Rethinking the sustainability and institutional governance of electricity access and mini-grids: electricity as a common pool resource

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Rethinking the sustainability and institutional governance of electricity access and mini-grids: Electricity as a common pool resource

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Abstract

Rural mini-grids are viewed as a key technology for providing access to electricity to the billion or more people that lack it by 2030 (in line with the UN's Sustainable Energy for All commitment). But at present no model for the sustainable management of rural mini-grids exists, which contributes to high failure rates. This paper makes a number of contributions. First, it explores how electricity in mini-grids might be understood as a Common Pool Resource (CPR), opening up potential to learn from the extensive literature on institutional characteristics of sustainable CPR management in the natural resource management literature. Second, it refines Agrawal's (2001) overarching framework of enabling conditions for sustainable CPR management institutions to develop a framework applicable to rural mini-grid management in developing countries. Thirdly, the utility of this refined framework is demonstrated by applying it to analyse data from 27 semi-structured interviews with actors with expertise in mini-grid development and management in Kenya and 2 field visits to rural mini-grids there. This contributes a nuanced basis for future application of CPR theory to mini-grids and a systematic analysis of institutional challenges and possible solutions, which have hitherto received limited attention in the energy and development literature.

1. Introduction

Over one billion people lack access to electricity – a vital precursor of many aspects of human and economic development [1]. In sub-Saharan Africa around two in every three people lack access, with electrification rates below 25% in some countries [2]. The UN's "Sustainable Energy for All" (SE4ALL) initiative (supported by Sustainable Development Goal 7) aims to solve this problem by 2030. But this aim is plagued by problems in practice. In this paper, we focus on developing sustainable institutions for managing the use of a key technology, mini-grids, which are estimated as needing to provide 45% of the connections required to achieve SE4ALL by 2030, the majority in remote rural locations [3].

Despite their promise, managing mini-grids in ways that can provide electricity access to poor people poses considerable technical, economic, socio-cultural and political challenges, with failure rates evaluated as being high as 50-100% [4, 5]. Part of the reason for this failure can be due to inappropriate equipment installation and/or inadequate maintenance; it can also relate to financial issues (e.g. tariffs being set too low). A persistent problem also, however, relates to collective over consumption of electricity, which in turn leads to equipment degradation and failure, indicating the presence of socio-cultural and institutional management dimensions to mini-grid failure (explored in more detail in Section 5) as much as technical or financial reasons [4, 5]. Whilst, as Section 2 demonstrates, the engineering and economic challenges relating to energy access in developing countries are relatively well researched, the socio-cultural and political challenges have received very little attention to date[1]. In this paper, we focus on the institutional aspects of managing mini-grids, which cut across all of the above challenges, but in particular cast analytic attention on the socio-cultural and political dimensions of energy access. We demonstrate how insights from the broad literature on common pool resource (CPR) management (which mostly focuses on natural resources) can shed light on how to sustainably manage a man-made resource, electricity in mini-grids. There are examples of scholars who have proposed that mini-grids are CPRs [4-7]. As demonstrated in Section 2, however, there is, to date, no systematic examination of the relevance, and applicability to mini-grids, of the well-developed literature (reviewed below) on the

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[1] Note, it is not our intention to imply that high mini-grid failure rates are purely the result of a lack of sustainable management models and that technical and financial problems do not also contribute to failure, rather we wish to explore the former in a research field previously dominated by a focus on the latter.

‘enabling conditions’ under which institutions will emerge that support sustainable management of CPRs.

Our core question is whether CPR theory can assist in analysing the enabling conditions that characterise institutions capable of sustainably managing mini-grids for pro-poor electricity access in developing countries. After reviewing relevant literature on energy and development and useful strands of the CPR literature, the paper makes its first contribution by analysing the conditions under which mini-grids display the characteristics of CPRs and hence how CPR theory might be relevant. We highlight similarities between electricity in a mini-grid and water in irrigation systems (the subject of a large part of the CPR literature) using the hydraulic analogy to explain the behaviour of electricity in closed circuits. The paper then makes its second contribution by developing a refined, mini-grid specific, analytical framework of enabling conditions for the sustainable management of CPRs (based on Agrawal [8]). The potential utility of this refined framework is then tested by applying it to analyse empirical data from 27 expert interviews and 2 site visits to mini-grids in rural Kenya. This provides a nuanced basis for future research. Our intention is not to produce overarching prescriptions for solving the complex problems that relate to managing rural mini-grids in developing countries. Rather, it is to develop and evaluate the usefulness of a new analytic, theoretically grounded approach with potential to inform future research and practice focussed on overcoming the high levels of failure observed in relation to rural mini-grids in developing countries.

2. Relevance of CPR theory for mini-grids

This paper engages with the CPR management literature made famous by Hardin’s [9] “Tragedy of the Commons” and Ostrom’s [10] later Nobel prize winning work, which demonstrated how social institutions can form and achieve sustainable management of CPRs, thus avoiding Hardin’s earlier hypothesized “tragedy”. We apply Ostrom’s and later authors’ insights on sustainable CPR management to local electricity provision in the form of mini-grids. This is motivated by recognition of the sophisticated body of theoretical and empirical work in the CPR and collective action field, compared to a lack of any well-developed institutional approaches within the energy access literature. Rather than starting from scratch, we want to see what we can learn from this work that, arguably, deals with systems similar to decentralized, collective electricity provision via mini-grids.

The existing energy access literature has, to date, been dominated by a focus on the financial and technological dimensions, with attendant disciplinary domination by economics and engineering, with insufficient focus on socio-cultural and political dimensions [11] – what Ockwell and Byrne [12] describe as the "scholarly deficit" in energy access research.

As a result, we know a lot about financial dimensions of mini-grids and rural electrification more broadly, such as: relative costs and benefits of technological options [e.g. 13, 14]; willingness and ability to pay [e.g. 15]; and the nature and appropriateness of different financing mechanisms for infrastructure [e.g. 16]. We also know much about: technology selection methods [e.g. 17]; applicability of technologies to specific physical contexts [e.g. 18, 19]; spatial mapping of technological applicability and least-cost scenarios [e.g. 20]; improving technological efficiency [e.g. 21]; technology adoption, e.g. the energy ladder [e.g. 22]; and scenario modeling [e.g. 23].

A handful of recent contributions have begun to grapple with political economy dimensions of energy access more broadly (as opposed to mini-grids specifically) [e.g. 24, 25-31]. And recent years have witnessed what might be described as a nascent "socio-cultural turn" [12] in energy access research, with a number of contributions operationalizing insights from the socio-technical transitions literature [32-39] and social anthropology [40-42]. These contributions have cast analytic light on a range of socio-cultural aspects of energy access, including understanding the social, cultural, gendered and, inevitably, political dimensions of electrification and the implications of involving potential users in the design, development and implementation of rural electrification projects. A number of recent contributions also operationalize insights from innovation studies, introducing an emphasis on indigenous capability building, albeit more at a firm/industry than community level [43-47]. There have also been recent attempts to bridge the fields of socio-technical transitions and innovation studies [see 12, 48]. More explicitly focussed on sustainable mini-grid management, a wider literature also exists (mostly focusing on

Indian experiences) which analyses enabling conditions for sustainable management of mini-grids, emphasizing, for example, the important role that village energy committees and other local institutions have played, as well as the broader importance of community participation [e.g. 49, 50, 51].

Despite this recent socio-cultural turn and the emerging literature on the politics of energy access, however, only four pieces of grey literature to date (two working papers and two doctoral theses, no peer reviewed journal articles) have explicitly engaged with institutional insights from the collective action literature [4, 5, 7, 52]. Of these, only three recognize the relevance of work in that literature on understanding enabling conditions for sustainable CPR management and all three of these demonstrate only a partial engagement with this work. Maier [5] 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 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 failed experienced external pressures, e.g. the arrival of the national grid. Maier does not venture beyond treating electricity as a CPR, identifying CPR attributes and describing resulting management challenges. There is no systematic application of theories of collective action or reference to overarching enabling conditions through which institutions and transferable approaches may be developed, although, given the importance of rules Maier identifies, the use of enabling conditions as an analytical tool would have been appropriate.

Greacen [4] also suggests that electricity in community-based micro hydro mini-grids, in this case 59 projects in Thailand, can be treated as a CPR. Rather than elaborating on the manner in which experiences from other instances of collective action could be used to overcome identified challenges, however, 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. Furthermore, this focus on technical fixes ignores potential institutional considerations that might still persist, e.g. managing distribution among 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 [7] also studies some aspects of collective action. He focuses on the contested effect of heterogeneity of user groups 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 and only engages with one of the 33 enabling conditions identified in Agrawal's [8] theoretical framework that we refine and test further below. There is therefore 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.

2.1 Conceptualizing mini-grids as CPRs

A CPR 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 exclusion from access to the resource is difficult [53]. This is in contrast to public goods, for example, which are non-rivalrous (e.g. street lighting). These characteristics of a CPR 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.' [53, p.120]. It is important to note that a CPR does not imply open access to all — exclusion is difficult but not impossible. Rather, a CPR may still be associated with a variety of property rights regimes [54]. The argument has been made that energy infrastructure exhibits CPR characteristics [55]. To our knowledge, however, only Gollwitzer [56], Gollwitzer, Ockwell and Ely [57] and Wolsink [6] have discussed in depth the relevance of CPR theory for micro-grids (the latter in the context of emerging, future 'smart-grids' in developed economies – see also [58]). The functioning and characteristics of (micro and) mini-grids in poor rural communities in developing countries differ significantly, hence, the lessons to be taken from the CPR literature may differ in significant ways.

Irrigation systems are considered typical examples of CPRs and, to structure our analysis, we work with the so-called "hydraulic analogy" to identify similarities and differences between irrigation systems and electric mini-grids. The analogy is between a system of water pipes and a closed electric circuit (water flowing through pipes being analogous to electrons flowing through a conductor - resistance in the electric circuit is analogous to friction in the pipes, voltage equates with pressure and current with volume flow). An independent mini-grid can be seen to share a number of characteristics with an irrigation system, e.g. the consumption limit imposed by the recharge rate. This leads to a number of similar operational management challenges. Water in an irrigation system is a rivalrous resource: if an upstream farmer uses all the water in the irrigation canal there is no water left for the remaining farmers further downstream. Mini-grids are rivalrous in the sense that there is a limited generation capacity that must be balanced with demand. Both generation capacity and demand typically vary over the day and over seasons, leading to periods of both scarcity and underuse. User access is typically controlled in the sense that the operators can decide the number of connections to the local grid, but there can be problems with illegal connections, and, once connected, users may under certain circumstances use more than their agreed share. 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 irrigation systems and mini-grids, action by one person may lead to reduced performance and potentially damage to the system (e.g. droughts or blackouts) affecting all users. It is important to emphasise, however, that, unlike water, electricity cannot be stored, or can be stored at very high cost, which means that generation and consumption often need to be more coordinated. This can also have implications in terms of the size of systems and their efficiency, with larger systems potentially seeming more efficient than smaller systems due to the possibility of economies of scale and better management of demand variability (such a perspective, however, often ignores the inefficiencies of transmission, especially over large distances to remote rural areas where mini-grids have most promise; it also ignores non-financial costs [e.g. environmental and social impacts], or 'externalities', associated with centralized, grid based electricity production and transmission).

There are further differences between irrigation systems and mini-grids, including important technical and economic considerations. In irrigation systems, the CPR (water) has no cost of generation (disregarding small potential costs for pumping), users do not commonly pay per unit and access is often hard to control. Electricity is not rivalrous in precisely the same sense (although there is a limit to simultaneous consumption) as the use by one customer will generate income for the utility (commonly proportional to use), and tariffs may be differentiated so that large consumers pay more per unit. On the other hand, 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*. In an irrigation system, rainfall limits the water flow whereas in an electric system the utility can, in theory, invest and add capacity to meet growing demand. Still, many mini-grids in East Africa (the focus of our empirical study) struggle financially as users have low capacity to pay tariffs that are cost-reflective, meters are expensive to install and small systems may therefore rely on flat tariffs, which create incentives for over-use. In practice, it can be impossible to add capacity to meet growing demand or install technical protections to over-use. In such situations, mini-grids – although not inherently CPRs – display CPR-like characteristics [52]. These similarities therefore imply potential value in exploring the application of a CPR perspective to institutional challenges in mini-grid management. In the rest of this article, we, hence, treat mini-grids as CPRs in order to explore the value of the CPR literature in the context of sustainable management of mini-grids.

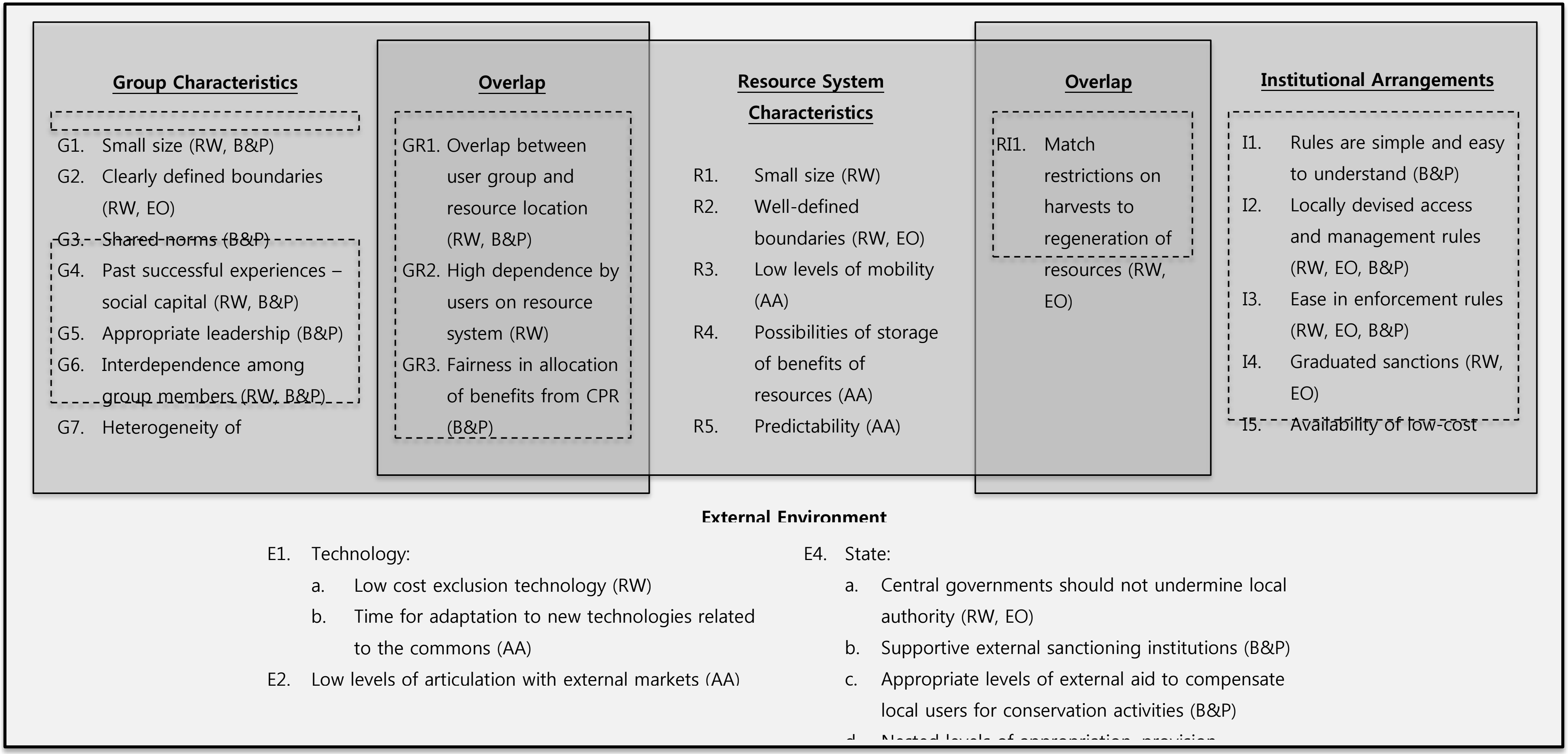
2.2 Enabling conditions for sustainable management of CPRs

Recognising similarities across the work of several key authors in the CPR management literature [in particular 10, 59, 60], Agrawal [8] reviewed work across the CPR literature and developed an overarching framework. This synthesizes the conditions under which sustainable management of CPRs is observed into 33 enabling conditions, grouped under 4 categories (Figure 1). This overarching framework has facilitated subsequent empirical analyses of reasons for long-term sustainability (or lack thereof) of institutions in the presence of a wide range of different CPRs. A review of 12 common property regimes involving forest, water and pasture in semi-arid Tanzania found no significant difference in the explanatory power of the enabling conditions among different types of CPRs [61] , suggesting application of the enabling conditions to other CPRs, like a rural mini-grid, would be equally relevant.

3. A refined analytical framework for rural mini-grids

This section refines Agrawal's [8] enabling conditions (Figure 1) based on their applicability and salience in analysing enabling conditions for the sustainable management of rural mini-grids for pro-poor energy access. We consider each of Agrawal's [8] 33 enabling conditions based on their relevance and applicability to mini-grids as CPRs. Agrawal's "external environment" (E1-4) category is not considered as it engages with issues beyond the scope of the unit of analysis focussed on in this paper, i.e. the applied management of a mini-grid. This does not imply in any way that these external environment conditions are irrelevant – on the contrary, as Ahlborg and Sjöstedt [62] illustrate, it is in the *encounter* between a local context in all its particularities and a sociotechnical system design that a unique and dynamic configuration emerges. How to analytically integrate such a sociotechnical perspective with Agrawal's [8] conditions represents a critical area for specific future analysis. The resulting refined framework is shown within the dashed boxes in Figure 1.

Figure 1. Analytical framework: Enabling Conditions for Sustainable Management of CPRs



Source: Authors based on Agrawal (2001)

Figure 1 caption: Figure 1 graphically represents the 33 enabling conditions for collective action collected and developed by Agrawal (2001). Those contained within the dotted lines are the conditions retained in the refined analytical framework developed and tested in this paper.

3.1. 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 analysis. Neither of Agrawal's sources that list small group size (G1) as an enabling condition [59, 60] specify a number constituting a "small group". It is, nonetheless, by definition, a characteristic of mini-grids. Clearly defined boundaries (G2), on the other hand, are more complex. It could be argued that G2 is defined by the extent of those either directly connected to, or directly interacting with the mini-grid (e.g. by paying to charge mobile phones or LED lanterns). During the initial establishment and subsequent operation of a mini-grid, however, boundaries and who has access to the grid can be a deeply political process and one warranting focussed, politically attuned analysis [26, 39, 40, 52]. As Wolsink [6, p.831] emphasizes; "The definition of system boundaries is particularly important for dealing with the interests within a community and with potential conflicts of those interests." And, all too often, such boundaries are assumed to be technical at the expense of considering the politics of the organizational and institutional delineations of such boundaries. The inherent dangers in making technocratic assumptions about what defines "communities" of energy are insightfully analysed by Campbell, Cloke and Brown [63].

The condition of shared norms (G3) does not apply to mini-grid management, as, according to Baland and Platteau [60], 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 [7]) are, however, a potentially relevant characteristic. This could be applied across sub-groups such as anchor loads, businesses and households, or at more granular levels, e.g. households within different income groups. Also, the cross-cutting issues of social differentiation based on gender, class, ethnicity, caste etc. can be analysed with G7 as a focal point, but are not limited to this condition (they are contextual). A related issue, which has not been studied before in the context of mini-grids, is the interdependence among group members (G6), which must be understood in the specific context of each individual 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. Critical reflection on the existing treatment of "identities and interests" in the literature that underpins Agrawal's [8] original framework of enabling conditions, however, reveals the limited way in which identities and interests have been treated to date. Several sources (see, e.g. [60]) consider this only in relation to socio-economic differentiation - less inter-household income inequality having been empirically observed in several studies to result in more equitable access to CPRs. Kirubi's (2009) later work also considers this in terms of the alignment of interests between elite actors and other mini-grid users (greater alignment resulting in greater likelihood of sustainable management). None of this, however, adequately captures the broader aspects of social inequality that extend well beyond income inequality and that are likely to be material to mediating both the sustainability of mini-grid management and the equity of access to electricity or energy services more broadly that result from access. Such aspects are contextual and include, amongst others, issues of gender and ethnicity. The treatment and application of G7 therefore needs to extend to these broader aspects of social inequality (E1-4 are not satisfactory in this respect), which will often cut across many of the other group characteristics (not least the question of leadership) in important, often complex and hidden ways (see, in particular Winther et al. [40] for more in-depth conceptual thinking on women's empowerment).

3.2. Resource System Characteristics

In a mini-grid, resource system characteristics are relatively straightforward to define. Small system size (R1) is a given, for reasons analogous to those outlined above regarding group characteristics. Well-defined boundaries, on the other hand, are again more complex. On the one hand, it could be assumed that these are analogous to the direct, physical area the grid covers. Similar to G2 above, however, there is not any natural reason why the institutional governance arrangement of a mini-grid should correspond spatially to the network of the grid. In many cases, for example, actors involved in the electricity generation side of the grid are part of the governance regime, as are the local elite (even when they are not connected to the grid in their own homes), donors, international NGOs, higher levels of government and civil groups (churches, women's groups, craftsmen, traders), etc. Many kinds of association tend to be given influence, even if these are very different from the group of "users" observed to be actively connected to and using the grid. In this sense, the boundaries of the resource could be argued to be as much an artifact of political processes that include and exclude certain actors, involve multiple considerations and can be contested and changed over time, as they could be considered to be a technically defined category. The energy resource base itself may also yield unique institutional challenges arising with conflicts over land, water and food/bioenergy. E.g. Ahlborg's [39, 62] analyses in Tanzania highlights the significance of decisions to initially electrify downstream but not upstream of a hydropower based mini-grid.

Low levels of mobility (R3) of the resource are present by definition, as electricity cannot leave the resource system (i.e. the mini-grid). 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 is included in the refined framework, as the aim here is to focus explicitly on institutional aspects of mini-grid management, as opposed to their technical design.

3.3. Group and Resource System Overlap

As with conditions G2 and R2 above, if one were to consider only the users connected to the mini-grid, the location of the resource system and user group might be considered to be identical, rendering consideration of the overlap between the two (GR1) moot. As alluded to in relation to R2, however, once the generation system is considered, as well as the many people that might pay for services from the grid without being connected themselves (e.g. for charging solar lanterns), then the degree of overlap becomes a more complex consideration, opening up myriad additional governance considerations.

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) highlighting 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.

3.4. Institutional Arrangements

Institutional arrangements are primary to the kinds of management considerations 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 (or allow for adaptive governance of local grids [6]). 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 greater importance. Finally, and crucially, monitors and other officials must be accountable to electricity consumers (I6) in order to minimize, for example, the risk for elite capture and squandering of revenues. All of the institutional arrangements are therefore included in the refined framework.

3.5. Resource System and Institutional Overlap

Matching 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 is included in the refined framework.

4. Methodology

Step 1: Theoretical refinement

As reflected in Section 3 above, each of Agawal's [8] 33 enabling conditions were considered in the context of rural mini-grids in developing countries and a refined framework produced.

Step 2: Case study selection and data collection

Kenya was selected as a relevant empirical context 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 and; 3) 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, furthering the diversity of perspectives to learn from.

Empirical data was collected from two field visits to rural mini-grids and 27 semi-structured interviews. The mini-grids were selected as both have community-based management arrangements, but differ in key characteristics (see Table 2), thus improving coverage of analysis. Each field visit lasted one day. Detailed tours were conducted. These were recorded by video and detailed notes taken. In Kitonyoni the guides were two members of the management committee. The village chief was also interviewed. In Olosho-Oibor the guide was the local technician and grid manager. Informal discussions were also conducted with two teachers, a shop operator (operating a solar lantern and mobile phone charging booth) and the manager of the Girl's Rescue Centre (that is connected to the mini-grid). Data was triangulated wherever possible with documentary evidence.

Table 1. Characteristics of field visit mini-grids

	Kitonyoni	**Olosho-Oibor**
Location	Makueni County, Eastern Province	Ngong, Kajiado County, Rift Valley Province

Operational since	2012	2009
Owner	Cooperative, donor-funded	Community-based organisation, donor-funded
Operator	Cooperative and University of Southampton E4D	Community-based organisation
Generation technology	Solar PV with diesel backup generator	Solar PV, single wind turbine, diesel backup generator
Generation Capacity	14 kWp PV and 37 kW diesel (diesel never run at time of visit)	10 kWp wind and solar, 10 kW diesel backup
Metering technology	Post-paid meters and prepaid meters using scratch cards	Flat fee, unmetered
Number of connections	20 business connections with 10 of these businesses also being attached to households and thus providing household connections	12-15, including private businesses (barber shop, printing shop, electronics shop), public institutions (school, dispensary, girl's rescue centre), a charging kiosk and 5-7 households nearby
Types of customers	Public institutions (e.g. clinic and school) and small businesses	Public institutions (e.g. clinic and school), households and small businesses

27 semi-structured interviews were subsequently conducted with 24 mini-grid experts in Kenya during January-February 2015. Interviewee sample covered a cross-section of backgrounds, institutions and sectors. Initial sample selection was based on identification of experts with experiences with mini-grid deployment and operation within Kenya. A snowballing approach was then applied to provide a diversity of backgrounds and perspectives. Sample coverage included: private sector (including energy consultancies, mini-grid technology providers, solar PV technology providers, energy finance specialists and off-grid electricity developers); NGOs (including those with an energy access focus and those with a rural development focus); public sector employees; donors; intergovernmental organisations; and academia. Findings were triangulated via cross-comparison across interviews and grey literature, including project reports and proposals.

Interviews were conducted using a semi-structured approach in the form of ‘in depth interviews’ [64], where conversation was permitted to flow freely, yet was closely guided by a catalogue of questions. Questions were designed to be open and non-leading, whilst directing conversation towards operational challenges faced in relation to rural mini-grids (see supplementary online material for full catalogue of questions).

Step 3: Data analysis and testing of refined framework

Data were then analysed via the refined framework of enabling conditions to test the framework’s utility. A methodological decision was made to exclude conditions G2, R2 and GR1 from the current analysis. As alluded to above, these conditions raise myriad complex political considerations which warrant significant, focussed analysis (in a similar vein to those previously conducted by a number of key authors [26, 35, 39, 62]) – analysis which was beyond the resources available for the current study. Similarly, in this initial empirical testing of the framework, we did not have the resources available to explore dimensions of social inequality (including gender and ethnicity/caste) beyond the original focus of the literature described above on socio-economic equality and alignment of interests between elites and the wider community of resource users. It should be emphasised, however, that this was a pragmatic decision based on resource availability and should in no way be taken to belittle the importance of these three enabling conditions, or these wider contextual dimensions of social inequality for future research.

5. Applying the refined framework

Here we apply the refined framework (Figure 1) to our empirical data to test its utility. We begin by considering resource system characteristics then discuss each of the enabling conditions included in our analysis as they emerge, often through clear links to one another.

A vital 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 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 direct our analytic focus to both the nature of this particular management challenge and potential solutions. On the demand side, the data suggested that seasonal variations are likely to be 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. The data also emphasised that agro-processing can be 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 afternoon and in the evening so the time of day affects balancing your power load [...]"* (Interviewee 1)

In addition to RI1, this 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.

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, 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. Conversly, 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 when they might need electricity the most; in the other case, expensive excess capacity is present 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, e.g. irons or kettles, or installing technologies like switches to control usage), 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. The data suggested that time-of-day rules can also be fairly simple; businesses are encouraged to operate during day time, when household electricity demand is low, and discouraged to operate after sunset, when electricity is required for household lighting and entertainment.

In a context like Olosho-Oibor, rules can obviate the need even for load limiters, as long as the entire community is aware of and abide by them. There are, however, limits to the usefulness of locally devised rules, e.g. in setting tariffs. Besides inherent conflicts of interest (communities may want lowest possible prices regardless of the effect on the financial sustainability of the mini-grid), our data suggest that there are additional potential pitfalls when determining tariffs with direct involvement of the community. In Kitonyoni, 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 they 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 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.

The other issue with locally-determined tariffs is the risk of elite capture and conflict [see 52], 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 agreed that this sometimes happened. Further conversation, however, suggested failure to pay had never resulted in disconnection, as the village committee has to agree to this step and to date had never done so.

This highlights the importance of appropriate leadership (G5), ease of enforcement of rules (I3) and 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 [see 65] – considered "a game changer" by Interviewee 5 – facilitate enforcement of rules, as they remove the need for cash collection and adjudication, and reduce risk of elite capture (although they cannot remove it entirely as elite capture can still happen in a myriad of ways). 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 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 by 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 that if enough people benefit locally (or are dependent on the resource - GR2) and the system is locally owned and managed, a mutual understanding develops that tampering with the system could affect everyone – an attitude typical of successful collective action. In comparison to large-scale grid infrastructure – where theft is a serious problem – mini-grids therefore benefit from the way social ownership and control deter free-riding behaviours.

Fairness in allocation (GR2) is also 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 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 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 to pay for electricity consumption, especially given tariffs are usually differentiated between businesses and households (a point 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 potential importance of finding the right balance between serving those customers who generate most revenue (businesses) and those who might be able to generate the most opposition within the community (in this case households). It could also be argued to be a key consideration in relation to any normative commitment to prioritise 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, a self-taught young man repairs electronics using a soldering iron, a skilled job he could not have done without, and the need for which is bolstered by, access to electricity. Revenue raised from such productive uses of electricity has important implications for financial sustainability of the mini-grid and, more generally speaking, broader economic development and poverty reduction as a result of electrification.

Considering the role that interdependence of group members and their dependence on the resource (G6 and GR2) play in sustainable operation of a mini-grid helps to further illustrate difficulties in 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 a whole community was shut off whenever a critical medical procedure occurred at the dispensary, e.g. surgery, or a woman delivering, in order to ensure 100% reliable electricity supply during that critical time. This level of interdependence is clearly problematic, especially if other users depend on the electricity for economically productive purposes, something that assists financial sustainability of the mini-grid.

Reducing such dependence on anchor loads and other critical loads potentially allows more reliable electricity supply to businesses and households (if additional generation capacity is not possible). This is particularly relevant to the long-term financial sustainability of the mini-grid as businesses often form the backbone of the mini-grid and are central to the realisation of economic opportunities resulting from electricity access:

> *"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 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 investor] 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)

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 that demand might not grow for as long or as quickly as expected. This approach is only possible in a donor-driven model less focused on financial sustainability than private sector models. In Olosho-Oibor, demand has not been able to grow as the system was undersized from the beginning (10 kWp wind and solar, 10 kW diesel backup compared to 14 kWp PV and 37 kW diesel in Kitonyoni) and investment in upgrades was not viable due to low tariffs. This has potentially stifled economic activity in the community.

Finally, we turn to appropriate leadership and ways in which 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 alternative manager often makes this impractical).

Both Olosho-Oibor and Kitonyoni have such dedicated management. In addition, however, interviewees suggested 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 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. Discussion and conclusion

The aim of this paper is to evaluate whether CPR theory can assist in analysing and designing sustainable institutions for managing electricity provision in rural mini-grids, in contexts where many people are poor and currently lack access to electricity grid services. Theoretically, the paper has contributed to advancing the state of the art in the energy and development literature by systematically and critically examining the ways in which mini-grids in poor rural contexts display CPR characteristics. Taking the context, as well as system characteristics into consideration, we developed a refined analytical framework of enabling conditions for sustainable management of mini-grids (Figure 1), and applied this empirically to the development of mini-grids in rural Kenya.

The result is a new analytic approach to assessing the characteristics of sustainable management approaches to rural mini-grids for pro-poor electricity access. In our view, the empirical analysis demonstrates how the refined framework usefully focuses analytic attention on multiple problems faced by users of rural mini-grids, as well as by expert practitioners whose role it is to design, implement and finance rural mini-grids in Kenya. In relation to previous studies of rural electrification and mini-grids in poor rural communities, our analysis supports previous findings on institutional challenges, such as being able to respond to changing supply and demand (including daily and seasonal changes, as well as longer-term, more gradual changes); and the role of local leadership and clear institutional frameworks and use rules [7, 66]. These previous findings are, however, scattered across various studies and their recommendations about institutional aspects typically lack grounding in institutional theory.

As emphasised in the introduction, we do not claim, nor did we aim to achieve, a comprehensive analysis of all of the complex management issues pertaining to the sustainable management of mini-grids. The analysis and theory development in this paper, nevertheless, represents a focussed and theoretically grounded attempt at arriving at a better understanding of institutional aspects and possible solutions, which can provide a useful focus for future research in this field. It is important to note here, however, that the methodological decision to exclude conditions G2, R2, GR1 and broader aspects of social inequality (including, but not limited to, gender and ethnicity/caste) from the analysis above was purely pragmatic based on available resources and represents a gap in this paper's analysis that warrants focussed future attention. We would point readers in particular to the emerging literature that attends to gender in the context of energy access [e.g. 39, 40, 67, 68, 69], including the ENERGIA[2] programme. Relatedly, this paper also does not review in depth the wider literature on participatory governance and energy access (mentioned in Section 2); a systematic review of this literature and the ways in which it overlaps and can speak to the refined, CPR inspired framework developed here represents an additional key area for future research effort.

[2] http://www.energia.org

Applying the refined analytical framework developed here to other examples of mini-grid management, or the design of institutions for managing future mini-grids, would also serve to generate the empirical basis for comparative analysis and further refinement of the research and policy/practice applications of the framework. In line with previous studies [36, 62], the analysis above points to the importance of developing 'use rules' that are widely understood and implementable and that, through shared community ownership, can contribute to what is widely perceived a fair allocation of benefits and responsibilities, not just 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). A related additional key area for future research (which the authors are currently writing up initial analysis on), 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 (as also highlighted by Wolsink [6]). 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 [33, 70]. It also raises questions regarding the interrelationship between technological, financial, socio-cultural, political 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 and whether or not poor and marginalised women and men gain or lose as a result [71].

The analysis in this paper contributes both theoretically and empirically to a nascent socio-cultural turn [12] 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. This in no way downplays the critical importance of the latter. Rather, it positions technology and finance as part of a broader perspective where socio-cultural and political considerations are of equal and sometimes greater concern in understanding and effecting sustainable energy access [65].

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