the private sector and the community.

#### ***5.4 Summarising the Empirical Findings***

In summary, this chapter has demonstrated the usefulness of systematically applying the refined framework of enabling conditions for collective action to the management of rural mini-grids. The key findings begin with the identification of two critical operational challenges: seasonality of supply and demand, and the challenges of intra-day load management; and the difficulty of serving various different consumer groups — anchors, businesses and households — and their different power requirements and expectations.

The analysis then demonstrated the importance of local, dedicated management and how a specialised organisation should be tasked with the operation and management of a mini-grid. However, rather than imposing this organisation entirely from the outside, the discussion gives rise to the conclusion that the community should be directly represented. This is useful in order to better understand the various interdependencies between community members and their uses for electricity, as well as to align interest around mini-grid management and the goal of fairly allocating electricity among different end uses. Thus, as has been hypothesised at the end of the previous empirical chapter, the empirical data support the idea that a platform for resource use negotiation, as advocated by Steins and Edwards (1999) in the context of a complex, multiple-use common-pool resource, could potentially be a useful innovative institutional arrangement for the management of pro-poor rural mini-grids.

While operationalising and empirically testing the benefits of such a local organisational structure is beyond the scope of this thesis, it is nonetheless clear that a management platform could serve a number of purposes. First of all, it could provide the forum for the creation of locally devised and simple to understand use rules in the form of type-of-use and time-of-day rules, which, to reiterate an important finding, take into account interdependencies within the community, degrees of dependence on electricity and the heterogeneity of interests within the community in order to arrive at an electricity allocation schedule which is considered as fair as possible. When it comes to the enforcement of those rules, a management platform could combine the ability to rely on mutual rule enforcement among community members with the benefits of a fully privatised approach to the enforcement of tariff payment, thereby greatly reducing the opportunities for elite capture and conflicts of interest. Finally, the analysis implies that

ensuring the accountability of officials within this management platform is a critical condition.

The following chapter considers all of these findings, as well as those presented in the previous chapter, and uses these insights to formulate empirically-informed original contributions to the theory of bundles of property rights as well as enabling conditions for collective action. It also further develops the concept of the management platform and demonstrates how the application of property rights theory and theories of collective action inform the operational/managerial role and position within the property rights regime of such a platform. This serves to further develop the practical implications of the findings of this thesis in terms of pro-poor access to electricity.



## **Chapter 6 - Discussion**

The previous two chapters have demonstrated how the theory of bundles of property rights and enabling conditions for collective action can be used to analyse key operational challenges in rural mini-grids, based on evidence from 27 interviews with 24 experts and three case studies in Kenya. As such, the analysis has followed the example of other literature operationalising those theoretical frameworks, especially enabling conditions for collective action, by systematically analysing the applicability and relevance of these theoretical frameworks using data from existing case studies. This methodology has been commonly applied to other contexts of collective action in the presence of common-pool resources; in particular, cases of water for irrigation such as those reviewed as part of the theory discussed and developed in chapter 2. This chapter follows the same basic structure as the theory development in chapter 2 to discuss the empirical findings presented in the two previous chapters.

The chapter begins by reviewing under which conditions electricity in a mini-grid exhibits characteristics of a common-pool resource and what this means for the broader applicability of the findings of this thesis. In particular, the importance of treating electricity as a complex, multiple-use common-pool resource is discussed. This leads into a discussion of the major operational challenges in a mini-grid, and in particular how they are affected by the introduction of prepaid meters and mobile money. This analysis is guided by a discussion of how the theory of bundles of property rights (see chapter 4) demonstrates how two property rights regimes, namely private and common property, may co-exist within the same system, involving the community as well as a

specialised private sector entity. A demonstration of the usefulness of this community involvement draws heavily on the findings from the analysis that applied the theory of enabling conditions for collective action (see chapter 5), and is motivated by the existence of operational challenges, which cannot easily be addressed through technological intervention but, rather, require institutional arrangements. Rather than merely verifying the presence of certain conditions in a case study against the theoretical ideal, they can be used to construct analytical flow charts in order to create narratives informed by the empirical data. These flow charts demonstrate the applicability of the theoretical framework as well as areas for further development of the theory. Two such analytical flow charts, which build upon each other, are developed to discuss the insights provided by applying theories of collective action to the operational challenges, which lend themselves to potential interventions in the form of institutional arrangements (see Figure 6.1 and Figure 6.2). As part of this discussion, some new theoretical developments are articulated. The final section contains a detailed discussion of the potential role that a management platform could play in the sustainable management of rural mini-grids in Kenya, thereby bringing together the two theoretical frameworks used in this thesis (bundles of property rights and enabling conditions for collective action) and opening up an important field for further research.

## ***6.1 Understanding Electricity as a Common-pool Resource and the Application of Theories of Collective Action***

Since treating electricity as a complex, multiple-use common-pool resource is one of the fundamental assumptions made in this thesis, it is worth returning to this issue to review the manner in which electricity exhibits the characteristics of a common-pool resource, and to what extent the underlying assumptions are met at the case study sites. First of all, electricity is rivalrous by its very nature, i.e. use of electricity is subtractive as each kWh can only be used once. Furthermore, in the case of a common-pool resource, it must be difficult to exclude users from accessing the resource. By choosing the mini-grid itself as the unit of analysis, it becomes possible to argue that, when connections are unmetered and unconstrained, it is difficult to control how much electricity each connected user can consume, leading to the potential for congestion, i.e. demand exceeding supply and consequently the system becoming overloaded. However, when more advanced metering and access control technology are introduced, in the form of prepaid meters in particular, exclusion becomes much less problematic. In essence, electricity becomes a private good, rather than a common-pool resource. As argued in section 6.2 below, however, in relation to bundles of property rights, this does not mean that the property rights regime must change completely from common property to private property.

Thus, as illustrated in section 4.2, the common-pool resource nature of electricity depends on the metering technology used. This makes electricity a different type of

common-pool resource compared with the more traditional examples that have been studied, such as pasture for grazing, forestry or fisheries. The mini-grid is a human-made resource system in which some aspects of access and excludability can be controlled through system design. Water for irrigation, however, is similar in this respect, in that system design can affect the institutions present in the resource system. Sarker and Itoh (2001, p. 92) referred to this connection as ‘the interdependent relationship between institutions (in other words, a special kind of social capital) and physical capital’.

In the Olosho-Oibor grid, for example, where electricity is sold based on a flat fee and consumption is unmetered, electricity is a typical common-pool resource. In the cases of Mageta Island and Kitonyoni, electricity as a resource has been privatised through the use of technology. This privatisation, however, as the previous chapter has shown and as is discussed further in section 6.2, does not make the application of theories of collective action any less useful. In fact, the applicability of theories of collective action to the context of a rural mini-grid depends on a number of other factors not directly related to the common-pool resource nature of electricity, but rather informed by approaching the operational challenges faced in a mini-grid from a common-pool resource management perspective.

These factors relate to the enabling conditions for collective action, and in particular the idea of small resource system (R1) and group size (G1) as well as the presence of a well-defined boundary for the group and the resource system (G2 and R2) (see Figure 2.2 to recap on the full set of enabling conditions). The relevance of these factors in the case of mini-grids makes them well-suited to the application of theories of collective action, given the fact that all three of the key foundational works on theories of

collective action (Baland and Platteau, 1996; Ostrom, 1990; Wade, 1988), which were reviewed by Agrawal (2001) for the development of the framework in Figure 2.2, mention these enabling conditions in some form. All of the mini-grids studied, as well as those discussed during interviews, fulfilled the following requirements: None of them is connected to the national grid and so they can each be defined as a closed resource system; and none of them has in excess of 100 connections or produces more than 20 kW of electrical power. Compared with a national grid, with thousands of kW in generating power and millions of connections, the mini-grids are clearly comparatively small.

The presence of a multiplicity of not just potential end uses for electricity but also types of user groups is another factor which has demonstrated common-pool resource theory and collective action to be useful perspectives for the analysis of electricity in a mini-grid. Through the logic of the complex, multiple-use common-pool resource, another important link between electricity in a mini-grid and theories of collective action is established:

*‘the activities/actions of one user group influence activities/actions by other user groups, that is, multiple uses are closely interconnected. Thus, it is the very nature of multiple use resources that makes collective action a necessity to deal with adverse impacts associated with multiple use.’* (Steins and Edwards, 1999, p. 245)

According to this argument, applying theories of collective action to the management of electricity in a mini-grid seems almost like a natural connection, considering that electricity can be used by a multitude of end users — anchors, businesses and households — for a variety of end uses ranging from agricultural

processing to appliance charging, entertainment and lighting. The similarities between water for irrigation (the prototypical complex common-pool resource) and electricity in a mini-grid are quite striking in this respect, as water may also be used by a multitude of end users (farmers, households, etc.) for a variety of uses beyond irrigation (drinking, cooking, agricultural processing, etc.). Thus, approaching the problem of managing a mini-grid from a common-pool resource perspective already hints at the operational challenge of electricity allocation, which is discussed further in section 6.3. However, there are a number of other operational challenges that should be properly discussed first.

## ***6.2 Bundles of Property Rights and the Role of Prepaid Meters***

It is worth re-emphasising that the focus of this thesis is on the operational challenges within the mini-grid itself. There are, of course, a number of other challenges related to the regulatory environment in Kenya, or other issues such as the poor state of physical infrastructure in many parts of Kenya, which have a direct impact on the difficulty of building and operating mini-grids. Nevertheless, as has been established in section 2.10, such external environment conditions are beyond the scope of this thesis. Furthermore, as canvassed in chapter 2, the purely financial and technical challenges involved in mini-grid operation are already comparatively well-researched. The operational challenges that are the focus of this section are therefore primarily located at the point of interaction between the end user and the mini-grid and its operator. Rural mini-grids face a number of key operational challenges of this nature which affect their long-term sustainability. Chapters 4 and 5 have identified a number of those challenges,

which emerged from the interview and case study evidence, but it is worth summarising them again.

One major challenge which mini-grids have faced in the past is the reading of electricity meters in person and physical collection of tariffs. Both of these activities are highly time-intensive, as they require going from end user to end user while they are present. In addition, the physical collection of cash poses further challenges, due to the lack of developed financial infrastructure in many remote rural areas. Not only is it a challenge for the customer to ensure they have sufficient cash available at the time of the tariff collection, but it may also be difficult for the mini-grid operator to deposit that cash into a bank account, as the nearest bank branch can be difficult to access. For example, there is no bank branch on Mageta Island. As chapter 4 demonstrated, however, prepaid electricity meters using mobile-enabled payment can completely remove these challenges. They obviate the need for tariff collection and meter reading at the same time, and thus are one of the most important technological innovations currently being implemented in mini-grids in Kenya. However, they also have an effect on the allocation of property rights within the mini-grid. As mentioned in the previous section, the introduction of metering technology in particular affects the nature of electricity as a resource, in effect privatising a common-pool resource. This is similar to the effect of volume and flow rate measurements privatising water for irrigation, as described by Yandle and Morris (2001). However, the effect of prepaid meters using mobile-enabled payment on the property rights regime is considerably more nuanced, when considered through the lens of the theory of bundles of property rights as shown in Table 2.2. Due to the importance of Table 2.2, and the fact that analysing the role that prepaid meters can play in the allocation of bundles of property rights represents a theoretical innovation, it has been reproduced below as Table 6.1.

**Table 6.1** - The Role of Prepaid Meters in the Allocation of Property Rights

	FULL OWNER	PROPRIETOR	AUTHORIZED CLAIMANT	AUTHORIZED USER	AUTHORIZED ENTRANT
ACCESS	X	X	X	X	X
WITHDRAWAL	X	X	X	X	
MANAGEMENT	X	X	X		
EXCLUSION	X	X			
ALIENATION	X				

Remote control instead of physical disconnection

Credit on Meter      No Credit on Meter

Source: Author (developed from original framework by Ostrom and Schlager (1996, pg. 133))

As Table 6.1 indicates, prepaid meters automate the allocation of withdrawal rights by simply disconnecting the authorised user as soon as the credit on the meter runs out. This offers obvious advantages over post-paid meters or flat fees, where the disconnection of a user who is in arrears requires an in-person interaction, thereby increasing the potential for conflict. This also means that management and exclusion rights may be exercised remotely, using the mobile network connection that prepaid meters with mobile-enabled payment automatically have, thereby facilitating operations for the owner/proprietor. This is a good example of another challenge that advanced metering and tariff collection may help to overcome. Setting and changing tariffs, typically, is a challenging task and should not be the sole responsibility of a community-based organisation. Evidence of this has, for example, been presented in section 5.1 in relation to Olosho-Oibor, where the community-based organisation was unable to agree on tariffs that would even cover operating costs, thus making the mini-grid dependent on continual donor support. This challenge has also been identified by other organisations implementing community-based mini-grids (e.g. GVEP, 2011). The granular demand data available through the use of remote controlled prepaid meters, on



the other hand, allows the owner/proprietor to precisely observe different levels of demand at different price points. However, as has been discussed in section 5.3, such tariff setting and, in effect, electricity allocation based purely on price discrimination, does not represent a pro-poor approach to electrification. A hybrid approach, which also gives community members a voice in such important decisions, has the potential to aid in overcoming this challenge.

The potential value of a hybrid approach echoes what has already been suggested in section 4.3 and is discussed in the following two sections in considerably more detail. It also closely relates to Ostrom's (2003) findings in a comprehensive review of property rights regimes associated with common-pool resource management, namely that no single property regime can be considered ideal for common-pool resource management. In the specific context of bundles of property rights, it is sufficient to say that the theoretical framework depicted in Table 6.1 provides the basis upon which to build a more nuanced allocation of property rights than any found at the case study sites. In Kitonyoni and Olosho-Oibor, all positions, from full owner to authorised claimant, are held by different community-based organisations entirely constituted of community members (with the exception of the involvement of the University of Southampton in Kitonyoni), whereas a private company holds all of those positions in the case of Mageta Island. However, as should be re-emphasised, the role of the authorised claimant, who holds important management rights such as the setting of tariffs and the ability to allocate electricity to different users at different times, should involve the community as well as a specialised and dedicated management organisation in order to ensure that the needs of the community are met, yet the operation, maintenance and repairs are performed by an entity with the appropriate technical and managerial capacity. This is particularly important due to the existence of two other major

operational challenges that have emerged from the empirical data, and which cannot be solved entirely through technological intervention, but rather should involve institutional arrangements to overcome. These remaining challenges are focused around two particular issues: the seasonality of supply and demand, which is closely related to the seasonality of income, and the mismatches this can create between supply and demand; and the difficulty of allocating a limited amount of electricity to a multiplicity of possible end uses and end users, i.e. the challenge of the complex, multiple-use common-pool resource nature of electricity in a mini-grid.

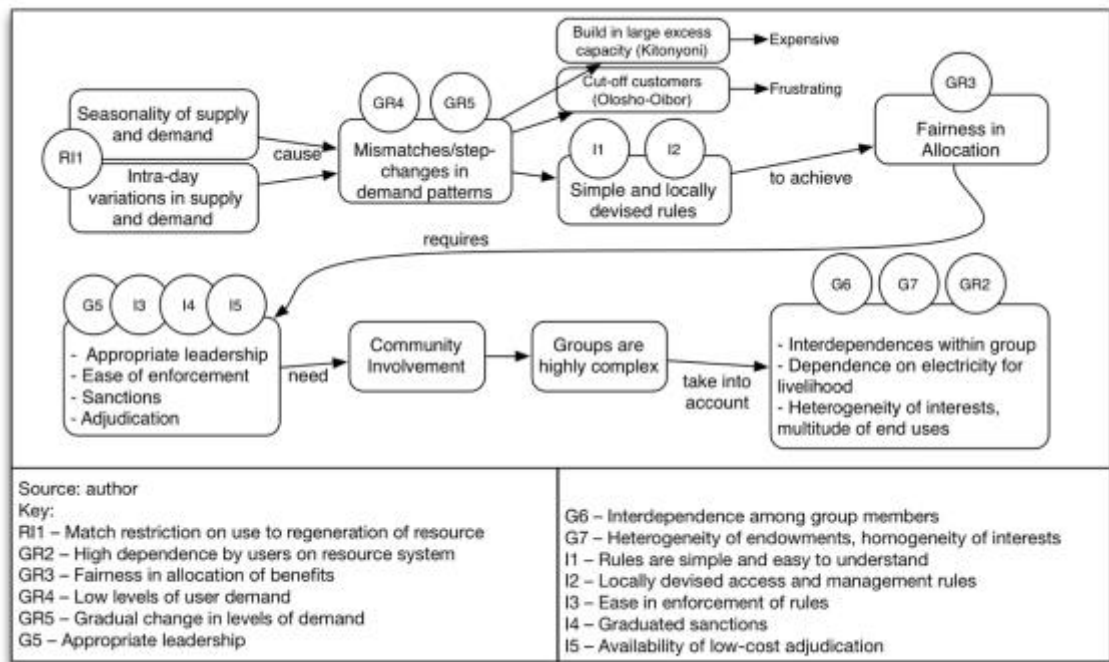
### ***6.3 Analytical Flow charts - Applying and Developing Enabling Conditions for Collective Action***

Given the complex nature of electricity in a mini-grid as a common-pool resource and the role that collective action can play in the management of a complex common-pool resource, the refined theoretical framework presented in Figure 5.1 may be applied in more than one way. It may be used to structure the analysis of empirical data, as has been demonstrated in chapter 5, thereby analysing the presence and applicability of each enabling condition for collective action at the case study sites. Furthermore, it can be used to construct analytical flow charts for the exploration of potential institutional innovations to help overcome the two major remaining operational challenges discussed at the end of the previous section. Figure 6.1 shows the first such analytical flow chart, which explores the issue of intra-day variations and seasonality of supply and demand and the potential mismatches this can create.

### *6.3.1 First Analytical Flow Chart – Mismatches in Supply and Demand*

By considering the operation of a mini-grid through the lens of enabling condition RI1 (match restrictions on use to resource regeneration), the twin challenges of seasonal and intra-day supply and demand variations become clear. As has been introduced first in section 4.1 and then expanded upon in the introduction to chapter 5, demand patterns not only change throughout the day, as agricultural processing for example is typically done during the afternoon or lights are needed after sunset, but also vary with seasons. These two sources of variation in electricity demand and supply patterns can lead to mismatches between supply and demand and step changes in demand levels in particular, which may be analysed and understood through the consideration of enabling conditions GR4 (low levels of user demand) and GR5 (gradual changes in levels of user demand).

**Figure 6.1** – Analytical Flow Chart for Challenge of Seasonality and Mismatches in Demand and Supply



Source: author

As has been shown in section 5.2, these two enabling conditions should be primarily understood as enabling the predictability of electricity supply and demand. Low initial levels of demand allow for slow and predictable initial growth in electricity demand, without immediately requiring system upgrades. As evidenced both in the interviews as well as the case study sites (in particular, Olosho-Oibor and Mageta Island), demand should be expected to grow, as end users increasingly establish new uses for electricity and begin to add electricity into their energy mix in addition to other more traditional energy sources such as kerosene. As demand thus grows slowly, the system may be upgraded to match the new demand levels and patterns, as has been done on Mageta Island. Thus it could be argued that condition GR5 (gradual changes in levels of user demand) should be augmented in the context of a mini-grid to state:

*GR5: Gradual and predictable changes in levels of demand*

Agrawal (2001) also identified the importance of predictability, but only in relation to the resource flow, i.e. the supply side (in the context of a mini-grid, this would translate into the particular choice of electricity generation technology) rather than the changes in levels of demand as proposed in the augmented enabling condition GR5. More closely related to Agrawal's definition of predictability (R5), a different route has been taken in Kitonyoni by incorporating large amounts of excess capacity at the outset and only slowly making it available to the community, rather than attempting to predict the exact timing of growth in demand. While this is, of course, an effective way to ensure that demand growth is limited to a pre-defined schedule, if demand grows more slowly than anticipated it is expensive to have this excess supply capacity sit idle for months or years until it is matched by demand. Alternatively, if demand grows faster than anticipated, it is frustrating for the end users to only slowly gain access to existing supply according to a pre-determined schedule. This approach is thus useful for a research project in order to understand how demand patterns grow and change (as is the case in the mini-grid operated by Southampton University in Kitonyoni), but is difficult to replicate in other settings.

Thus, if demand patterns change more quickly than anticipated, there is insufficient capital for system expansion (as is the case in Olosho-Oibor) or this expansion simply requires time to be installed, applying theories of collective action to the problem of electricity allocation can suggest useful solutions. As has been suggested in section 5.3, there is a bi-directional relationship between the presence of an enabling condition for collective action and the potential for successful collective action itself. The relationship between condition GR5 (gradual and predictable changes in levels of user demand) and

conditions I1 (simple and easy to understand rules) and I2 (locally devised access and management rules) is one good example. Gradual and predictable changes in demand provide the time needed to develop use rules to cope with excess demand, for example in the form of time-of-day use rules or rules restricting the use of certain power-intensive appliances such as irons or kettles. At the same time, this relationship also works in reverse: such use rules can encourage low initial levels of demand and gradual changes in demand. Caretta (2015) presents a useful example of this connection between use rules and predictability of demand changes in relation to water for irrigation in a Tanzanian community. The community organisation that manages water supply adjusts its allocation rules seasonally, according to the crops being planted and their water requirements. These changes in demand are gradual and predictable and thus lend themselves to management through collective action.

Either way, if use rules or other demand-side management techniques are required, such as switching off branches of the mini-grid at certain times of day (or times of year) or limiting the amount of power that users can draw, condition GR3 (fairness in allocation of benefits from resource) becomes critical. Consequently, any form of demand-side management that is employed should be designed with fairness in allocation in mind. However, as section 5.3 has already shown, fairness in allocation in and of itself is difficult to define. Fair to whom? Does fairness simply mean that every connection to the mini-grid receives exactly the same amount of electrical capacity allocated at all times? The evidence from the interviewees in particular seems to suggest that *perceived* fairness in allocation by the different consumer groups is the most important factor. This also includes the pricing of the electricity as an allocation tool. Even though it is, of course, a reasonable strategy from a purely for-profit private sector business perspective to sell electricity to those who are able to pay the highest price, this

practice raises the issue of the impact on poorer community members, who are pushed out of the market or excluded from the outset. This could therefore further deepen already entrenched gaps in wealth within a community. The fact that such price discrimination is not perceived as fair has been demonstrated in the case of Mageta Island. This is not to say that the Mageta Island mini-grid is therefore unsustainable in the long term, but rather to argue that electricity allocation purely based on price is not compatible with the pro-poor focus of this thesis, and arguably is no better at achieving a perceived fair allocation of electricity than an arbitrary schedule imposed by an entity that is exogenous to the community. This leads to a suggested alteration to enabling condition GR3. At least in the context of electricity in a mini-grid, a more appropriate formulation thus would be:

*GR3 – Perceived fairness in allocation of benefits from the common-pool resource*

While Agrawal (2001) also noted the importance of the perception of fairness, this alteration to condition GR3 makes this emphasis more obvious and marked. Returning to the analytical flow chart presented in Figure 6.1, attempting to achieve this perception of fairness in allocation in the presence of excess demand, be it temporary, seasonal or chronic, and using the enabling conditions of the refined framework and the empirical evidence from chapter 5 as a guide, requires the presence and understanding of four further enabling conditions. First of all, the presence of appropriate leadership is necessary, as identified in enabling condition G5 (appropriate leadership is required). As has been discussed in section 5.1, appropriate leadership in the literature on enabling conditions for collective action has to date been defined as being young, familiar with changing external environment and connected to the elite. The evidence from all three case studies as well as the interviews, however, suggests that leadership does not need

to be young and, in the case of a mini-grid, must have some technological capability to operate the mini-grid and be locally present on a permanent basis. To cite a phrase repeatedly used in section 5.1, a mini-grid needs local, dedicated management. Furthermore, the evidence presented in section 5.1 has also suggested that appropriate leadership does not need to be in the form of a single person, but rather may be held by two separate entities, where one entity, for example, assumes technically capable, dedicated operational management and another manages interaction with the community. Appropriate leadership should thus be defined as being locally present, well-connected to the community and technically capable. In the case of a mini-grid, the group characteristics of the enabling conditions for collective action should therefore be expanded by a management condition in addition to the leadership condition (G5). This suggested new enabling condition requires:

*G9: Dedicated operational management with technological capabilities and local presence.*

This addition of a management condition G9 picks up the strand of the potential for a management platform bringing together a private owner/proprietor and the community as suggested in chapters 4 and 5, which is discussed in more detail in section 6.4. However, there are three additional enabling conditions which can be used to understand how to facilitate perceived fairness in allocation and that further support the argument for a hybrid management platform. These are conditions I3–5 that concern the ease of enforcement of rules, graduated sanctions for those who break the rules and the presence of low-cost conflict adjudication mechanisms. As the joint treatment of these three conditions in section 5.3 has shown, they further indicate the potential for joint management by a private owner/proprietor and the community, and are closely related



to the leadership condition G5 (appropriate leadership) as well as the new management condition G9 (dedicated operational management with technological capabilities and local presence). A specialised organisation, i.e. the organisation that also assumes the role of the locally present and technologically capable management, should be responsible for the enforcement of tariff collection and the adjudication of any conflict arising in connection with tariff payment. This includes the final decision on tariff-setting after community consultation, as has been discussed in section 5.1 in relation to condition G5 (appropriate leadership). However, there is considerable scope for community involvement in other aspects of rule enforcement and sanctioning. First of all, section 5.3 has shown that community involvement discourages electricity theft from bypassing the meter, as the community can see the benefits of a functional system, understands the limitations of this system and, as a result, appreciates the potential damage that could be inflicted by tampering with it (in addition to the inherent dangers posed by tampering with an electrical circuit). Furthermore, as corroborated by several interviewees in relation to early community-based mini-grids in the Mount Kenya region, use rules can be mutually enforced by community members, as they are aware of the types of appliances that are being used by their neighbours. However, if such mutual enforcement is to be successful in ensuring a fair allocation rather than creating more potential for conflict, other aspects of the complexity of community involvement must be understood. The aforementioned example of a community-based irrigation scheme in northern Tanzania (Caretta, 2015) provides a particularly stark example of the dangers of this type of rule enforcement. Conflict arose between two farmers who were irrigating at the same time, which escalated to the point that one farmer killed the other. This tragic example further emphasises the need for appropriate conflict adjudication mechanisms (I5) that are easily accessible to the resource users in order to

avoid such escalation. The irrigation scheme in question reacted by increasing the number of locally available officials, further corroborating the validity of the new condition G9 for a common-pool resource (dedicated operational management with technological capabilities and local presence), even when the resource is different than electricity in a mini-grid.

Three enabling conditions in particular can be applied to better understand critical factors to take into account when considering the involvement of the community in aspects of the operational management of the mini-grid, and in particular the allocation of a limited amount of electrical capacity. Condition GR2 (high dependence by users on resource system) was previously discussed in section 5.2, where it was suggested that the presence of a variety of productive uses for the electricity creates higher dependence on the resource system, in particular in the form of a variety of micro and small businesses, but also in the form of community facilities such as the Girls' Rescue Centre in Olosho-Oibor. This dependence, in turn, supports the evolution of collective action in the management of electricity as a resource, according to the logic of the enabling condition. This is evidenced, for example, in the development of use schedules in Olosho-Oibor, where productive uses are prioritised during the day and the uses of the Girls' Rescue Centre and village lighting are prioritised after sunset. Because the community is involved in the management decisions of the mini-grid through the community-based organisation that owns it, these allocation schedules take into account the complexity of the different dependencies on electricity by different user groups. The relevance of high dependence on the resource (GR2) as an enabling condition for collective action has also been confirmed for other common-pool resources such as forestry and water for irrigation (Fisher et al., 2010).

Additionally, as alluded to during the empirical discussion of condition GR2 (high dependence by users on resource system) in section 5.2, this dependence of anchor and business loads on electricity as a resource forms a reciprocal relationship with the operational sustainability of the mini-grid. In particular, the importance of micro and small businesses in generating the revenue required for financially sustainable operation is evidenced in the interviews and the case studies. One such example is Kitonyoni, where only micro and small businesses have been connected to the mini-grid. The mini-grid, however, depends less on the rest of the community, i.e. the households, for its revenue, as they consume far less electricity than the commercial loads. Thus, the households depend to some extent on these commercial loads to make the mini-grid sustainable so that the mini-grid, in turn, can provide the electricity they require. There is hence a relatively clear interdependence among group members (condition G6).

As introduced in section 5.1, the interdependence of group members is also a relevant enabling condition in other ways. Using the examples of Mageta Island and Kitonyoni, which are active and relatively diversified village economies, if community members depend on each other for specialised goods and services that require electricity to be available in order that they be provided, the increasing interdependence of group members should enable the emergence of collective action if electricity becomes a scarce resource. Neither Mageta Island nor Kitonyoni were experiencing significant electricity shortages at the time of the field work, so this remains a hypothesis at this point, albeit one supported by evidence from interviews that recounted examples of use rules emerging in mini-grids with large amounts of excess demand.

The final enabling condition that forms part of the analytical flow chart presented in Figure 6.1 is G7 (heterogeneity of endowments and homogeneities of identities and

interests). During the in-depth analysis of the applicability of this enabling condition in section 5.1, the role of the heterogeneity of endowments could not be established conclusively. This aligns with the contested role of heterogeneity in endowments in the collective action literature. Gebremedhin et al. (2004), for example, find that heterogeneity of endowments, as measured by the ownership of oxen, negatively affects the success of collective action in pasture management. However, homogeneity of interest in the form of a pre-existing community organisation, such as the Girls' Rescue Centre in Olosho-Oibor, may be beneficial to the long-term sustainability of the mini-grid. This point is also closely related to the idea of a community being a community of interest, as formulated by Campbell et al. (2016) (canvassed in section 2.3), thereby locating the mini-grid within the wider socio-cultural context of the community. This therefore denotes the potential for some form of joint management between a private owner/proprietor and the community as a way to support increased homogeneity of interests. One further factor that is closely related to this condition, but also conditions G6 (interdependence of group members) and GR2 (high dependence by users on resource system), is the presence of heterogeneous productive and non-productive end uses for electricity, which has also been identified by other studies (e.g. Yadoo and Cruickshank, 2010). This also relates to the complex nature of electricity as a multiple-use common-pool resource as discussed in section 6.1, yet is not featured in the literature on enabling conditions for collective action or reflected in Agrawal's (2001) framework (Figure 2.2). In the context of electricity in a mini-grid as a resource, a new condition GR6 should thus be added to the group-resource system overlap category of the refined theoretical framework shown in Figure 2.3:

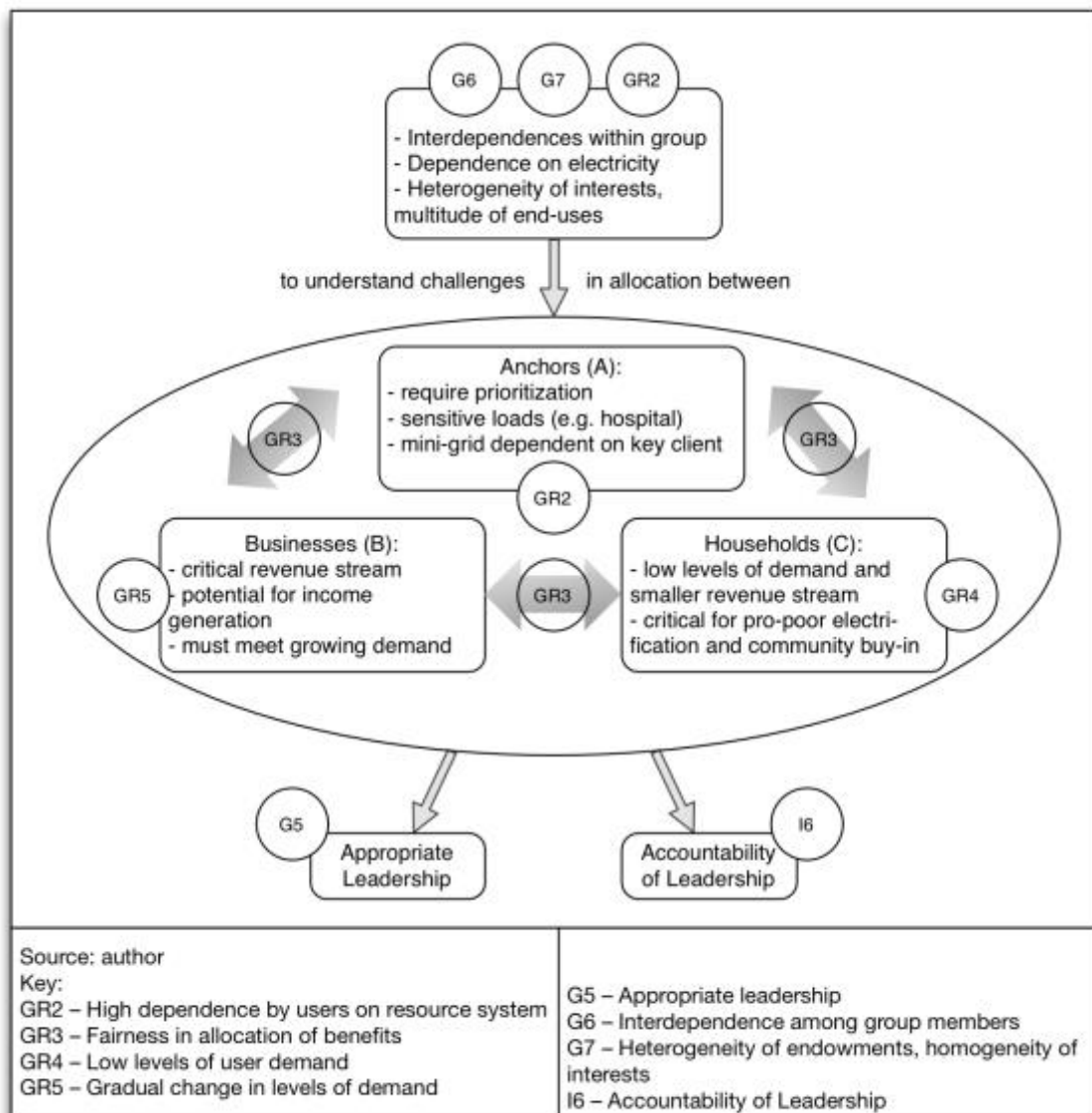
*GR6: Heterogeneity of productive and non-productive end uses for the resource*

The addition of this sixth group-resource system overlap enabling condition leads directly into the construction of the second analytical flow chart, which may be created using the refined framework of Figure 2.3 as a guideline. This flow chart is concerned with the second remaining major operational challenge identified in section 6.2, namely, the balancing of interests among a multitude of different end-user groups in a mini-grid, further demonstrating the complex nature of electricity as a common-pool resource.

Figure 6.2 shows this second analytical flow chart.

### *6.3.2 Second Analytical Flow Chart – Balancing the Needs of Multiple End-user Groups*

The second major operational challenge is balancing the different needs of multiple end-user groups within the same mini-grid with limited electrical capacity, which was introduced in section 6.2 and also discussed partly in the first analytical flow chart. The discussion of the current flow chart begins with the same issue of group complexity that was featured the end of the previous flow chart. In doing so, the second major remaining operational challenge can be addressed in more detail. Specifically, in order to understand the varying needs of different user groups, we return to the A-B-C (Anchor-Business-Community) classification of user groups, which was first introduced as part of the introduction to the concept of complex, multiple-use common-pool resource in section 2.6.

**Figure 6.2** – Analytical Flow Chart for the Challenge of Serving Multiple End-user Groups

Source: author

Anchor loads (A) such as mobile phone towers, hospitals or other larger businesses, require prioritisation during times of electricity shortages due to their high dependence on the resource system (condition GR2), i.e. the mini-grid. This may be due to the fact that they are particularly sensitive to power outages, as is the case for hospitals or cell phone towers, where an interruption in the electricity supply can have considerable knock-on effects. However, they are not just dependent on the mini-grid. If an anchor is

present, the mini-grid is likely to be particularly dependent on the anchor load in return, not only in terms of its financial planning, but also because in times of shortage, the mini-grid operator heavily depends on the cooperation of the anchor load.

As discussed in section 5.2, in relation to the all-important perceived fairness in allocation, this can have advantages as well, as the operator may only need to find an arrangement with one customer in order to shift large amounts of demand to different times of day when necessary. However, this allocation schedule still must be perceived as fair by the anchor client itself, as well as the other customer groups, according to the modified enabling condition GR3 (perceived fairness in allocation of benefits from the common-pool resource).

Businesses (B), referring to micro and small businesses in this context, also exhibit a considerable dependence on electricity (condition GR2), but in addition have the potential to cause rapid and unpredictable changes in demand as they quickly develop more productive uses for electricity (see the discussion of conditions GR4 (low levels of user demand) and GR5 (gradual change in levels of demand) in section 5.2). This growing demand must be met in order to enable the small businesses to generate the additional income from the use of electricity that is required to pay for the electricity itself. As has been previously noted, businesses are the backbone of the mini-grid, because they can earn additional income from the use of electricity. This income can be used in part to operate a financially sustainable mini-grid, by means of the business' payment for electricity. Thus there exists a reciprocal relationship between the mini-grid and the small businesses depending on it. Therefore, these small businesses must also perceive the allocation as being fair (GR3).

Finally, the community (C), which is understood as being the households in the community, also has its own demands. The households characteristically exhibit low levels of user demand (GR4) and thus represent a smaller revenue stream for the mini-grid. Their potential for demand growth is also much smaller than for A and B, because unlike the productive uses of those two user groups, household use of electricity is rarely productive and thus does not generate additional income to pay for itself. Instead, electricity supplements and partially replaces other energy sources, such as kerosene for lighting. Demand growth can only be easily afforded through efficiency improvements, so that a larger energy equivalent can be purchased for the same amount of money. Nevertheless, meeting the demands of the households is paramount to a long-term sustainable mini-grid - as it is seen in this thesis - for two reasons. First of all, household electrification is critical for the goal of pro-poor, universal rural electrification, which is the focus not only of this thesis but a number of global initiatives as enumerated in chapter 1 (e.g. the SDGs and SE4All). Secondly, household electrification is critical for community buy-in. As the discussion in relation to GR3 (fairness in allocation of benefits from common-pool resource) in section 5.2 has demonstrated, while the households may be the smallest income stream, they can be the most disruptive. One need only recall the case described in section 5.3 where community members set the house of the village chief on fire after he had appropriated all the mini-grid assets. Therefore, naturally, the households in the community also must perceive the allocation of electricity as being fair.

Perceived fairness in allocation among these user groups thus requires the presence of conditions G5 (appropriate leadership) and G9 (dedicated operational management with technological capabilities and local presence), as well as mechanisms through which leadership and management can be held accountable for their actions (I6).



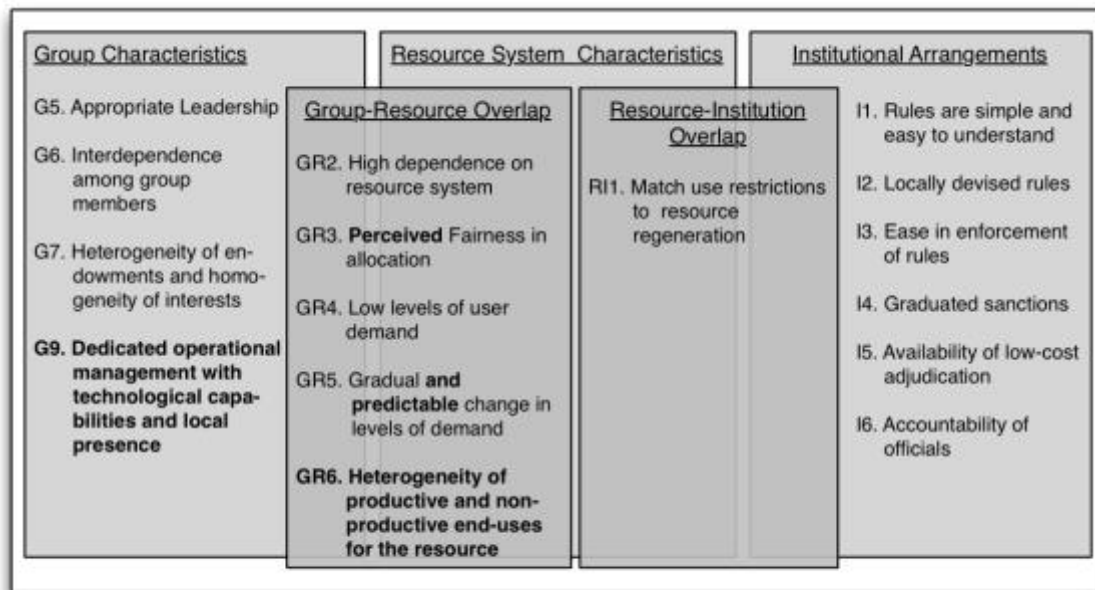
Appropriate leadership and management in this case could take the form of the aforementioned management platform, as promoted by Steins and Edwards (1999) and introduced in section 2.6 above, where the needs of the different user groups are understood. That is, a platform that is rooted within the community, but that is also aware of the technical and financial limitations of the system and therefore capable of developing, when necessary, electricity allocation schedules that take into account those limitations as well as the requirements of the different user groups. This is done in order to arrive at a system of simple and locally designed use rules (I1 and I2), which are perceived as fair by the majority, if not all, of the end users (GR3). These factors strengthen the argument for a joint management platform for the owner/proprietor and the community, bringing together the different end-user groups through community representation and a dedicated operational management (G9). Before further discussing this outcome, however, there are a number of theoretical developments that emerged from the discussion in this section to be reviewed, as they represent a key part of the original contribution to theory of this thesis.

### *6.3.3 Additions and Augmentations to the Refined Framework of Enabling Conditions for Collective Action.*

The first original contribution to theory was using the refined framework of enabling conditions for collective action to construct analytical flow charts for the discussion of the two challenges of mismatches in supply and demand and balancing the electricity requirements of three different potential end-user groups. This, in turn, led to four distinct augmentations to the refined framework of Figure 2.3, representing another

contribution to theory. Figure 6.3 shows those augmentations and additions in bold text, thereby creating a revised, rather than a refined, theoretical framework.

The new group characteristic condition G9 (dedicated operational management with technological capabilities and local presence) has emerged directly from the evidence collected at the three case study sites as well as in the course of the interviews. Its importance, and the omission of this condition in the traditional theory on enabling conditions for collective action (see sections 2.7 and 2.8), is largely due to the increased technical and thus operational complexity of a mini-grid compared to the typical cases of common pool resources systems such as fisheries, pasture for grazing or even water for irrigation, albeit to a lesser extent. Furthermore, the inclusion of technological capabilities in this condition provides a potential link to the literature on innovation studies and specifically the role of learning mechanisms in achieving this level of technological capability (see e.g. Hansen and Ockwell, 2014) – a link that could be productively explored by means of further research.

**Figure 6.3** - Revised Framework of Enabling Conditions for Collective Action

Source: Author (developed from original framework by Agrawal (2001, pg. 1659)

Key: Building on the refined framework presented in figure 2.2, this framework represents a revised framework of enabling conditions for collective action. Augmentations and additions to the original enabling conditions are shown in **bold text**

The augmentation of condition GR3, making it ‘perceived fairness in allocation’, rather than merely ‘fairness in allocation’, emphasises the difficulty of defining an objective measure for fairness. Explicitly focusing on the perception of fairness by all resource users places greater emphasis on the importance of being inclusive of all user groups and interacting with them, a particularly critical point when considering pro-poor universal rural electrification. The alteration to condition GR5 to include the predictability of changes in demand levels is also a simple, yet crucial clarification, which makes this condition easier to understand and thus apply. While slow changes in levels of demand are open to interpretation (‘slow’ means different things in different contexts), explicitly including the predictability of changes in demand makes this condition a more useful tool for analysis. As has been demonstrated above, the ability to reliably predict changes in electricity demand patterns is highly useful, especially in the context of a mini-grid, where system upgrades can be very costly.

The final theoretical development in this section is the addition of a sixth group-resource system overlap condition in the form of GR6 (heterogeneity of productive and non-productive end uses for the resource). This addition not only emerges directly from the empirical observations, particularly the interview evidence, but also serves to link this framework to the concept of complex, multiple-use common-pool resources.

Meinzen-Dick and Bakker (1999), for example, also identify a number of different uses for water as a complex common-pool resource, including productive uses (field crops, garden crops and livestock) and unproductive uses (drinking, bathing and cooking for personal consumption). However, they do not make the link to enabling conditions for collective action as suggested in this thesis. While not fully explored in this thesis, this implies that some of the theory development may, through future research, also be of value in informing common-pool resource theory more generally, beyond the context of electricity in rural mini-grids.

With the inclusion of these four augmentations, the revised framework of enabling conditions in Figure 6.3, together with the analytical flow charts in Figure 6.1 and Figure 6.2 thus provides a useful tool for the analysis of rural mini-grids. It should be noted, though, that the applicability of some of the conditions warrants further empirical testing. In particular, the role of the heterogeneity of endowments and homogeneity of interests (G7) could not be addressed conclusively in this thesis. Furthermore, low levels of user demand (GR4) are not desirable in the context of electricity in a mini-grid to the same extent as in natural resource systems. However, initially low levels reduce the initial capital costs required and thus still remain a relevant and applicable condition, in particular as related to the revised condition GR5 (gradual and predictable change in levels of demand). Finally, it should be noted that an entire second doctoral thesis could be written about conditions I1–I5, i.e. the design and enforcement of simple

and easily understood rules as well as the adjudication of conflicts resulting from their enforcement. While the next section begins to explore a potential platform that could take on this role, at least in part, this issue is too complex to be covered in its entirety in a thesis which primarily set out to demonstrate, for the first time, the value of systematically applying the theory of enabling conditions for collective action to the new context of rural mini-grids. It would also require significant new empirical fieldwork based on longer-term analysis of mini-grid management dynamics and community–management interactions based on a range of in-depth case studies (see areas for future research in chapter 7).

#### ***6.4 The Potential for Common–Private Property Hybrid Management Platforms***

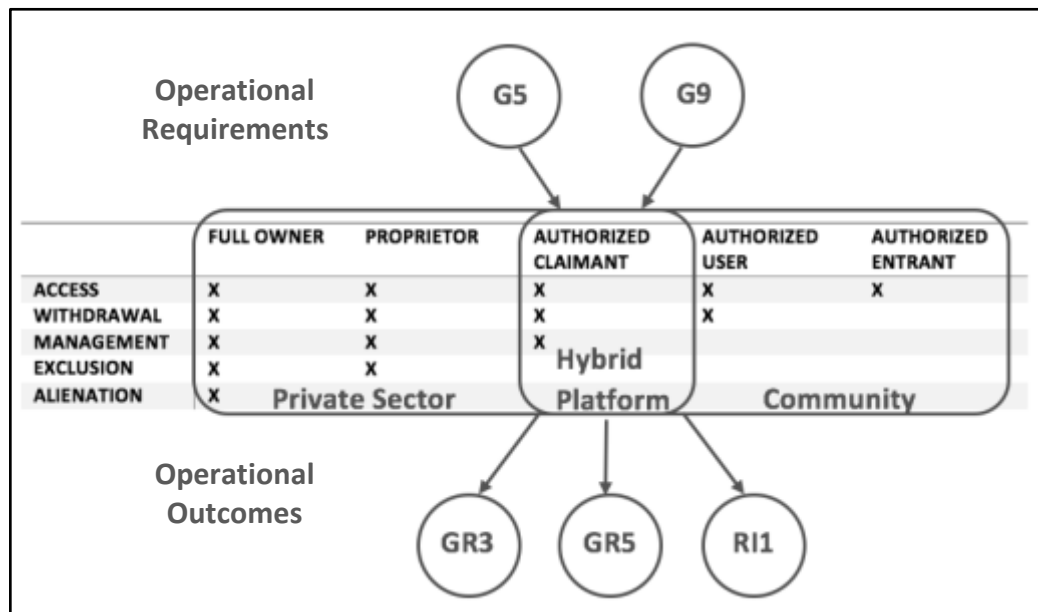
The previous two sections discussed the findings and thus contributions to theory, which emerged from the application of the two key theoretical frameworks used in this thesis — bundles of property rights and enabling conditions for collective action. This section combines the two theoretical frameworks in order to advance the development of institutional innovation for the management and operation of rural mini-grids. Throughout the empirical and analytical chapters of this thesis, the potential usefulness of a management platform that brings together the community with a specialised private sector owner/proprietor in the management of a rural mini-grid has been developed as a potential institutional innovation consistently backed by empirical evidence. This analysis includes empirical application of the theory of bundles of property rights in

chapter 4, the discussion of those findings in section 6.2 and the two analytical flow charts developed using the framework of enabling conditions for collective action in section 6.3.

The application of the theory of bundles of property rights has shown that there is room for more than one property rights regime to simultaneously co-exist within the same mini-grid system, as suggested in section 4.3. Specifically, based on the case studies used in this thesis as well as the interview evidence, there is scope for an approach that combines private and common property rights regimes into a ‘best of both worlds’ approach to mini-grid management. This is in contrast to the property rights regimes present at the case study sites, which are either fully private or common property. Such a hybrid property rights regime would mean that electricity as a resource is fully privatised through the use of prepaid meters with mobile-enabled tariff collection (with all of its operational benefits). Yet the different bundles of property rights (i.e. positions within the property rights regime that is the mini-grid) would be allocated to a specialised private sector owner/proprietor as well as the different possible end-user groups for electricity, ranging from anchor tenants, micro and small businesses to households. More specifically, the community would hold access and withdrawal rights, i.e. be the authorised user, and the private sector entity would exclusively hold exclusion and alienation rights, i.e. be the full owner of the system. Importantly, however, management rights would be held jointly by the private sector owner/proprietor and the community. The latter would be represented, for example, by a community-based organisation representing the various end-user groups. Thus, the authorised claimant position in the mini-grid would be held by a joint entity, which is referred to in this thesis as the common–private property hybrid management platform, due to its emergence from property rights theory.

The importance and role of this management platform can be explained using the discussion of enabling conditions for collective action, thereby bringing together the two theoretical frameworks. Together, appropriate leadership (G5) as well as appropriate management (G9) interact in the management platform. They facilitate a match in supply and demand (RI1), predictability in demand pattern changes (GR5) and an allocation of electricity in times of shortage that is perceived as being as fair as possible by the entire community (GR3) while respecting the technical limitations of the mini-grid. In this context, appropriate leadership must be rooted in the village community and be inclusive not only of different end-user groups, but also other groupings such as women and young people. Appropriate management is defined as being a specialised organisation with local presence and technological capabilities. Figure 6.4 schematically shows how the two theoretical frameworks come together to define the role and position of the common–private property hybrid management platform.

A common–private property hybrid management platform thus provides the nexus where the two theoretical frameworks intersect. While not all of the enabling conditions included in the new and revised framework in Figure 6.3 directly feed into the schematic in Figure 6.4, it nevertheless shows how the two narratives supported by bundles of property rights and enabling conditions for collective action combine to develop a new institutional arrangement for rural mini-grids.

**Figure 6.4** - Role and Position of a Common–Private Property Hybrid Management Platform

Source: Author (developed from original framework by Ostrom and Schlager (1996, pg. 133))

Key:

RI1 – Match use restrictions to resource regeneration

G5 – Appropriate leadership

G9 – Dedicated operational management with technological capabilities and local presence

GR3 – Perceived fairness in allocation

GR5 – Gradual and predictable change in levels of demand

As has been previously mentioned, Steins and Edwards (1999) also identify the need for management platforms for collective action in the context of their discussion of collective action in the management of complex, multiple-use common-pool resources, focusing on fisheries and forestry. They do not, however, specifically identify common–private property hybrids as a potential organising principle for these platforms. As a result of their analysis, they formulate five discussion statements which, according to the authors, should guide the study of these platforms (Steins and Edwards, 1999, p. 253):

- *‘Discussion statement 1: Platforms for resource use negotiation in multiple-use CPRs must consist of representatives of the different user groups (i.e. individual user groups need to appoint a representative who negotiates on their behalf in the platform)’.*



- *‘Discussion statement 2: Platforms must be physically (i.e. place and timing) and culturally (i.e. constitution and operation of meetings) accessible to representatives of all user groups’.*
- *‘Discussion statement 3: Platform performance depends on the level of organization of individual user groups within the platform, the relations between the various user groups, and the strengths and skills of the representatives of the individual user groups’.*
- *‘Discussion statement 4: New platforms for resource use negotiation in complex, multiple-use CPRs must not be built on existing forums for single-use resource management’.*
- *‘Discussion statement 5: Platforms must be facilitated by a third party to co-ordinate multiple user groups, to ensure continuity and to reduce or absorb the transaction costs of forming and operating the platform’.*

While Steins and Edwards argue that these are not prescriptive design principles for collective action platforms, further research — including this thesis — has demonstrated the usefulness of these statements when studying the effectiveness of platforms in managing a complex common-pool resource such as water for irrigation and other uses (Meinzen-Dick and Bakker, 1999; Ravnborg and Guerrero, 1999). Given that these discussion statements were formulated by Steins and Edwards as a result of an examination of the complexities of managing multiple-use common-pool resources, it is useful to compare their findings with the findings presented in this thesis in relation to the potential role and organisational structure of a common–private property hybrid management platform for rural mini-grids.

The first discussion statement directly echoes one of the findings of this thesis, namely, that the management platform must consist of representatives of all the different user groups. In this thesis, the user groups have been defined as anchors, businesses and households, yet more research is needed to identify and include other important user groups. In particular, the representation of households must be considered carefully in order to also include groups that typically are marginalised and underrepresented, such as women, young people and the poorest community members. Nevertheless, the finding that a management platform must be representative of all the different user groups is one that is also supported by the analysis in this thesis.

In the second discussion statement, Steins and Edwards emphasise the importance of the physical and cultural accessibility of the platform to all representatives. This statement is closely linked to the leadership and management conditions G5 (appropriate leadership) and G9 (dedicated operational management with technological capabilities and local presence). Condition G9, which has been added to the original theoretical framework as a result of the empirical findings in this thesis, relates particularly closely to this discussion statement and emphasises the importance of local accessibility of the management platform, which not only needs to include representation from all user groups but, crucially, the owner/proprietor as well. Again, the findings from this discussion align well with those formulated by Steins and Edwards in relation to management platforms for multiple-use common-pool resources.

For a better understanding of the third discussion statement in relation to management platforms for rural mini-grids, however, considerably more research is required. In this statement, Steins and Edwards focus on the organisation and relationship among group members and the skills of their representatives. There is

clearly some overlap between this statement and the discussion that has been included in this thesis in relation to conditions G6 (interdependence among group members) and G7 (heterogeneity of endowments and homogeneity of identities and interests). The empirical data presented in this thesis offered some support for the hypothesis that a higher degree of interdependence among group members and homogeneity of interests (e.g. the Girls' Rescue Centre in Olosho-Oibor) is an enabling condition for collective action, and thus would support the effectiveness of a management platform and positively impact the operational sustainability of a mini-grid. However, more research is necessary to conclusively establish the role of these complex interdependencies. This conclusion also relates to the issue already raised in relation to the first discussion statement, i.e. that further research will be required into appropriate mechanisms to identify all relevant user groups and their representatives. The literature on participatory development may offer a starting point for further research into this issue. Platteau and Abraham (2002), for example, offer a useful account of the difficulties involved in such approaches and particularly the dangers of elite capture. Rural mini-grids certainly are not immune to this danger, given the example of the village chief appropriating all the assets of an early community-based mini-grid, as described in section 5.3.

The fourth discussion statement also exhibits a close overlap with the findings of this thesis in stating that the management platform must be purpose-built for the task of negotiating resource use. This is echoed in the finding that operational management should be executed by a dedicated and specialised organisation that is also responsible for implementing the common-private property hybrid management platform. This provides a further link to the fifth discussion statement on the role of a third-party facilitator for the management platform.

A comparison of the results of the discussion in this thesis with the discussion statements proposed by Steins and Edwards thus has a threefold use. First of all, the close overlap between the discussion statements and the findings from this thesis further support the hypothesis that electricity in a grid-independent mini-grid exhibits many of the same characteristics and thus involves similar management challenges as a complex, multiple-use common-pool resource. This further supports the systematic application of theories of collective action to the case of a rural mini-grid. Secondly, the overlap in the findings provides further guidance on the role and structure of the proposed common-private property hybrid management platform, and supports the role and position of the platform within the property rights regime suggested in the schematic of Figure 6.4. Finally, and crucially, it denotes those areas where there is a particularly strong need for future research related to the organisational design of the management platform and the complexities involved in operationalising such a new structure, which would bring community representatives together with the private sector owner/proprietor. Chapter 7 provides a more detailed description of the need for further research identified in this discussion.

## **Chapter 7 - Conclusion**

In this concluding chapter, the findings from the empirical chapters 4 and 5 and the discussion in chapter 6 are summarised, and the resulting empirical contributions and contributions to theory and practice, as well as the scope for future research, are formulated. First, the empirical contribution to knowledge is presented, demonstrating the validity of the methodology used for the purpose of this study based on the three case study mini-grids and 27 interviews. Second, the original contributions to theory made in this thesis are considered, beginning with the validity of the application and refinement of the theoretical frameworks used and recapping the revisions and additions to these frameworks developed during the discussion. In the process of reviewing both the theoretical and empirical contributions of this thesis, the findings are linked directly to the main research question and five sub-questions formulated in section 1.5. This is followed by a discussion of directions for future research based on the limitations of the thesis. Finally, the implications for practice that follow from the contributions to theory and the empirical contributions are summarised.

Before continuing into this synthesis of the findings, it is important to recall the research questions as well as the motivation behind the research as formulated in the introduction in chapter 1. The research motivation can be summarized as follows. In principle, due to their ability to support productive as well as non-productive uses for electricity (due to their increased capacity compared to SHSs), mini-grids offer great promise in remote rural areas of the developing world in bringing electricity access to currently unserved populations (approximately 600 million of whom live in sub-

Saharan Africa). The importance of electricity as a necessary precondition to human and economic development has been emphasised by the inclusion of universal access to modern energy as SDG 7, a goal shared by SE4All. In order for mini-grids to play a significant role in the achievement of this goal, however, replicable and scalable approaches to mini-grid management must be found, which combine a pro-poor focus that considers the needs of the entire spectrum of end users in a community with professional managerial and technological capabilities in order to achieve long-term operational sustainability. In this context, ‘sustainability’ is defined as the ability of the mini-grid to not only cover its operating costs and maintain, repair and upgrade the entire system, but also understand the needs of the end users in order to avoid and resolve conflict, which may arise from demand exceeding supply, or a mismatch of demand and supply patterns. The focus of this thesis has been explicitly placed on socio-cultural factors in the form of institutions (defined very narrowly as local specialised organisational structures for the management of a boundaried resource system), rather than placing further emphasis on technical and financial factors involved in long-term sustainability of a mini-grid. While these technical and financial factors are obviously critical, to date they have been the focus of much of the literature on energy access in general and mini-grids in particular. The focus on institutional factors is clearly evident in the empirical and theoretical contributions to knowledge made in this thesis.

Against the backdrop of this research motivation, the main overarching research question asked: *To what extent can theories of collective action and property rights address challenges affecting the long-term operational sustainability of pro-poor rural mini-grids?*

This research question has then been subdivided into the following five sub-questions:

- Sub-Question 1: What underlying assumptions must be made in order to treat electricity in an isolated rural mini-grid as a common-pool resource?
- Sub-Question 2: What are the major operational challenges faced in different types of community-based and private-sector mini-grids in Kenya?
- Sub- Question 3: How does modern demand-side technology, such as prepaid meters and mobile money enabled payment systems, affect the allocation of bundles of property rights in the mini-grid; which operational challenges can thus be overcome and which challenges remain?
- Sub-Question 4: How can the existing theory on enabling conditions for sustainable institutions for common-pool resource management be used to analyse these challenges in mini-grids and develop non-technical institutional responses to them?
- Sub-Question 5: Based on this analysis, what lessons can be learned from community-based and private sector mini-grids in Kenya for the operational sustainability of mini-grids, and how may these two approaches be combined?

## ***7.1 Empirical Contributions***

The empirical contributions this thesis makes to the literature on mini-grids for rural electrification in developing countries support the choice of methodology used, which includes case studies as well as expert interviews. This choice enabled the analysis to draw conclusions from a broader evidence base, together with the more detailed data collected on the field trips to the case study sites. The first empirical contribution identified a set of key operational challenges faced in mini-grid management. The challenge of making a mini-grid financially sustainable with flat-fee tariffs for electricity stands out as one of the main obstacles, which was faced by the earlier community-based mini-grids in Kenya in particular. Additionally, collecting tariffs in cash is not only time- and labour-intensive, but also requires the presence of the financial infrastructure needed to deposit cash payments, which is often lacking in rural areas. The identification of these challenges provides a partial answer to sub-question 2, which is concerned with the major operational challenges faced in mini-grids in Kenya.

While post-paid meters improve financial sustainability, since customers pay for the electricity they actually used, they do not solve the problem of tariff collection. On the contrary, they exacerbate these problems, because customers may find that they have consumed more electricity than they are able to fund at the end of the billing period. Prepaid meters using mobile-enabled payment systems (M-Pesa being the most widespread mobile money standard in Kenya) completely change this dynamic, as they remove the need for in-person tariff collection and cash transactions. Pueyo (2013), for



example, noted their value in simplifying the operation of rural mini-grids, but lacked sufficient evidence to support this observation. The empirical data collected for this thesis provides such further support. Some interviewees, primarily those from the private sector, saw a few drawbacks related to prepaid meters, chiefly due to the fact that they encourage customers to use less electricity when they are trying to maximise sales. However, based on the evidence presented in this thesis, the overall operational benefits still dominate. This conclusion forms a direct response to sub-question 3, which is concerned with the impact of different metering technologies on mini-grid operations.

However, these technologies are less suitable in addressing the other operational challenges, which emerged from the study of the empirical data in response to sub-question 2. These challenges primarily revolve around the allocation of electricity within the mini-grid. Such allocation can become necessary due to seasonality of either supply or demand, causing mismatches between the total electricity demanded from the system and the capacity available. Alternatively, it may be due to the challenge of serving a variety of different productive and non-productive uses for electricity throughout the day. If there is no consensus on allocation schedules in these situations, there is a possibility for a ‘tragedy of the commons’ to emerge, in which over-consumption (or unbalancing of resource use and regeneration) can place the whole system at risk — the action of one end user can negatively affect the potential of all other end users to consume electricity.

An analysis of these challenges has yielded a number of additional key empirical findings, by using the theory of enabling conditions for collective action as a framework to structure the empirical analysis and construct analytical flow charts. These findings respond to sub-question 4, which considers how the theory of enabling conditions for

collective action can be used to develop institutional responses to operational changes. First of all, the resulting analysis has emphasised the need for a locally present, dedicated and specialised operator with appropriate technological capabilities. This entails the ability to operate, maintain, repair and upgrade the mini-grid system and source necessary spare parts and supplies. The operator is also ultimately responsible for tariff-setting, metering and tariff collection (even though tariff collection is automated when prepaid meters with mobile-enabled payment are used).

However, there are also a number of advantages in involving the community in some aspects of management, especially as it relates to finding solutions (e.g. simple rules) to the challenges around electricity allocation that are perceived fair by all end users. These include anchor tenants (if present), micro and small businesses as well as households. All of these types of end users, as well as other groups that are often under-represented, such as women or the poorest community members, should be represented in a community-based organisation, which is created especially for the purpose of working together with the specialised operator in questions of electricity allocation. The benefits of community involvement are discussed in more detail when formulating implications for practice in section 7.4.

Finally, combining insights from private sector and community-based mini-grids in order to respond to sub-question 5, this thesis has developed the concept of a common-private property hybrid management platform, which brings together a specialised operator and a community-based organisation representing the needs of the different end users. While the concept of a management platform has already been developed in the context of other complex, multiple-use common-pool resources, conceptualising it as a way of bringing together a professional, private sector mini-grid operator with a

community-based organisation to solve challenges around electricity allocation and resolve conflicts arising from it represents a key innovation, and the main empirical contribution to knowledge of this thesis. However, given the theoretically exploratory nature of this thesis, there also are a number of theoretical contributions to knowledge, which help to further explain the role of this management platform and the position it holds within the property rights regime of the mini-grid. These are summarised in the next section.

## ***7.2 Contributions to Theory***

By means of the theory development in chapter 3 and the discussion in chapter 6, this thesis has developed a number of theoretical contributions to the literature on collective action for common-pool resource management (specifically, the theory of enabling conditions) and the theoretical field of bundles of property rights when both of these are operationalised in the context of sustainable management of pro-poor rural mini-grids. The first theoretical innovation is the systematic application of these two theoretical frameworks to the context of the management of rural mini-grids. While three other authors in the grey literature, identified in section 2.9, have previously touched on the possibility of electricity in a mini-grid as a common-pool resource and have applied certain aspects of theories of collective action to mini-grid management, their work has only resulted in partial application of these frameworks and they have not advanced the theory with the same systematic and analytical rigour as this thesis.

Before summarising this thesis' contributions to the fields of collective action and property rights theory in more detail, however, another theoretical insight should be emphasised, which is developed in response to sub-question 1 relating to the assumptions required to treat electricity in a mini-grid as a common-pool resource. When electricity is unmetered and the mini-grid itself is seen as the unit of analysis, electricity can exhibit the characteristics of a common-pool resource. However, as soon as metering technologies, such as prepaid meters, are introduced, electricity as a resource becomes in effect privatised and thus the application of common-pool resource theory ostensibly becomes less useful. Once it is argued, however, as this thesis has done, that electricity is in fact a complex, multiple-use common-pool resource, many of the challenges around the need for resource allocation continue regardless of the impact of technology, in particular due to seasonal and intra-day fluctuations among a variety of end users identified in section 7.1. Thus, the application of theories of collective action for common-pool resource management remains relevant and potentially useful.

This finding is further supported by the fact that, owing to the logic of Ostrom and Schlager's (1996) concept of bundles of property rights, and as argued by Ostrom (2003), several different property rights regimes can co-exist within the same common-pool resource management arrangement. This already points towards combining the theory of bundles of property rights with the theory of enabling conditions for collective action, which presents another theoretical innovation that is discussed below.

However, it should be noted that Table 7.1, which shows the effect of prepaid meters on the allocation of property rights within the mini-grid, represents another contribution to theory and directly responds to sub-question 3 concerning the impact of metering technologies on the allocation of property rights within a mini-grid. Most

importantly, it demonstrates that prepaid meters automate the allocation of withdrawal rights. That is, an authorised entrant who has a connection to the mini-grid in the form of a prepaid meter in her household or business only becomes an authorised user once credit is loaded on to that meter. As a result, the prepaid meter facilitates the execution of management and exclusion rights held by the owner and proprietor of the system. This further supports the prior findings of Yandle and Morriss (2001) and Ostrom (2003) regarding the effect of resource storage and flow measurement technology on the ease of implementing property rights in practice, for example, in the case of water for irrigation. As outlined in section 7.1, this resolves a variety of operational challenges, yet some remain that may usefully be studied through the lens of theories of collective action.

**Table 7.1** - The Role of Prepaid Meters in the Allocation of Property Rights

	FULL OWNER	PROPRIETOR	AUTHORIZED CLAIMANT	AUTHORIZED USER	AUTHORIZED ENTRANT
ACCESS	X	X	X	X	X
WITHDRAWAL	X	X	X	X	
MANAGEMENT	X	X	X		
EXCLUSION	X	X			
ALIENATION	X				

Remote control instead of physical disconnection

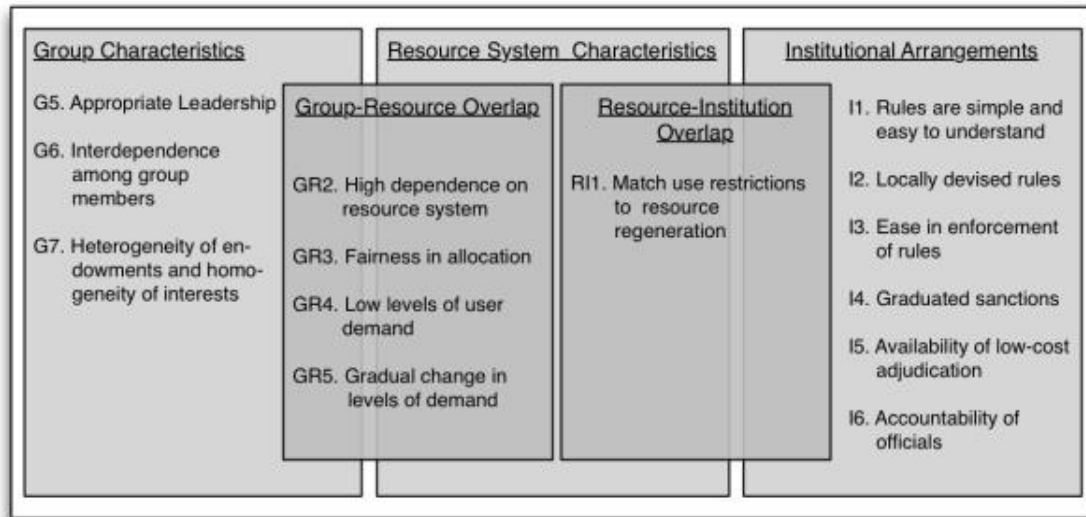
Credit on Meter      No Credit on Meter

Source: Author (developed from original framework by Ostrom and Schlager (1996, pg. 133))

The application of the theory of enabling conditions for collective action in the context of mini-grid management leads to further theoretical contributions, and therefore directly responds to sub-question 4. First of all, in order to reduce the ‘sheer number of conditions that seem relevant to successful management of common pool resources’ (Agrawal, 2001, p. 1660) to a more manageable number, those conditions most suited to the application to mini-grid management were determined by excluding

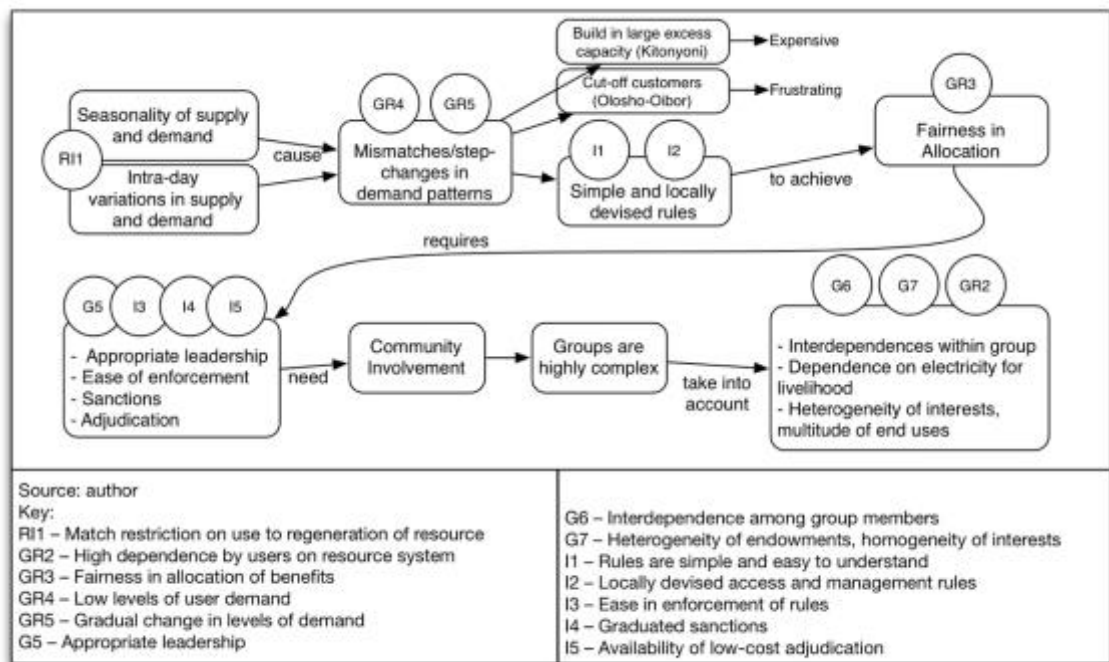
redundant and normatively or substantively inapplicable conditions, resulting in the refined framework in Figure 7.1.

**Figure 7.1 - Refined Theoretical Framework**

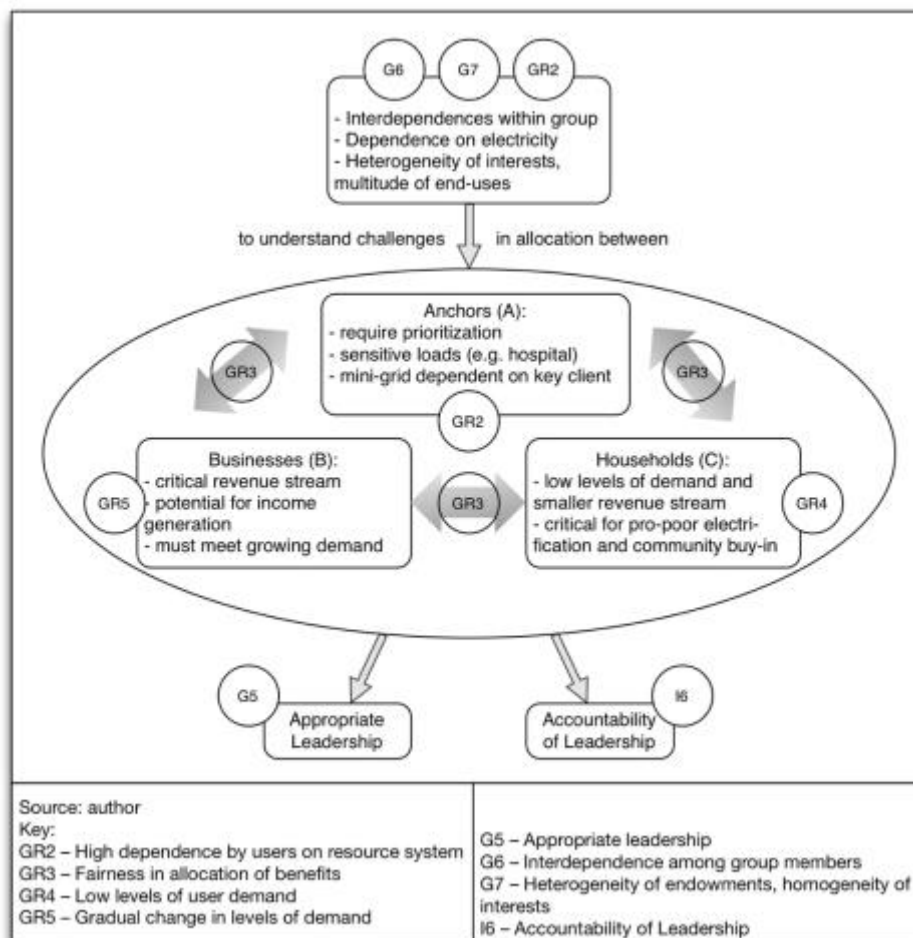


Source: Author (developed based on framework by Agrawal (2001, pg. 1659))

This refined framework was then used to structure the analysis of the empirical data and create analytical flow charts for the discussion of these findings, shown in Figure 7.2 and Figure 7.3, which represent original contributions themselves. These flow charts create narratives around the two key operational challenges of (a) seasonality and intra-day variations in supply and demand causing mismatches between supply and demand, and (b) the difficulty of serving a variety of different types of end users having different demands and expectations within a single mini-grid with a limited supply of electricity. These narratives are informed by the refined framework of enabling conditions for collective action. They therefore demonstrate the applicability and usefulness of this framework in the analysis of these operational challenges faced in rural mini-grids, thus forming a further response to sub-question 4.

**Figure 7.2** - Analytical Flow Chart for Challenge of Seasonality and Demand/Supply Mismatches

Source: author

**Figure 7.3** - Analytical Flow Chart for the Challenge of Serving Multiple End-user Groups

Source: author

Based on this analysis, the thesis developed several augmentations and additions to the refined framework (Figure 7.1), which represent a significant contribution to the theory of enabling conditions for collective action in the context of mini-grids (and potentially theories of enabling conditions for collective action in other resource types). Since they represent a key theoretical contribution of this thesis, these are listed below, with additions and augmentations to the original refined framework of Figure 7.1 shown in bold:

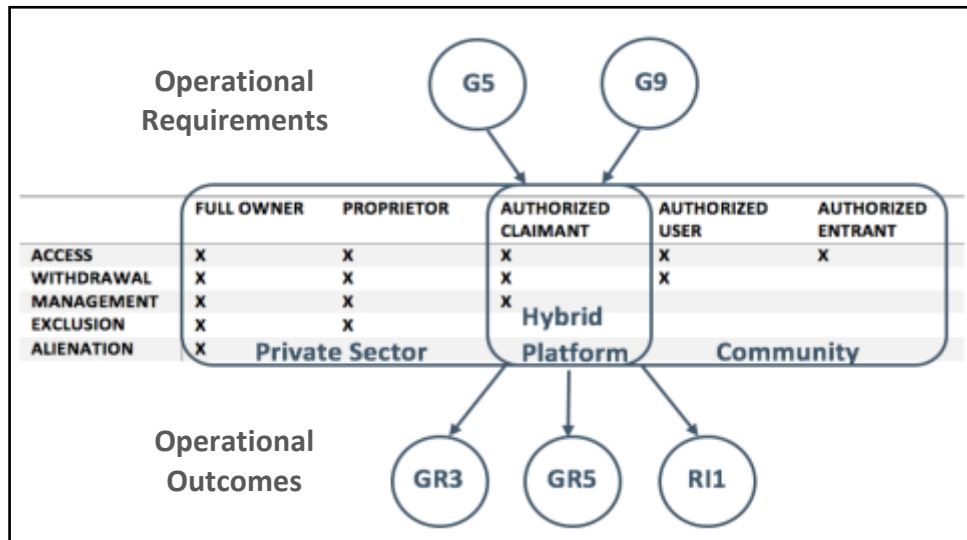
- G9: **Dedicated operational management with technological capability and local presence**
- GR3: **Perceived** fairness in allocation
- GR5: Gradual **and predictable** change in levels of demand
- GR6: **Heterogeneity of productive and non-productive end uses for the resource**

The two new enabling conditions for collective action (G9 and GR6) and the two augmentations to existing conditions (GR3 and GR5) lead to the potential for future research into their applicability, which is discussed below. At this point it should also be noted that this research has not been able to shine further light on the role of heterogeneity of endowments (part of condition G7) as an enabling condition for collective action, which mirrors its contested role in the collective action literature as discussed in section 6.3.1 above. Homogeneity of interests (the other part of condition G7) as well as the interdependence of group members (condition G6), however, if they are defined, as in this thesis, to relate to the degree of specialization and interdependence within the village economy, can be considered potentially beneficial for the long-term sustainability of the mini-grid as a boundaried resource system. This



view on interests and interdependence has also led to the development of the new condition GR6, suggesting that heterogeneity of productive and non-productive end uses for electricity are further enablers for collective and thus sustainable resource management.

The final theoretical contribution of this thesis is the combination of the two previous theoretical developments, which merges the property rights considerations in Table 2.1 with the revised set of enabling conditions for collective action presented above, thereby responding to sub-question 5 concerning the role that an approach combining aspects of private sector and community-based mini-grids can play in improving operational sustainability. This combination forms a new framework that simultaneously describes the position held by the common-private property hybrid management platform within the property rights regime of the mini-grid as well as the enabling conditions it requires to function and those it helps to promote. Because it represents the culmination of the empirical and theoretical developments presented in this thesis, this framework is reproduced in Figure 7.4.

**Figure 7.4 - Role and Position of a Common–Private Property Hybrid Management Platform**

Source: Author (developed from original framework by Ostrom and Schlager (1996, pg. 133))

Key:

RI1 – Match use restrictions to resource regeneration

G5 – Appropriate leadership

G9 – Dedicated operational management with technological capabilities and local presence

GR3 – Perceived fairness in allocation

GR5 – Gradual and predictable change in levels of demand

Thus, this thesis has developed contributions to the fields of collective action for the management of common-pool resources and the concept of bundles of property rights within the novel context of the sustainable management of pro-poor mini-grids. These theoretical contributions are situated alongside the empirical contributions outlined in section 7.1, which represent contributions to the literature on sustainable energy access in developing countries and, specifically, the recent socio-cultural turn in this body of literature described in section 2.3. Together, these empirical and theoretical contributions demonstrate the ability of property rights theory and theories of collective action to analyse and address certain challenges affecting the long-term operational sustainability of pro-poor rural mini-grids, thereby directly responding to the main research question of this thesis. Furthermore, by bringing together these diverse areas of academic work, the thesis reveals various opportunities for future research, which are reviewed below.

### ***7.3 Opportunities for Future Research***

The methodological limitations of this thesis, due to the time and cost constraints of self-funded doctoral research, have already been discussed in section 3.4. The limitations identified are primarily concerned with the fact that a more in-depth and longitudinal empirical observation of the case studies would be likely to provide richer empirical data concerning daily operational challenges. While the expert interviews have helped to address many of these gaps, they also reveal another gap, namely, the lack of government representatives among the interviewees. Thus, the methodological weaknesses provide the first opportunity for future research which would focus on directly addressing these weaknesses.

The second avenue for a follow-up study, which could build on the theoretical contributions of this thesis and thus test their applicability further, is the operationalisation of the common-private property hybrid management platform advocated herein. This would require a mini-grid project that is currently under development by a private owner/proprietor, who is willing to collaborate with academic researchers on empirical data collection and the implementation of the management platform. The research would be critical in determining what factors affect the most suitable organisational structure of the management platform. For example, should the community be represented by a relatively simple community-based organisation or a more complex cooperative? As well, further research may determine whether such a platform can indeed successfully resolve the operational challenges around electricity

allocation treated in this thesis, thereby verifying whether or not the role and position of the management platform defined in Figure 7.4 translates into practice. Furthermore, there is a need to develop and empirically test other ways to categorise user groups in a more granular manner than anchor (A), business (B) and community (C) in order to ensure that the management platform is inclusive of minority groups that might otherwise be underrepresented, which relates to the further research goals identified when considering Steins and Edwards' (1999) Discussion Statements 1 and 3. Finally, research in this area could also result in the early development of a blueprint for other practitioners in the rural electrification sector for continuous community engagement in the operational management of a mini-grid.

In addition, there is a need for future research resulting from the omission of the external environment conditions of Agrawal's (2001) framework in this analysis. Their relevance to and impact on the operational sustainability of mini-grids remains to be studied, as does the manner in which government regulation could support the creation of common-private property hybrid management platforms. In particular this research would need to engage with the literature on governance and the political economy of energy transitions – something that Newell and Phillips (2016) have, for example, engaged with in depth in the Kenyan context. The political economy of the articulation with external markets (condition E2) and the change of this level of articulation (E3) could, for example, be explored by reintroducing the potential of connecting mini-grids to the national grid and the governance challenges this creates. Furthermore, the analytical and empirical treatment of conditions E4a-d concerned with the role of the state in supporting local institutions and authority would need to consider the wider context of the devolution of power currently being implemented in Kenya and how this affects the governance of the renewable energy sector more specifically. This research

could help in defining the appropriate organisational structure of the proposed common–private property hybrid management platform within the existing political economy landscape of devolved, yet nested, levels of governance. This research would also need to overcome the aforementioned methodological weakness of a lack of interviewees from the public sector.

Finally, testing the refined framework of enabling conditions for collective action developed in this thesis (see section 7.2) as applied in the context of other, more traditional common-pool resources, such as water for irrigation, pasture for grazing, or fisheries, also presents an opportunity for future research. In particular, sophisticated irrigation schemes that include the storage of water and measurement of flow rates of water at the various end-user points share many similarities with the effect of metering technology in a mini-grid. Thus, the similarity in resource characteristics could provide an opportunity for the testing of the refined framework developed in this thesis. This would aid in determining whether the additions and augmentations to the enabling conditions, having been developed based on the insights from mini-grid management, translate to other instances of common-pool resource management and are thus contributions to the theory in general, or whether they are unique to the case of mini-grid management. In the latter case, they open the door for testing in other rural mini-grids in different contexts (e.g. different socio-cultural and political contexts, via different combinations of technologies, etc.).

### ***7.4 Implications for Practice***

The first clear implication for practitioners is that prepaid meters with mobile money enabled payment considerably simplify the operation of rural mini-grids, in particular in Kenya, where mobile money is widespread. They remove the necessity of in-person tariff collection and the associated handling and management of cash. Customers can no longer be in arrears and physical disconnection of delinquent customers is not necessary. Finally, they provide granular demand data to the mini-grid owner/proprietor, thereby facilitating mini-grid operations by making demand fluctuations more predictable and allowing the owner/proprietor to react to increases or decreases in demand.

A further implication for practice is the importance of locally-present management that has the ability to operate and maintain the mini-grid on a daily basis, perform simple repairs, coordinate more complex repairs with the owner/proprietor and be the first point of contact for customers. This interaction with the community is also important in relation to another key implication for practitioners. Some aspects of operational management must be taken on collectively by a private owner/proprietor together with an entity representing the diverse energy needs of the various types of end users (anchors, businesses and households). While the initial organisation of such a management platform might seem daunting, the evidence presented in this thesis suggests that the long-term benefits for the operational sustainability of the mini-grid outweigh this initial effort.

Involving the community in decisions of electricity allocation in times of scarcity helps to gain an understanding of the needs of different end-user groups and develop mutually satisfactory use schedules, which ensure that demand patterns closely match supply (e.g. in a solar PV mini-grid, the most energy-intensive activities should be done during those hours of the day when the power output of the PV panels peaks) and that a share of the limited amount of electricity available is allocated to each end-user group in a manner that is perceived as fair. These use schedules can also be mutually enforced by community members if appropriate conflict resolution mechanisms are in place, as is the case in other instances of collective action (e.g. Caretta, 2015; Meinzen-Dick, 1997). Developing such allocation schedules to closely match demand to the available supply offers the added potential to smooth demand peaks and thereby reduce the need to incorporate expensive excess capacity (which sits idle for the better part of the day or year), reduce the required size of battery banks and decrease upfront costs. Furthermore, community involvement in the management of the mini-grid also means that, together with the data provided by prepaid meters, the owner/proprietor of the mini-grid can better anticipate future demand changes as community members develop more uses for electricity. Thus, it will be possible to anticipate when upgrades to the system will become necessary and be economically sound, thereby positively affecting the long-term operational sustainability of the mini-grid.

Finally, this thesis has emphasised the importance of micro and small businesses in the long-term operational sustainability of mini-grids. Serving different types of end users, such as businesses and households, within the same mini-grid while possessing a limited capacity to supply electricity presents a number of challenges, as this thesis has shown. However, the concept of the common-private property hybrid management platform provides a conceptual approach to overcoming these challenges. The supply of

electricity to households as well as businesses is particularly important in the context of pro-poor rural electrification. The poorest households in a community often do not have an associated business, yet this should not affect their chances of being connected to a mini-grid. The improved financial sustainability provided by the revenue from small businesses, however, can enable the owner/proprietor of the mini-grid to also supply electricity to poorer households. By creating a carefully designed management platform with representation from all groups of end users, including households, the demands of the poorest members of the community have a significantly improved opportunity of being heard and met, and thus a step towards true ‘sustainable energy for all’ can be made.



## **Annex 1 – Catalogue of Interview Questions**

### **General Background**

1. What is your current role at your organisation and how did you arrive in your current position?
2. Could you briefly describe your past experiences relevant to rural electrification in Kenya and, where applicable, in other countries and regions?
3. What, if any, experience do you have specifically with the regulation, development, construction or operation of mini-grids in Kenya?
4. Do you have experience with specific cases of rural mini-grids that you would be willing to talk about? These can be successful as well as unsuccessful cases.

### **General factors affecting long-term sustainability of mini-grids**

5. In broad terms, what factors do you think are most important in determining the long-term sustainability of rural mini-grids?
6. What, in your experience, are the most effective ways of managing electricity demand to match supply within a mini-grid?
7. What are the major advantages and disadvantages of community-based mini-grids compared to private sector mini-grids?

**Challenges specific to community-based mini-grids**

8. What are challenges to the long-term sustainability specifically of community-based mini-grids?
9. What are the most important factors in determining the financial sustainability of community-based mini-grids?
10. How are tariffs set (and changed) and what are the key determinants?
11. What, in your experience, are the most successful institutional setups (cooperative, village energy committee, etc.) for community-based mini-grids? What can be learned from this for private mini-grids?
12. Do you think there are certain factors/conditions that make a community more likely to successfully manage their electricity supply?
13. Are you aware of any particularly successful community-based mini-grids and, based on the previous discussion, what were the main reasons for their success?
14. Are you aware of any failed community-based mini-grids and, based on the previous discussion, what do you think were the main reasons for their failure?

**Challenges specific to private sector mini-grids**

15. What are challenges to the long-term sustainability specifically of private sector mini-grids?
16. What are the most important factors in determining the financial sustainability of private sector mini-grids?

17. How are tariffs set (and changed) and what are the key determinants?
18. What are the best ways for the private sector to engage with their customer base before and after installation of the mini-grid?
19. Are you aware of any particularly successful private companies installing mini-grids in Kenya and, based on the previous discussion, what were the main reasons for their success?
20. Are you aware of any private companies who were installing mini-grids in Kenya in the past and have since gone out of business and, based on the previous discussion, what were the main reasons for their failure?

**Social interventions to the challenges (collective action)**

21. In mini-grids with unmetered access to electricity (flat fees):
  - a. What rules governing the use of electricity have you encountered, both in terms of the time of day and total demand?
  - b. Which of these rules are most successful at managing demand to match the supply available?
22. How and by whom were those rules determined?
23. How are these rules enforced, i.e. what monitoring mechanisms exist?
24. What sanctions/penalties are in place to punish rule breakers and discourage free riders?
25. How do these rules change and evolve over time as demand patterns within the mini-grid evolve?

**Technical interventions to the challenges (metering and payment)**

26. In your opinion, which challenges in operating mini-grids can be overcome using the following technologies:
- a. Current limiters?
  - b. Post-paid electricity meters?
  - c. Pre-paid electricity meters?
  - d. Mobile money (M-Pesa)?
27. What are the trade-offs between an unmetered system and one using prepaid meters?
28. What impact do these different technologies have on the financial sustainability of the mini-grid? Specifically with regards to tariff setting, revenue collection and O&M (incl. transaction) costs?
29. How do these different technologies affect the relationship between the electricity provider and the consumer/different consumer groups (institutions, enterprises, households)?
30. Are you aware of other technological means not covered in the previous questions, which are being used to overcome some of the operational challenges of rural mini-grids?

**The A-B-C of customer groups**

31. Briefly describe what the key challenges are in selling electricity to the following customer groups:
- a. Large institutional/corporate ‘anchor loads’
  - b. SMEs, i.e. local businesses
  - c. Households, i.e. the local community

32. For each of these customer groups, what do you think is the best tariff collection technology and why (unmetered flat fee, post-paid meter, prepaid meter)?
33. Which of these customer groups is most critical for the long-term financial sustainability of the mini-grid?
34. Do you think it is possible and desirable to have different tariffs (cross-subsidisation) and different collection technologies for each customer group within the same mini-grid?

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