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Institutional Innovation in the Management of Pro-Poor Energy Access in East Africa

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Institutional Innovation in the Management of Pro-Poor Energy Access in East Africa

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Abstract

This paper articulates a new theoretical perspective on the management of rural mini-grids for facilitating pro-poor electricity access in developing countries. Bridging the literature on common pool resource (CPR) management/collective action (including its application to irrigation systems) with the hydraulic analogy for explaining the behaviour of electricity in closed electrical circuits, a refined theoretical framework is produced for analysing the socio-cultural institutional conditions for sustainable management of rural mini-grids. The utility of the framework is demonstrated via empirical analysis of mini-grids in rural Kenya. This yields insights on socio-cultural approaches to addressing challenges relating to sustainable mini-grid management, e.g. seasonality of demand and fair allocation of limited amounts of electricity to different consumers, in ways that are acceptable to, and to some extent also enforced by the entire group of diverse resource users. The paper contributes to both the literatures on sustainable CPR management/collective action and the literature on pro-poor sustainable energy access in developing countries, providing a novel theoretical and empirical contribution to the emerging socio-cultural turn in the latter.

Keywords: Electricity Access; Energy Access; Electrification; Kenya; Mini-Grid; Collective Action; Common Pool Resource

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1. Introduction

From early contributions in the 1960s (Hardin 1968; Olson 1965) through to seminal developments in the 1980's and '90's (Ostrom 1990; Ostrom 1992; Ostrom, Gardner, and Walker 1994; Wade 1987a; Wade 1988), the field of Common Pool Resource (CPR) management has cemented itself as central to work on problems of sustainable natural resource management as well as broader work on collective action problems (e.g. (Gerber et al. 2011; Hudalah, Winarso, and Woltjer 2010; J. Patchell 2008; Jerry Patchell 2014; Trebbin and Hassler 2012). This paper seeks to take this thinking and practice in a new direction. It demonstrates how CPR theory might be developed in ways that can assist in the management of a man-made (as opposed to natural) resource system (electricity mini-grids) and, in doing so, contribute towards addressing one of the most pressing sustainable development issues of our time, namely pro-poor access to sustainable electricity in developing countries.

Around 1.3 billion people worldwide lack access to electricity (IEA 2014), a pre-cursor to most aspects of economic development and poverty reduction. In sub-Saharan Africa this rises to around 2 in every 3 people, with electrification rates below 25% in some countries (ibid). Electricity access cuts across all of the Millennium Development Goals (UNDP 2007) and has been made a specific goal (7) under the emerging Sustainable Development Goals. The possibility of tackling the problem of energy access via the use of lower carbon, renewable energy technologies has thus garnered significant policy interest in recent years, e.g. the UN's Sustainable Energy for All (SE4ALL) initiative with its ambitious goal of universal energy access by 2030.

80% of those lacking access to electricity in Sub-Saharan Africa live in rural areas (IEA 2014). One of the most promising emerging approaches through which to facilitate access to electricity in remote rural areas of developing countries is the implementation of mini-grids; essentially an isolated electrical grid with a generation capacity ranging from about 10-100kW, with anywhere up to 200 connections. Mini-grids are usually isolated from the national electricity grid and therefore appropriate for supplying electricity in both geographically and economically isolated areas (e.g. remote rural areas or urban slums). SE4ALL considers clean energy mini-grids one of their "High Impact Opportunities" (Wiemann and Lecoque 2015), whilst the International Energy Agency (IEA 2012) estimates that the SE4ALL goal of universal electrification by 2030 requires over 45% of rural connections to be via mini-grids.

Despite their promise, however, to date mini-grid based energy delivery models that are scaleable and replicable to the extent required to deliver against the IEA's projections have not been identified. Managing a mini-grid in a way that can provide electricity access to poor people poses considerable technical, economic, socio-cultural and political challenges with failure rates ranging from 50-100% (Greacen 2004; Maier 2007). Understanding the key factors affecting long-term sustainable management of mini-grids therefore represents a critical gap in existing knowledge.

This paper defines a sustainably managed mini-grid as: a) being financially viable, where revenues over time equal or exceed all operating, maintenance, repair and expansion costs (what (Ulsrud et al. 2015) refer to as "economic self-sustenance"); and b) meeting the needs of all users, including any anchor tenant (large commercial users with high electricity demand), micro and small enterprises and, critically, poor women and men in individual households. The latter condition is directly linked to the institutional organisation of the mini-grid, including the organizational set-up of the mini-grid (cooperative, community-based organization, private mini utility etc.) and the wider institutions in place within the community in the form of established norms, customs and practices ("the rules of the game" (North 1990)). Given the explicit focus of this analysis on pro-poor electricity access, it should furthermore be noted that in the context of this paper "pro-poor" should be understood to mean that the mini-grid can serve the needs of not just anchor loads, businesses or the comparatively wealthier households often directly attached to micro and small enterprises in rural areas of Kenya, but all households, including the comparatively poorer ones, whose demand initially might not exceed a single LED light and mobile phone charger. This definition is naturally more in flux as a quantitative definition of poor households (e.g. less than $1 per day) but is more useful in this context as it remains inclusive of all as demand patterns are expected to change and evolve over time.

The majority of existing literature on energy access in sub-Saharan Africa is characterized by a two-dimensional focus on finance and technology hardware from conventional economic and engineering perspectives. This has led to an important body of knowledge on the nature of the engineering and economic aspects of managing mini-grids (e.g. (Bhattacharyya and Palit 2014)). Detailed attention has been given, for example, to: the selection of different generation technologies (Kishore, Jagu, and Nand Gopal 2013; Mainali and Silveira 2015; Welsch et al. 2013); performance of specific technologies (Kusakana 2014; Maher, Smith, and Williams 2003; Murni et al. 2012); specific challenges of hybrid power sources for mini-grids (Mohammed, Mustafa, and Bashir 2014); specific geographic applications (Neves, Silva, and Connors 2014); interactions between cost and technology (e.g. (Lee, Soto, and Modi 2014); demand creation and willingness to pay (Abdullah and Jeanty 2009; Monroy and Hernández 2005); and financing instruments (see Bhattacharyya (2013), for a useful overview).

Socio-cultural and political aspects of the energy access problematic have, however, been largely ignored (Watson et al. 2012). Similar to the case that Shove (2010) makes in relation to climate policy more broadly, this failure to attend to socio-cultural considerations represents a fundamental gap in research on sustainable mini-grid management and sustainable energy access more broadly. This paper aims to contribute to a small, emerging body of recent contributions to the sustainable energy access literature, which have begun to foreground socio-cultural considerations. This includes contributions by authors who operationalize a socio-technical perspective on the problem (Ahlborg and Sjöstedt 2015; Rolffs, Ockwell, and Byrne 2014; Ulsrud et al. 2015; Ulsrud et al. 2011), as well as recent anthropological accounts (Winther 2008). This recent socio-cultural turn in the emerging literature has, both implicitly and explicitly (e.g. (Brent and Rogers 2010; Davis et al. 2011), begun to foreground the core role that institutional (understood in the broadest sense, as defined above) considerations play in determining key aspects of both the social and economic sustainability of mini-grid management. This includes, for example, how electricity is allocated amongst users (e.g. avoiding capture of benefits by more powerful people in community hierarchies), how individuals are prevented from over loading (and thus bringing down) the grid at different times of day (e.g. early morning or evening peak times) and different times of year where electricity demand changes (e.g. high demand at harvest time when incomes to pay for energy are higher), how revenues are collected and how maintenance of the grid is managed and funded.

Building on the socio-cultural turn in the emerging literature, together with the hydraulic analogy for explaining the behaviour of electricity in closed electric circuits, this paper seeks to contribute to the existing literatures on both pro-poor sustainable energy access and CPR management/collective action by demonstrating (for the first time in the peer reviewed literature) how the well established literature on CPR management might be refined to assist in analysing the socio-cultural institutional conditions under which sustainable management of rural mini-grids in developing countries can be achieved. It does this via two distinct steps. First, the overarching framework of Agrawal (2001) (in which he attempted to summarize all the key enabling conditions for sustainable CPR management from key contributions to the CPR literature) is refined to a more instrumentally-informed and targeted framework that retains only those conditions of relevance to the socio-cultural aspects of managing rural mini-grids for pro-poor electricity access. Second, this refined conceptual framework is used to analyse both the operational experiences of experts working on the implementation of rural mini-grids in Kenya (via expert interviews) and two specific examples of community managed mini-grids in Kenya (via field visits and interviews with stakeholders and members of the community). The specific aim of this second step is not to produce over-arching, one-size fits all recommendations on sustainable management of rural mini-grids, rather it is to contribute an empirical demonstration of the potential value of the refined conceptual framework when applied in practice. This paper hence represents a novel application of the theory and expansion of the existing literature on CPR management/collective action, as well as a potentially important theoretical and empirical contribution to research, policy and practice around pro-poor sustainable energy access in developing countries.

Section 2 introduces the literature on collective action and CPRs, its relevance to the management of mini-grids and Agrawal's (2001) theoretical framework upon which the paper builds. Section 3 describes the methodology used for this analysis and Section 4 develops a refined theoretical framework, which is then applied to empirical analysis in Section 5. Section 6 concludes and articulates an agenda for future research.

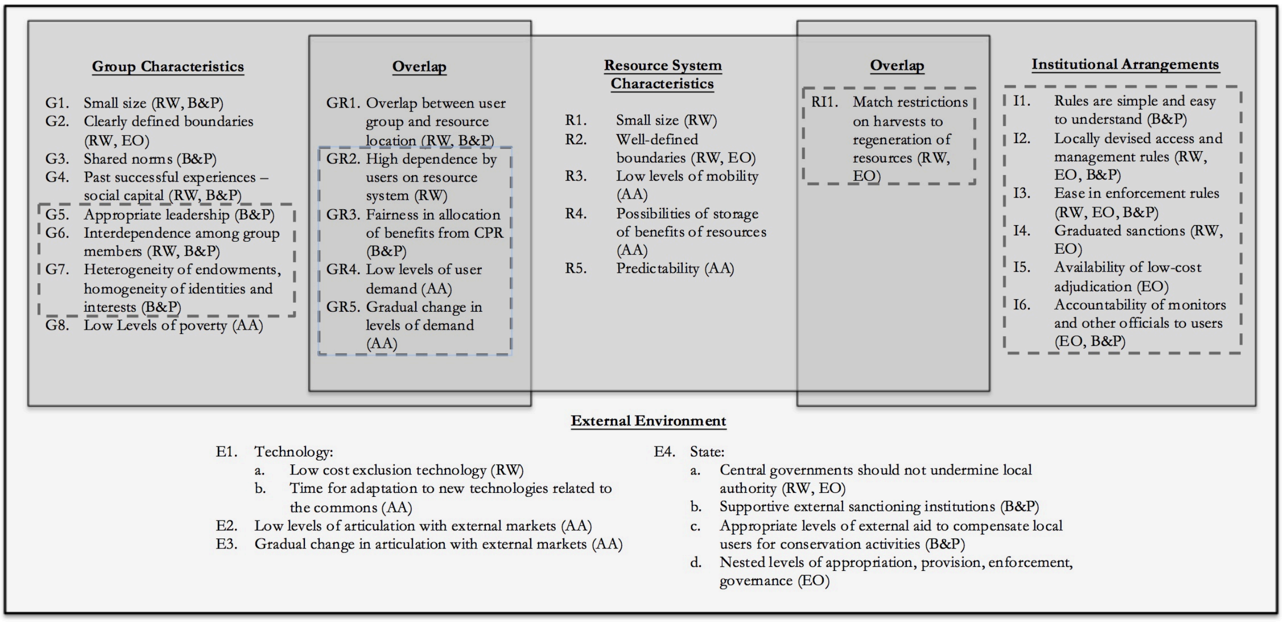
2. Theories of collective action and the management of mini-grids

This section introduces key aspects of the literature on collective action and CPR management and their relevance to the management of mini-grids.

2.1 CPRs and Collective Action

A CPR is defined as being rivalrous, yet non-exclusive, meaning that a resource unit consumed by one resource user can no longer be used by another and that access to the resource is not restricted. This is in contrast to, for example, a public good, which is non-rivalrous (e.g. street lighting). Typical examples of CPRs are fishing grounds, grazing pastures or water for irrigation. Whilst this literature has its roots in the relatively pessimistic perspectives of Hardin (1968) and Olson (1965), more recent contributions inspired by Ostrom (e.g. (1990; 1992) and Wade (1987a; 1987b; 1988) shifted the focus to case studies of long-lasting collective action institutions which have formed and persisted (sometimes for centuries) against the odds outlined by Olson and Hardin.

Figure 1 - Enabling Conditions for Sustainable Management of CPRs.



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

Key: Condition first identified by AA = *Agrawal (2001);* B&P = *Baland & Platteau (1996);* EO = *Ostrom (1990);* RW = *Wade (1988). The 14 conditions contained within the dashed boxes are most relevant to the analysis in this paper, as will be discussed in detail in section 4.*

Recognising similarities across the work of several key authors in this field (in particular (Baland, Platteau, and Olson 1996; Ostrom 1990; Wade 1988), (Agrawal 2001) developed an overarching framework that synthesizes the enabling conditions for sustainable management of CPRs into 33 enabling conditions grouped under four categories: group characteristics; resource system characteristics; institutional arrangements; and external environment (Figure 1). This facilitates analysis of reasons for long-term sustainability (or lack thereof) of existing collective action institutions in the presence of CPRs. Particularly in the case of irrigation, a large literature exists exploring subsections of these enabling conditions in the context of community-based water management systems (Araral 2009; Ito 2012; Sarker and Itoh 2001; Theesfeld 2004). 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 between different types of CPRs (Quinn et al. 2007).

Since a mini-grid is a man-made resource system sharing many characteristics of an irrigation system, the electricity it transmits (which can generally be thought of as rivalrous but non-exclusive) is, arguably, a type of CPR and hence suitable for the application of this theoretical framework. It is important to point out that the electricity being non-exclusive depends on the mini-grid and only those consumers connected to it constituting the unit of analysis, without any technical limitations on consumption. The non-exclusive, rivalrous nature of electricity within rural mini-grids presents a plethora of institutional issues in relation to the sustainable management of mini-grids (including technical and economic issues, as well as the socio-cultural issues focused on in this paper).

2.2 The Hydraulic Analogy

The analogy between a system of water pipes and a closed electric circuit is often used to explain the way electricity behaves - water flowing through pipes being analogous to electrons flowing through a conductor (the "hydraulic analogy" (Greenslade 2003)). Resistance in the electric circuit is analogous to friction in the pipes, voltage equates with pressure and current with volume flow. As a result, an independent mini-grid shares a number of characteristics with an irrigation system, such as, for example, the consumption limit imposed by the recharge rate. This leads to a number of similar operational challenges. If an upstream farmer uses all the water in the irrigation canal there is no water left for the remaining farmers further downstream. Similarly, if one electricity user continues to add powerful loads she will eventually overload the system resulting in voltage drops and potentially causing a black out. In both circumstances action by one person leads to reduced performance and potentially damage to the system (e.g. droughts or blackouts) affecting all users.

It should be noted, however, that there are also differences between irrigation systems and mini-grids. Most importantly, mini-grids are subject to very different technical (including knowledge and capabilities) and economic (including financial sustainability) considerations than irrigation systems. In irrigation systems the actual CPR (water) has no cost of generation (disregarding small potential costs for pumping), whereas the infrastructure required for electricity generation in a mini-grid necessitates specific technical knowledge to manage, maintain and operate, and capital investment to establish *de novo*. These issues are addressed in the concluding section when articulating areas for future research.

2.3 Collective Action and Mini-grids in the Literature

Literature searches identified three existing pieces of grey literature (two doctoral theses and a working paper) that touch on how electricity in mini-grids could be treated as a CPR (albeit in a more limited and less systematic way than attempted here). Maier (2007) explicitly uses a CPR perspective to analyse reasons for successes and failures of 27 community-based micro hydro mini-grids in Northern Pakistan. He finds that communities have set up institutions and various use rules and concludes 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. The analysis does not, however, systematically apply CPR theory or relate back to overarching enabling conditions for collective action through which transferable approaches might be developed.

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 CPR. Rather than elaborating how experiences from other instances of collective action could be used to overcome the challenges faced by existing projects, however, he suggests that a technological fix, in this case current limiters, which technically limit the maximum current that can be drawn by each household, could be used to address the problems. Again, there is no attempt at a theoretical expansion of the collective action literature. Furthermore, as discussed below, technical fixes are unable to address several socio-cultural institutional considerations that still persist (e.g. managing distribution amongst users during seasonal demand that exceeds generating capacity).

In an analysis of the economic impacts of 5 community-based micro hydro mini-grids in rural Kenya, Kirubi (2009) also studies some aspects of collective action. He focuses on the contested effect of heterogeneity of the group (condition G7, Figure 1) 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 sub-section 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). There is therefore currently no precedent in the peer-reviewed or grey literature for applying a complete theoretical framework of enabling conditions for collective action to the issue of sustainably managing mini-grids for pro-poor rural electrification.

3. Methodology

The methodology is designed around three analytical steps, one conceptual and two empirical. In Step 1, each of Agrawal's (2001) 33 enabling conditions were reconsidered in relation to their relevance and applicability in analysing the sustainable management of pro-poor mini-grids as a specific type of CPR. Analysis specifically focuses on the socio-cultural aspects of the management of a mini-grid for the purpose of facilitating pro-poor electricity access (in line with both the policy priorities and gap in research literature identified in the introduction). Agrawal's "external environment" (E1-4) category is not considered as it engages with issues beyond the scope of control in the applied management of a mini-grid and therefore is beyond the scope of this paper. This does not imply that these external environment conditions are irrelevant - they represent a critical area for specific future analysis. Each of the remaining five groups of characteristics in Agrawal's framework are considered in turn. Enabling conditions with relevance to the socio-cultural aspects of mini-grid management for pro-poor electricity access are retained in the resulting refined theoretical framework.

This refined framework was then used to inform the design of semi-structured questionnaires in step 2 of the methodology. This involved empirical data collection in Kenya (May 2014 and January-February 2015), including 24 semi-structured expert interviews and site visits to two rural mini-grids. Kenya was selected as a case study because: 1) national access levels are well below the continental average, less than 25% of Kenyans having access to electricity, rendering this a particularly urgent development priority that fits with the pro-poor focus of this paper; 2) there is a relatively rich (compared to other countries in sub-Saharan Africa) history of mini-grid development in Kenya – starting with donor led pilots of community-based mini-grids over a decade ago, providing a relatively (compared to other countries) rich experience of operational challenges to learn from; 3) following the success of the solar home system market, Kenya has, over the last two years, attracted a relatively large number of private sector actors to the market for rural mini-grids with around twenty mini-grids established by three key private sector entrants, further improving the diversity of perspectives to learn from.

Interviewees from a variety of backgrounds, institutions and sectors were selected first based on their experiences with mini-grid deployment and operation within Kenya and second via a snowballing approach to provide as diverse an overview of perspectives as possible:

Interviewee 1	International NGO focussed on rural energy access
Interviewee 2	Donor agency
Interviewee 3	Private sector mini-grid developer active in East Africa
Interviewee 4	International NGO focussed on rural energy access
Interviewee 5	Private sector company focussing on mini-grid operation in East Africa
Interviewee 6	International NGO focussing on technical assistance in rural areas
Interviewee 7	International NGO focussing on technical assistance in rural areas
Interviewee 8	International private sector technology provider for off-grid solutions (formerly employed by Kenyan public utility)
Interviewee 9	Private sector developer of mini-grid and off-grid energy access solutions
Interviewee 10	International NGO focussed on rural energy access

Findings were triangulated wherever possible via cross-comparison across interviews and comparison with grey literature e.g. project reports and proposals.

The two site visits to rural mini-grids were selected as they are both community-based, yet different in several ways, thus improving coverage of the analysis and at the time of the field visits had been operational for at least one full year. It should be highlighted, that both mini-grids were visited together with other experts and that this limitation has not allowed for an unbiased understanding of the dynamics within the community but rather provided a useful overview of critical operational challenges. Key characteristics of each mini-grid are:

	Olosho Oibor	**Kitonyoni**
Location:	Ngong county	Machakos county
Implementing agency:	UNDP	University of Southampton
Year installed:	2009	2012
Ownership type:	Community organisation	Cooperative
Power source:	PV-wind hybrid, diesel backup	PV, diesel backup
Generation capacity:	10kW	14kW
No. of connections:	10-15	40-50
Type of customers:	Public institutions, business hub, Households	Public institutions, small businesses and household charging services
Metering technology:	Unmetered flat fee for service	Prepaid meters

Additionally, the Olosho-Oibor mini-grid, although operational for 6 years, has repeatedly relied on further donor support to maintain and operate the system. The Kitonyoni grid is unique as it can be remote controlled by the University of Southampton and at the time of the visit the national grid had been extended past the community. The community decided not to connect to the national grid due to perceived superior reliability of the mini-grid, expensive national grid connection fees (about

KSH 35,000) and, according to the village chief during a conversation, a sense of pride in their own mini-grid.

4. Refining Agrawal's (2001) Framework

This section refines the enabling conditions in Figure 1 based on their applicability and salience in analysing socio-cultural enabling conditions for the sustainable management of pro-poor rural mini-grids. It systematically examines the extent to which, and the ways in which, they relate to the management of electricity as a CPR in mini-grid contexts. The resulting refined framework is shown within the dashed boxes in Figure 1.

4.1. 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. Neither of Agrawal's two sources (Baland, Platteau, and Olson 1996; Wade 1988), listing small group size (G1) as an enabling condition specify a number for what constitutes a small group. It is nonetheless, by definition, a characteristic of mini-grids. 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 the or directly interacting with the mini-grid in other ways, e.g. by paying to charge mobile phones or LED lanterns. The condition of shared norms (G3) does not apply, as, according to Baland et al. (1996), these are only a requirement if group size is large. With regards to mini-grids in contemporary East Africa, it is unlikely that any significant past successful experience (G4) will be found with operating mini-grids - as emphasised in the introduction, most mini-grids in the developing world struggle to operate sustainably. Low levels of poverty (G8) is also not a viable characteristic as the explicit interest of this paper (and the policy efforts it seeks to inform) is in providing access to electricity for poor people via mini-grids. Heterogeneity of endowments and homogeneity of identities and interests (G7) (as demonstrated by Kirubi (2009)) are, however, a potentially relevant characteristic. In the context of this analysis the different sub-groups, between which heterogeneity of endowments and homogeneity of interest might exist, are limited to just three categories: anchor loads, businesses and households. Of course there are considerably more granular sub-groups within each of these, 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 utilising the resource for economically productive uses upon which other users depend might, for example, act as facilitators of collective action. This also creates a risk of elite control or capture, which can be problematic, especially if appropriate leadership (G5) is lacking.

4.2. 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 a 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. Possibilities 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) is again a function of the energy source used (solar/ hydro/gen-set/other). Since conditions R4 and R5 relate to specific technological considerations, neither of them are included in the refined framework, as the aim here is to focus explicitly on socio-cultural aspects of mini-grid management.

4.3. 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. Low levels of user demand (GR4) are to be expected initially, as communities will take time to begin to use 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. High dependency by users on the resource system (GR2) in this context relates to how different uses can increase dependency on the system and also potentially help generate income streams necessary to maintain the system in the long run. This, however, requires fairness in allocation of benefits (GR3) pointing to the potential importance of conflict between, particularly, household uses (e.g. lighting and mobile phone charging) and productive uses (e.g. refrigeration or agricultural processing). As a result conditions GR2-5 warrant closer analysis in this context.

4.4. Institutional Arrangements

Institutional arrangements are primary to the kinds of socio-cultural issues this paper seeks to engage with; they can potentially play a crucial role in the sustainability of mini-grids, offering opportunities to create enabling conditions from the outset. Rules (I1) need to be simple and easy to understand, requiring members of the community to be able to understand 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 the potential role that these could play could yield useful insights. Similarly, as sanctioning processes become more and more refined, the availability of low cost adjudication (I5) takes on a greater importance. Finally, and crucially, monitors and other officials must be accountable to electricity consumers (I6) in order to minimize, for example, the chances for elite capture and squandering of revenues. All of the institutional arrangements are therefore included in the refined framework.

4.5. 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 needs to be included in the refined framework.

5. Application of Refined Conceptual Framework

The systematic analysis in the previous section leads to a refined framework of 14 enabling conditions relevant to the socio-cultural aspects of the management of mini-grids for pro-poor electrification (identified by the dashed boxes in Figure 1). In this section the utility of the refined framework is tested in relation to the empirical evidence from the expert interviews and field visits in Kenya.

A vitally important challenge for many mini-grids, due to high cost and relative inefficiency of storing large amounts of electricity, is to match use of the resource to available (re-)generation capacity (condition RI1). Whilst this balance of supply and demand is common to all electric grids, seasonal fluctuations of supply and demand are particularly challenging in a rural mini-grid.
The enabling conditions in the refined framework immediately cast analytic focus on both the nature of this particular management challenge and potential solutions.

On the demand side, seasonal variations are greatest in areas in which agriculture dominates the village economy. Here, disposable income is largely dependent on harvest season when households can spend more on electricity. Agro-processing can also be very energy intensive, e.g. use of mills and grinders, leading to major peaks in the annual demand schedule. Furthermore, demand varies throughout the day, household demand peaking after sunset as demand for lighting increases. This peak is exacerbated by traditional practices in agricultural areas:

". . . there are challenges because traditionally people tend to do processing in the after-noon and in the evening so the time of day affects balancing your power load as well." (Interviewee 1)

In addition to RI1, this problem also relates to GR4 and GR5 (initial low levels and gradual change in demand) as demand levels change with seasonality in a step-change form rather than a gradual increase/decrease.

As well as demand-side issues, seasonality also creates problems on the supply side. Even in the equatorial climate of Kenya, solar PV and wind are subject to seasonal variations in sunshine and wind speed, albeit less so than small hydro power which is significantly affected by the rainy and dry seasons. There are several relatively crude ways of dealing with this problem. In Olosho-Oibor, for example, the mini-grid operator simply switches off entire branches of the mini-grid during times of low supply, i.e. overcast days with very little wind. At the other end of the spectrum, in Kitonyoni a very large amount of excess capacity has been built into the system from the beginning, while the number of connections has been fairly limited. Estimates gathered during the field visit suggested that, at that time, consumption at no point exceeded 10-15% of the available generation capacity. Neither of these solutions is optimal; in one case consumers are switched off by brute force when they might need electricity the most; in the other case expensive excess capacity is held back without generating any revenue for the mini-grid or benefits to potential consumers.

Looking to the other conditions in the refined framework, however, a number of alternative solutions are implied for balancing supply and demand. The first step in this direction is simple and locally devised rules (I1 and I2) that allocate the electricity to each user.

"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 2)

This also relates to condition GR3 (fairness in allocation). Through, for example, creation of type-of-use rules (e.g. prohibiting use of energy intensive appliances such as irons or kettles), the limited electricity supply available in a small mini-grid can benefit a larger number of people than it could without those rules. This was, for example, described by Interviewee 1 in relation to an older community-based micro hydro mini-grid (Kathamba in the Central province of Kenya). Such rules can also ensure each community member gets access to a similar amount of electricity, e.g. by determining that each household must at least be able to light two light bulbs. Time-of-day rules can also be fairly simple; businesses are encouraged to operate during the day time, when household electricity demand is very low, and discouraged to operate after sunset, when electricity is required for household lighting and entertainment.

In some cases, e.g. Olosho-Oibor, rules can obviate the need even for load limiters, as long as the entire community is aware of them. There are, however, limits to the usefulness of locally devised rules, namely in the setting of tariffs. Besides inherent conflicts of interest (communities may want lowest possible prices regardless of the effect on the financial sustainability of the mini-grid), there are two additional potential pitfalls when determining tariffs with direct involvement of the community. In Kitonyoni, for example, tariffs were set based on community surveys. According to the village chief, community members were asked to state what they would be able to pay for electricity based on current expenditure on other sources of energy. Community members did not want to appear poor so overstated their ability to pay, resulting in initial tariff levels considerably higher than anything the community had spent on energy before. This relates back to condition G7 and the role of the heterogeneity of endowments, in this case interpreted as the variation in ability and willingness to pay (WTP) within the community. In order to ensure the viability of the system, tariffs had to be lowered quickly to accurately reflect the ability to pay. This implies a role for more rigorous WTP analyses, learning from the economics based literature on mini-grid management reviewed in the introduction.

The other issue with locally-determined tariffs is potential for elite capture and conflict, highlighting the importance of accountability of officials (I6), especially in closely-knit communities:

"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. When asked whether failure to pay tariffs was a problem, the local mini-grid manager and technician who was the initial contact at Olosho-Oibor agreed that this sometimes happened. Further conversation, however, suggested that failure to pay had never resulted in disconnection, as the village committee has to agree to this step.

This evidence highlights the importance of appropriate leadership (G5), ease of enforcement of rules (I3) and the availability of low-cost adjudication (I5). The apparent absence of these and other conditions might explain why Olosho-Oibor has repeatedly had to raise donor funding to remain operational. Technological developments such as the introduction of prepaid meters using mobile payment systems increasingly are "a game changer" (Interviewee 5) in this respect as they remove the need for cash collection and adjudication, and the risk of elite capture. A similar concern led Kitonyoni to adopt prepaid meters. There is, however, still a role for community involvement in enforcement of rules, which can greatly affect the ease of enforcement (I3). In particular, enforcement of type-of-use rules mentioned above can be carried out very 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 6)

"...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 1)

An additional benefit of this level of community involvement is that it discourages theft through wiring around the meter. Several interviewees mentioned that despite expectations of theft becoming a problem it did not transpire in practice to the degree they feared it might. This suggests 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. This again relates back to fairness in allocation (GR2), which is particularly relevant in a mini-grid serving a variety of customers. If an anchor tenant (a high demand commercial user) is present it is often given priority in allocation of electricity, with other businesses being next in line and households being the lowest priority during the day. This allocation is often then revised after sunset to give household lighting higher priority.

". . . we find that in most instances even in other places a community centre or maybe if you are powering a hospital or people are charging their phones, the priority will be given to that common centre compared to the households. [...] So they look at what is the priority for now. It's just an arrangement. They are looking at who needs power at what particular time and then can work with the system." (Interviewee 7)

It is important, however, that this allocation is perceived as fair by everyone since homogeneity of interests (G7) in this process is far from guaranteed. In Olosho-Oibor, public institutions (the school, dispensary, church and a rescue centre for girls being protected from the practice of female genital mutilation), are given clear priority in allocation of electricity, an arrangement that at least those community members spoken to during the field visit (the local technician, two teachers, a worker at the dispensary and the head of the rescue centre) seemed to understand and agree with. In another example described by Interviewee 8 (Mpeketoni in Northern Kenya), the mini-grid managers decided to favour businesses in electricity allocation due to their superior ability to generate income with which to pay for their electricity consumption (a point that will be raised again later in this analysis). Households felt they were being treated unfairly, even though they were customers like everyone else, and they effectively forced the management to revise their allocation schedules. This highlights the importance of finding the right balance between serving those customers who generate most revenue (businesses) and those who can often generate the most opposition within the community (households). It is also a key consideration in relation to any normative commitment to prioritising electricity access for poor women and men.

In Kitonyoni, the challenge of addressing very different user needs has been pre-empted by not connecting any households and instead offering charging services for lanterns and cell phones through a commercial outlet. While this approach, at least in the literal sense, does not pursue universal electrification, the business benefits of access to electricity are clearly visible, for example in the form of a small shop run by a self-taught young man who repairs electronics using a soldering iron, a skilled job he could not have done without access to electricity. Such productive uses of electricity have important implications in relation to the financial sustainability of the grid, and broader considerations around economic development and poverty reduction as a result of electrification.

Consideration of the role that interdependence of group members and their dependence on the resource (G6 and GR2) plays in sustainable operation of a mini-grid helps to further illustrate the difficulties of serving differing customer needs within the same closed resource system. In particular, over-reliance on one anchor load can be problematic in light of the goal of universal electrification, highlighting the interdependence of resource users (G6):

"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 2)

This interdependence becomes even more critical if there is one particularly important anchor customer, i.e. if condition G7 is not met and interests are especially heterogeneous. Interviewee 8, again in relation to the Mpeketoni mini-grid, described how the whole community had to be shut off whenever there was a critical medical procedure at the dispensary, such as surgery or a woman delivering, in order to ensure 100% reliable electricity supply during that critical time. This level of interdependence is clearly problematic, including if other users depend on the electricity for economically productive purposes, something that assists the financial sustainability of the mini-grid.

Reducing such dependence on anchor loads and other critical loads potentially allows for more reliable electricity supply to businesses and households in the community, particularly as businesses form the backbone of the long-term financial sustainability of the mini-grid and the creation of economic opportunities in the community:

"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." (Interviewee 5)

Demand from businesses, however, does not appear automatically as soon as electricity becomes available. Creating supplementary businesses (intersecting again with G6 and G7) such as charging stations, agro-processing enterprises, water pumps or even TV broadcasts of major sporting events can help generate revenue from productive uses, foster economic development in the community, or create demand during daylight hours, allowing sale of electricity to households at night at more affordable rates (Interviewees 5 and 10).

When building an increasingly powerful mini-grid with such productive uses in mind, however, it should be noted that demand can grow quite rapidly rather than gradually over time (condition GR5) despite starting out at very low levels (GR4). If demand growth is not anticipated it can cause grid reliability problems and customer dissatisfaction:

"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 8)

Both Kitonyoni and Olosho-Oibor exhibit this problem in different ways. In Kitonyoni, large excess capacity has been built in, which sits idle until demand catches up. There is an inherent risk in this as demand might not grow for as long or as quickly as expected. This approach is only possible in a donor-driven model that is less focused on financial sustainability than a private sector model. In

Olosho-Oibor, demand has not been able to grow as the system was undersized from the beginning and unable to invest in upgrades due to the aforementioned low tariffs. This has potentially stifled economic activity in the community.

The final factors considered in this discussion are the presence of appropriate leadership for the mini-grid and ways in which their accountability can be ensured (G5 and I6). Several interviewees (1, 2, 7 and 9) stressed the importance of appropriate leadership, which they understood as dedicated and technically educated management with a local presence. First and foremost a need was articulated for a local dedicated manager employed by the organization operating the mini-grid and available to the local community for customer service and simple repairs:

"He [the local leader] 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 9)

Importantly, since this manager is an employee of the organization owning and operating the mini-grid s/he can be let go if there are problems with the management of the system, in theory ensuring accountability (although the lack of an alternative manager often makes this impractical).

Both Olosho-Oibor and Kitonyoni have such dedicated management. In addition, however, interviewees suggested that local management should be supported by an organization with the technical capacity to conduct more complex system maintenance, repairs and upgrades. Ideally such an organization could facilitate low-cost adjudication and any form of graduated sanctions (I4 and I5). While Kitonyoni has a dedicated cooperative and can, for now, rely on the University of Southampton and its partners for technical support, Olosho-Oibor has been struggling with this, resulting in poor state of repair of the system, including a broken off wind vane on the wind turbine and poorly performing batteries, as well as the aforementioned problems with rule enforcement.

6. Conclusion

As emphasized in the introduction, the aim of this paper is not to produce overarching prescriptions for solving the complex problems that relate to the sustainable management of rural mini-grids in developing countries. Rather, the intention was to provide a novel theoretical basis for further research on the socio-cultural aspects of sustainable mini-grid management for pro-poor electricity access, supported by an initial empirical demonstration of the potential utility of the refined theoretical framework developed above. The empirical analysis demonstrates how the refined framework casts analytic attention on several problems in sustainable mini-grid management as well as implying several socio-cultural solutions. Challenges seen in other CPR contexts are highlighted around balancing supply and demand and being able to respond to changing demand (including daily and seasonal changes as well as longer-term, more gradual changes). Potential ways forward illustrated by the analysis include developing simple 'use rules' that are widely understood and implementable, and - through shared community ownership - can contribute to a fair allocation of benefits and responsibilities, not only between homogenous groups of users such as households, but also across diverse groups of interdependent users that are present in many mini-grids (including private sector anchor tenants or community organisations such as schools or hospitals).

In this way, the analysis contributes both theoretical and empirically to the emerging socio-cultural turn in the literature on sustainable energy access, further strengthening the case for moving beyond the literature's previous two-dimensional focus on technology/finance and engineering/economics based analysis. As emphasized in the introduction, however, this in no way down plays the critical importance of the latter. Rather, it positions technology and finance as part of a broader perspective where socio-cultural considerations are of equal and sometimes greater concern in understanding sustainable energy access. This mirrors in important ways Shove's (2010) call for broader attention to socio-cultural considerations and the role of social practices more broadly in analytic approaches to climate policy (of which the sustainable energy access problematic represents an increasingly high profile sub-field).

Applying the refined theoretical framework developed here to other examples of mini-grid management or, indeed, the design of institutions for managing future mini-grids, would serve to generate the empirical basis for comparative analysis and further refinement of the research and policy/practice applications of the framework. An additional key area for future research, building directly on this paper's application of CPR management theory, is a closer analysis of the issue of property rights in relation to mini-grid management. This plays a central role in much of the CPR literature and raises interesting questions for the management of mini-grids insofar as the application of different technologies (e.g. prepaid meters and mobile payment systems) can influence the nature of the property rights that characterize different mini-grids. This also raises questions regarding the interrelationship between technological, socio-cultural and other institutional considerations. Questions include how these technologies affect the dynamics of resource management and collective action potential and whether key issues highlighted in the analysis above, such as seasonality and fair allocation, persist regardless of the effective property rights regime implied by different technological applications. This also speaks to broader debates in the CPR literature that engage with tensions between moves towards privatizing CPRs vs. collective action based solutions. This is taken up in a follow-on paper to the current one.

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