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Community-based Micro Grids: A common property resource problem

Lorenz Gollwitzer

Rural Electrification

STEPS centre

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This paper introduces a new methodological and theoretical foundation for studying the reasons for successes and failures of community-based micro grids (CBMGs). While technical and financial factors involved are very critical they are comparatively well researched. This analysis argues that further research into, in particular, the institutional design of CBMGs is required in order to improve long-term sustainability. The paper suggests that the electricity in an isolated micro grid can be treated as a common property resource (CPR), which then opens up the established academic literature regarding collective action in the presence of CPRs. More specifically this paper analyses how the rich set of enabling conditions for collective action, which has been established in the context of traditional CPR situations such as water for irrigation or pasture for grazing, can be applied to the context of CBMGs. The goal is to arrive at workable recommendations for policy-makers and practitioners to inform the design and improve the long-term sustainability of CBMGs. Ultimately this has the potential to contribute towards efforts to bring modern energy services to significant parts of rural populations without electricity access.

About the Author

Lorenz Gollwitzer is currently researching institutional arrangements for community-based rural electrification in East Africa for his PhD at SPRU (Science Policy Research Unit) at the University of Sussex. His past research and work has focused on accelerating deployment of low-carbon technologies for rural electrification in developing countries as well as new financing mechanisms for resilient and sustainable infrastructure. He holds an MA in International Relations and Economics from the Johns Hopkins School of Advanced International Studies (SAIS) and a BSc in Engineering and Business from Warwick University.

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A Common Property Resource Problem

Lorenz Gollwitzer

STEPS Working Paper 68

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

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Contents

Acronyms

ARE	Alliance for Rural Electrification
CPR	Common property resource
CBMG	Community-based micro grids
GVEP	Global Village Energy Partnership
IEA	International Energy Agency
IGO	Intergovernmental organisation
ITDG	Intermediate Technology Development Group (now Practical Action)
LED	Light-emitting diode
MDGs	Millennium Development Goals
NGO	Non-governmental organisation
PV	Photovoltaic
SHS	Solar home systems
UNDP	United Nations Development Program

Abstract

This paper introduces a new methodological and theoretical foundation for studying the reasons for successes and failures of community-based micro grids (CBMGs). While technical and financial factors involved are very critical they are comparatively well researched. This analysis argues that further research into, in particular, the institutional design of CBMGs is required in order to improve long-term sustainability. The paper suggests that the electricity in an isolated micro grid can be treated as a common property resource (CPR), which then opens up the established academic literature regarding collective action in the presence of CPRs. More specifically, this paper analyses how the rich set of enabling conditions for collective action which has been established in the context of traditional CPR situations, such as water for irrigation or pasture for grazing, can be applied in the context of CBMGs. The goal is to arrive at workable recommendations for policy-makers and practitioners to inform the design and improve the long-term sustainability of CBMGs. Ultimately this has the potential to contribute towards efforts to bring modern energy services to significant parts of rural populations without electricity access.

1. **Introduction**

This paper proposes a novel way to study reasons for successes and failures of community-based rural electrification efforts in developing countries and determine factors that will increase the long-term sustainability of future efforts. In order to gain insight into the institutional and social factors involved this paper treats the electricity in an isolated micro-grid as a common property resource (CPR). This distinction then opens up the rich academic literature regarding collective action in the presence of CPRs, creating an opportunity to apply the findings of this literature to a new context. Rather than demonstrating the application of CPR theory to community-based rural electrification, this paper seeks to develop and articulate a detailed conceptual approach, which will facilitate the analysis of critical enabling factors for social cooperation in the sustainable management of community-based micro grids (CBMG). This is not to suggest, that community-based approaches are always the optimal solution, but rather that they are an important option to consider. The ultimate goal, for which the analytical framework presented in this paper is the foundation, will be to contribute significantly towards the current sparse academic literature, applying theories of collective action in the presence of CPR to the context of off-grid electricity. Furthermore, by applying this analytical approach in future research it will be possible to arrive at workable recommendations for policy-makers and practitioners to:

- determine the suitability of a CBMG-approach as part of the project design process
- create a suitable institutional setup within the community
- avoid costly mistakes by reducing the failure rates of CBMG projects
- improve energy access levels in the developing world

To this end the author is planning to apply the analytical framework presented in this paper to a series of case studies in East Africa.

Section 2 of this paper outlines the current state of rural electricity access in Africa and introduces options for electrification. Section 3 introduces the rationale behind community-based approaches in development, leading to a short overview of the current state of the research on community-based micro grids in Section 4. In section 5 an overview of lessons learned from the study of collective action in the presence of CPR is provided and the theoretical framework is introduced. Section 6 introduces electricity as a CPR, leading to a literature review of collective action in the context of off-grid electrification in Section 7. Section 8 narrows down the theoretical framework in order to apply it to the context of rural electrification. The paper is finished off with an outlook on policy implications of the analysis and concluding remarks in the last two sections.

2. Pathways to Rural Electrification

Access to electricity, while certainly not directly causing or guaranteeing economic and human development, is nonetheless widely accepted that 'development is not possible without energy' (SE4All 2012: 4). Yet, according to the International Energy Agency (IEA 2012) there are still around 1.3 billion people worldwide without any access to electricity, which amounts to just under one fifth of the global population. The situation is most dire on the African continent, where a total of 57 per cent of the population lack access to electricity, with electrification rates below 5 per cent in large parts of rural Africa (*ibid*.). Expanding electricity access in these areas currently deprived of modern energy would not only allow the pursuit of entrepreneurial opportunities (see for example GVEP 2012) thereby advancing economic development, but also provide the necessary foundation for multiple other benefits.

According to a review of electrification projects in Asia and the Pacific by the United Nations Development Program (UNDP 2011) electricity access contributes positively to the achievement of all eight Millennium Development Goals (MDGs). Fuel efficiency gains and the productive use of energy, for example, can lead to a 'reduction in extreme poverty and hunger' (MDG 1). Improved lighting for studying helps to 'achieve universal primary education' (MDG 2). and the opportunity for women to learn new skills 'promotes gender equality and empowers women' (MDG 3). The reduction of indoor pollution caused by kerosene lamps and the burning of biomass 'reduces childhood mortality' (MDG 4) while also 'improving maternal health' (MDG 5). The potential to refrigerate medicines and vaccines is critical in the pursuit of 'combat[ing] HIV/AIDS, Malaria and other diseases' (MDG 6). Reduced consumption of fuel wood and fossil fuels such as kerosene, and the potential for improved access to water through mechanical pumps, contributes towards 'ensuring environmental sustainability' (MDG 7). Furthermore, access to electricity is crucial for communication, be that in the form of radio, television, telephone or the Internet, as well as access to finance and simple banking facilities, particularly in the case of Africa where mobile phone banking is very widespread. These benefits help in the 'promotion of a global partnership for development' (MDG 8).

From this it can be seen that there exists a great opportunity and challenge to develop ways to bring modern energy services to dispersed rural populations. The extension and expansion of national grids, alongside the addition of centralised electricity capacity, is one possible way to frame a solution to this problem. While this is often seen as the most promising way to electrify urban and peri-urban areas, it is more difficult to be made profitable in rural areas with widely dispersed populations.

Using East Africa as an example, and assuming fixed costs of $22,000 per kilometre for transmission lines and $9,000 per kilometre for distribution line, Anderson *et al*. (2012) estimate that grid extension is not economically feasible in areas that would average less than five connections per kilometre of grid extension. Given the fact that over 80 per cent, 65 per cent and 60 per cent of the population live more than 20km from the nearest substation in Tanzania, Kenya and Uganda, respectively (Eberhard *et al*. 2011) grid extension is not likely to be a feasible solution in large parts of rural East Africa. Even though Deichmann *et al.* (2011) estimate that 'decentralised power supply is unlikely to be cheaper than grid supplies any time soon' (p.225), this does not mean that it is an option that households can easily afford, given the fact that most African utilities charge fairly substantial connection fees. In Kenya, for example, the national utility charges each household $370–$500 in connection fees, an amount that is unaffordable for most rural households. In addition, if the household is further than 600m from the furthest substation, it has to cover the full cost of grid extension.[1]

[1] See the information on: http://www.rea.co.ke/index.php?option=com_content&view=article&id=88&Itemid=533&limitstart=1

Furthermore, even taking into account the high capital cost of solar PV at $7,230 per kW installed power, the levelised cost of solar PV mini-grids 'will generally be competitive with that of grid extension when the extension would imply <10 connections/km' (Anderson *et al.* 2012: 5). In addition, the existing power generation infrastructure in many cases is already unable to meet the current levels of demand, let alone the additional demand created by connecting more rural households to the power grid. Kenya, Uganda and Tanzania already average about 80, 70 and 65 days of power outages per year respectively and their total installed generation capacity is less than 30W per capita, or the equivalent of two typical compact fluorescent light bulbs (Eberhard *et al*. 2011).

One possible solution to this challenge are solar home systems (SHS), consisting of a small photovoltaic (PV) cell charging a battery, typically a lead-acid battery such as is found in cars[2], which can then be used to power a compact fluorescent or light-emitting diode (LED) light bulb, or a number of appliances such as a radio or a refrigerator. These systems are quite popular and have been successfully implemented across the developing world and Sub-Saharan Africa, especially in Kenya (Sebitosi, *et al.* 2006). Alternatively, instead of electrifying individual households, it is possible to connect whole communities or villages by constructing a mini or micro grid, independent of the national grid, that draws its power from one (or, in a hybrid system, two or more) small centralised power source(s). This approach has been realised very successfully, particularly in East Asia and Latin America, typically relying on small hydro plants or diesel generators as the source of electricity (Casillas and Kammen 2011). As a result, the IEA (2012) estimates that mini grids are the most suitable electrification option for 45.5 per cent of rural areas, while grid extension is the most viable option in only 30 per cent of rural areas.

Micro grids, by their very nature, also offer a number of other advantages over SHS. They generally involve higher generation capacities, meaning that with proper load management there is a higher potential for productive uses, such as water pumping for irrigation, as well as milling, grinding or welding, thereby improving the ways in which electrification can be a catalyst for economic development. Furthermore, while the benefits of an SHS are limited to one household or institution (e.g. a school or dispensary) only, micro-grids spread benefits across the whole community and may include the electrification of households, businesses, public institutions - such as schools and health clinics – simultaneously. They may also include the installation of street lights, which have been shown to significantly increase safety, particularly for women (Ilskog *et al.* 2005). Yet, due to the micro grid's higher initial capital costs and the much higher complexity of operating, maintaining and managing, they pose considerably greater technical and institutional challenges than SHS.

A final benefit of mini or micro grids is that they avoid technological lock-in into a centralised power system. While industrialised nations are now struggling to integrate intermittent renewable energies into the rigid, centralised power infrastructure prevalent, there seems to be an opportunity for developing countries to leapfrog this set up, in a similar way to which they have leapfrogged the telephone landline with cell phones. Such decentralised systems are much better suited to the decentralised nature of renewable energy generation and as a result could support and promote a more sustainable and environmentally friendly electricity system.

[2] See for example 'Universal Technical Standard for SHS': http://138.4.46.62:8080/ies/ficheros/102Standard_IngV2.pdf

3. The Relevance of Community-based Approaches

One potential way of organising and institutionalising rural micro-grids is a community-based approach, meaning in this context that 'the community becomes the owner, and operator of the system and provides maintenance, tariff collection, and management services' (Rolland and Glania 2011: 21). In addition, particularly in the case of developing countries, a community-based approach involves early consultation of community members to estimate demand and, in many cases, enlists the help of the community in the construction of the micro-grid, contributing what is often called 'sweat capital'. This, of course, assumes that these micro grids are established with the outside assistance of non-governmental organisations (NGO), intergovernmental organisations (IGO) or the government. Although theoretically it would be conceivable for a community to finance, design, build, maintain and operate a micro grid without outside assistance at any of those steps, this seems a tall order and the author is not aware of any examples of such self-initiated micro grids in the developing world.

Research has shown that there are a number of reasons why community participation can be a critical factor in achieving long-term sustainability of electrification efforts. First of all, based on a review of experiences made by Intermediate Technology Development Group (ITDG) (now Practical Action) over 25 years, community-based approaches are considered a pre-requisite for long-term sustainability and equity of benefits of any local infrastructure investment, such as a micro-grid (Holland et al. 2001). In a review of institutional options for rural electrification in developing countries Foley (1992) also finds that, based on experiences in Bangladesh, Nepal and the Philippines, devolving operation and management authority for the local electricity supply to a community-based organisation rather than a centralised rural electrification agency can have a number of advantages, such as reducing bureaucracy and transaction costs. In a review of literature on access to modern energy services Bazilian *et al.* (2012) identified active participation throughout and community ownership as two of the general principles that need to be followed for successful improvement of access to modern energy services in the developing world. In fact, this ability of communities to mobilise around local projects (specifically involving renewable energy) has not only been observed in the developing country context but also in the developed world, explaining the rise of, among others, energy cooperatives in Germany (Bilek 2012) and the emergence of community energy projects in Scotland (Bomberg and McEwen 2012).

Furthermore, since private sector investment is unlikely to be attracted to the very narrow profit margins involved in operating rural micro-grids in developing countries, a not-for-profit community organisation, such as an electricity cooperative, is a suitable alternative business model to explore in this context (Ilskog *et al*. 2005). Based on best practices for rural electrification outlined by the World Bank, it has been argued that setting up such community organisations requires outside assistance for upfront feasibility studies as well as financing and capacity building (Terrado *et al.* 2008).

While community participation can clearly be advantageous, therefore, it also presents a number of challenges. In addition to the outside assistance needed to build capacity within the community and to set up the relevant community organisations, communities first of all need to be willing to cooperate in the management and operation of the micro grid, including the rationing of electricity when necessary. This typically means that community members need to be willing and able to elect an energy committee (the exact designation of this may vary from case to case), which is then responsible for the management and operation, typically including tariff collection and the management of funds for maintenance and repairs. These activities are often hampered by a lack of clarity of roles as well as poor levels of quality of leadership (Krithika and Palit 2013). Furthermore, 'elite capture', in which the comparatively rich and influential members of the community end up controlling the electricity supply and allocating most of it to themselves and their peers, can clearly be a problem in this set-up (GVEP

2011; Kirubi 2009). These issues are, however, not unique to the management of micro grids, but can be found in the management of any scarce resource.

This analysis therefore proposes that the management of a micro grid is analogous to other situations of joint resource management and ownership, such as for example irrigation systems and aquifers, and that studying it using common property resource (CPR) theory and theories of collective action is a potentially very useful tool to fill some of the gaps in the current research literature on micro grid-based electrification. The next section will therefore review existing research on factors relevant to the success or failure of community-based electrification approaches, and then outline a method to analyse those factors which are currently comparatively under-researched based on a theoretical framework adapted from theories of collective action.

4. Current State of Research on Micro Grid-based Electrification

In general there are four groups of factors affecting the long-term sustainability of rural electrification efforts as identified by Watson *et al*. (2012): economic (e.g. capital cost, cost recovery, maintenance cost); technical (e.g. equipment quality, technical capacity to maintain and operate); political and institutional (e.g. regulation, corruption, institutional weaknesses); and cultural and social. The technical and economic factors, particularly, are very well researched and there exists strong and consistent evidence regarding their role as barriers to modern energy access.

The different characteristics of various power generation technologies for the use in micro grids has been analysed by a number of authors. Kishore *et al.* (2013) provide a particularly useful overview by comparing micro hydro, biomass gasification, biomethanation, solar PV, small wind and biodiesel in terms of their operational cost, capital cost, technological maturity (including barriers and limitations), resource availability and social and environmental benefits. They suggest that based on this analysis, and due to the large number of factors that need to be considered, multi-criteria decision aids should be used in order to choose the technology that is most appropriate for the local setting. In general it is clear that technology selection is a very complex process, yet there are useful analytical tools available. Barry *et al.* (2011), using eight case studies in Malawi, Rwanda and Tanzania, develop and verify thirteen factors that need to be considered for sustainable, renewable energy technology selection in Africa. These factors range from ease of maintenance, to site selection, government support and financial capacity. This demonstrates that the technical factors involved in rural off-grid electrification go beyond just the selection of a suitable technology, they also include the technical capacity required to operate and manage them within a certain regulatory, environmental and economic context. It appears therefore that, while by no means simple or straightforward, the factors involved in selecting the most suitable technology for off-grid electrification as well as the technical aspects of operating and managing these technologies, are comparatively well researched.

Similarly a lot of valuable research and insight into ways of financing off-grid electrification and making it financially sustainable is already available. Bhattacharyya (2013) provides a useful overview of a large selection of potential financial instruments available for supporting off-grid electrification efforts, ranging from donations and subsidies to grants and partnerships, as well as fee for service or leasing models and tax reductions. He also emphasises the importance of micro credits, particularly for financing at the end-user level, a conclusion that is shared by the UNDP (2011). This necessity to focus on the demand side of rural electrification is also identified by Monroy and Hernández (2005), based on an analysis of 185 questionnaire responses from international experts on rural electrification. They found that almost 60 per cent of respondents identified a demand-side focus as a main parameter influencing the sustainability of electrification projects. They therefore conclude, among other things, that micro-financing and the development of productive initiatives are the two factors with the largest influence on long-term financial sustainability. Similar to the literature on technical factors, it therefore becomes apparent that reasons for financial sustainability and how to support them are well researched. This is not to say that financial as well as technical challenges are overcome and that no further research is necessary. 'Far from it, a lot of challenging questions remain to be answered in these areas, in particular around energy storage and allocation, as well as suitable subsidies and business models. Yet, technical and financial research also cannot cover the full spectrum of factors that need to be understood in order to improve the long-term sustainability of mini grid-based electrification.

It is those remaining factors around, particularly, social, cultural and institutional factors that are comparatively under-researched. Social and cultural challenges can for example be related to gender issues, as a lot of the household chores which are made less onerous through electrification are typically carried out by women, yet the financial decisions of the household, including whether or not to spend money on electricity, are often made by men (Pellegrini and Tasciotti 2013). Institutional factors in this context include the actual organisational set-up of the micro-grid (e.g. cooperative, community-based organisation, private mini utility) as well as the wider institutions in place within the community in the form of established norms, customs and practices. In this sense institutions are not rigid constructs but rather they 'emerge as sites of social interactions, negotiation and contestation comprising heterogeneous actors having diverse goals' (Mehta *et al.* 1999). A number of authors have, in fact, identified the need to focus on these factors and particularly their relationship between each other in future research. Brent and Rogers (2010), for example, conclude their review of the sustainability of mini grids in Malawi by identifying a need to. '[…] understand the complexity of social-institutional (and ecological) systems as they relate to technological systems […]' (p.265). Similarly Davis *et.al*. (2011) argue, also in the context of community energy in Malawi, that 'scalable models of deploying community energy that feature appropriate levels of community participation, training and support need to be developed' (p.24).

This paper proposes that these institutional, cultural and social factors can be studied in a very insightful and useful way by drawing on some of the lessons learned in the management of common property resources. Rolland and Glania (2011), for example, point to evidence that '[…] the organization or committees that typically are formed to manage the [micro grid] system are often vulnerable to the tragedy of the commons […]'and that 'hence, the social shaping of the committee which will be in charge of the system management is important, as are the rules of leadership' (p.22). Other authors – the work of whom will be discussed in more detail in Section 8 – have also identified this opportunity to apply collective action theory in a new context (Greacen 2004; Jenny *et al.* 2006; Kirubi 2009; Maier 2007; Rolland and Glania 2011), yet they only represent a small subset of the very extensive literature concerned with collective action in the presence of CPR. The approach presented in this paper will enable an expansion of this literature.

5. Lessons from studies of collective action in CPR management

A CPR is a special case of a public good. Like a pure public good it is non-excludable, i.e. access to it cannot be restricted easily, but unlike a public good it is rivalrous, meaning that the resource is finite and that a resource unit used or consumed by one actor cannot be consumed by a second actor. Typical examples for CPRs are fishing grounds, grazing pastures or aquifers for irrigation.

The study of collective action in the presence of CPRs is largely founded on two seminal works. In his book, 'The logic of collective action', Olson (1965) argued early on that in the presence of public or common goods self-organised collective action is very unlikely to occur due to the inherent free-rider problem involved if the benefits of the good in question are accessible to everyone, regardless of their participation in collective action. Collective Action, according to Olson, would not occur in the presence of non-excludability. The other critical early analysis of the issue, 'The Tragedy of the Commons' (Hardin 1968), presents a similarly pessimistic outlook on the potential of sustainably managing CPRs without strong external coercion, due to the inherent incentive structure in which the most beneficial short-term behaviour for each resource appropriator is to maximize the consumption of the resource, which in turn will invariably lead to its collapse.

Since then, however, there has been a shift in analysis and understanding of collective action in the presence of CPRs, chiefly led by Elinor Ostrom's and Robert Wades' numerous assessments of this issue (Blomquist and Ostrom 1985; Ostrom 1990, Ostrom 1992; Wade 1987a, Wade 1987b, Wade 2008). Their analysis, as well as that of various other authors (e.g. Baland *et al.* 1996; Schlager *et al.* 1994) have focused on case studies of actual long-lasting collective action institutions which have formed and persisted against all the odds outlined by Olson and Hardin. A large proportion of these case studies are village collectives or cooperatives that have been formed to manage pasture or irrigation resources and in some cases have been able to persist for centuries (see for example Ostrom 1990: 58–87). There are, of course, a number of differences between these cases and a micro grid, not the least of which being the different nature of the resource itself, which will be discussed in more detail in Section 6. Furthermore most of the collective action institutions studied in the aforementioned literature have not been created by fiat, as would be the case in a micro grid, but have emerged over time to respond to the need to manage sustainably a scarce resource. Nonetheless, particularly in the context of community-based natural resource management, there also are many examples of collective action institutions that have been created with outside assistance, see for example Fabricius and Collins (2007) and Schmidtz and Willott (2003).

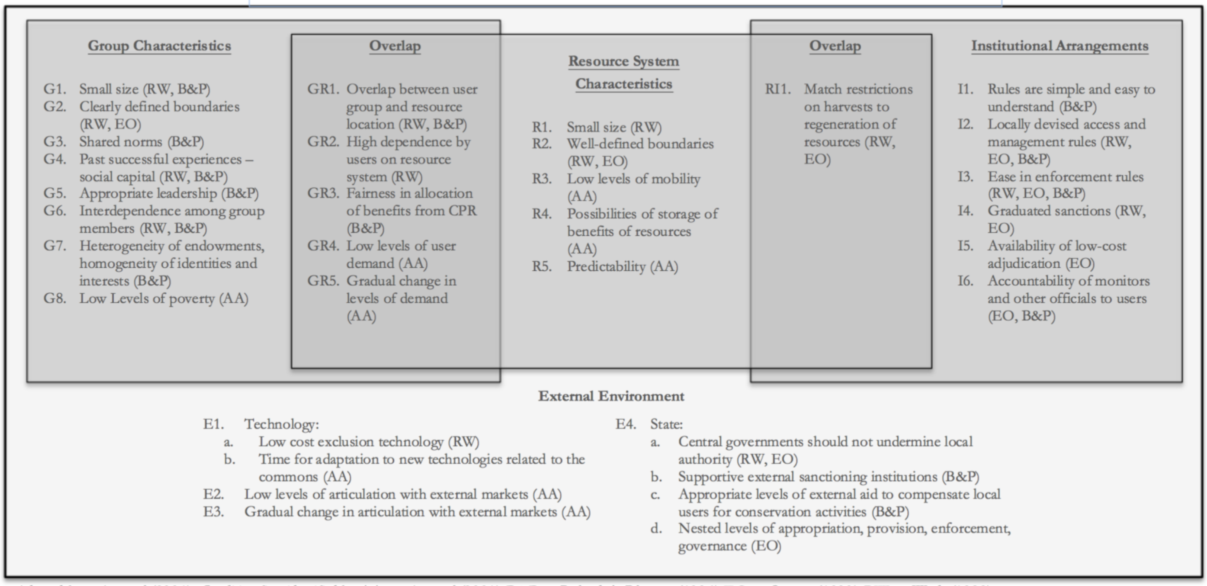
Three seminal publications in particular have laid some of the most widely recognised foundations for understanding and analysing institutional sustainability in the management of CPRs. 'Village Republics' (Wade 1988) is the earliest of these three works and is based on the study of several villages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

In a similar manner 'Governing the Commons' (Ostrom 1990) is also based on case studies of collective action institutions. After reviewing the existing literature on the commons as well as institutional approaches for self-organisation, Ostrom focuses on analysing three different questions using case studies: how and why long lasting self-governed and self-organised CPR institutions survive; how self-organised institutions can deal with change; and why CPR institutions fail. As part of this analysis Ostrom defines eight design principles for long-enduring CPR institutions. She defines a design principle as, '[…] an essential element or condition that helps to account for the success of these institutions in sustaining the CPRs and gaining the compliance of generation after generation of appropriators in the rules in use.'(p. 90).

The third work, 'Halting Degradation of Natural Resources' (Baland *et al.* 1996), begins with an extensive review of natural resource management and commons theories, including a review of the prisoner's dilemma and game theory in this context. The second part of the book, however, sets out to conduct an empirical assessment of the feasibility of local resource management, similar to those presented in the two publications mentioned above. After an extensive review of empirical analyses on this issue, including Wade's and Ostrom's, as well as an examination of their own empirical work, Baland and Platteau reach eight conclusions regarding conditions for successful collective action.

Clearly there are not only similarities in the analytical approach of these three publications but there also exists considerable overlap and complementarity between the three different sets of enabling conditions for sustainable governance of CPRs. Hence, there are insights to be gained from synthesising all of these conditions into one comprehensive framework. Agrawal (2001) set out to do just that, but through the course of his synthesis he also identifies gaps within the existing conditions which he fills by proposing additional enabling factors. The result is the theoretical framework summarized in Figure 5.1, which presents 33 enabling conditions for sustainability of the commons grouped into four categories: Group characteristics; resource system characteristics; institutional arrangements; and external environment.

Figure 5.1: *Enabling conditions*



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

This comprehensive set of enabling conditions allows a detailed analysis of reasons for long-term sustainability (or lack thereof) of existing collective action institutions in the presence of CPR. In the case of irrigation systems, particularly, a relatively large research literature exists, which applies certain subsections of these enabling conditions. Araral (2009), for example, applies a subset of these conditions to an econometric analysis of collective action irrigation institutions in the Philippines and finds that 'collective action is associated with water scarcity, proximity to markets, group size, farm size, and governance structure. In another application of Collective Action theory to the case of irrigation institutions, this time in Japan, Sarker and Itoh (2001) examine how well Ostrom's eight principles explain the long-enduring success of these institutions and find that the eight principles, in fact, do account for the main reasons for this sustainability. There are many other examples of authors applying subsets of these conditions to irrigation institutions (see for example: Beyene 2009; Bravo and Marelli 2008; Ito 2012; Kerr 2007; Theesfeld 2004), though a full review of this literature is beyond the scope of this analysis. A comprehensive review by Cox *et al.* (2010) of 91 studies applying Ostrom's design principles to (mostly) forestry, fishery and irrigation CPRs and evaluating their explanatory performance, however, finds that the empirical evidence generally supports the conditions very well. Furthermore, and directly related to the geographical focus of this analysis, 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.) All of these studies therefore implicitly encourage the application of the enabling conditions to other common property regimes such as, arguably, community-based micro-grids, as such a man-made resource system shares many key characteristics with an irrigation system and, arguably, is just another type of CPR.

6. The Hydraulic Analogy – Linking Collective Action, CPR and Community-based Micro-grids

The analogy between a system of water pipes and a closed electric circuit is often used in educational material to help explain the way electricity behaves, since water flowing through pipes can be seen as analogous to electrons flowing through a conductor, the 'hydraulic analogy (Greenslade 2003). Hence all the basic components of an electric circuit can be described using hydraulic analogues. 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 micro grid shares a number of characteristics with an irrigation system. First of all, the total amount of water available in an irrigation system depends on the storage capacity of the water reservoir (m^3) and the recharge rate of the reservoir (m^3/s), whereas the total amount of electricity (or rather electric energy) available in a micro grid depends on the storage capacity of batteries (kWh), if any, and the generator capacity (kW). A micro grid with no battery storage, therefore, would be analogous to an irrigation system with no reservoir, which could be called a 'run-of-the-river' irrigation system. Regardless, the two factors of storage capacity and recharging capacity determine the maximum discharge rate in cubic meters of water per second or Joules of electric energy per second (one Joule per second equals one watt).

Given these similarities of resource system characteristics, a micro grid and an irrigation system therefore have the following operational challenges in common. 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 with an unrestricted electricity connection continues to add powerful loads she will eventually demand more than the total electric capacity available in the system, thereby overloading it, resulting in voltage drops and potentially causing a black out. In both circumstances action by one person therefore leads to reduced performance and potential damage to the system (e.g. droughts and blackouts) affecting all users.

It should be noted, however, that there also are marked differences between irrigation systems and micro-grids. Most importantly financial sustainability is usually much less of an issue in an irrigation system than in a micro-grid, as the actual CPR – water – has no cost of generation (disregarding small potential costs for pumping). Even though community irrigation institutions often charge their members' small water tariffs to maintain the physical infrastructure of weirs, canals, gates, pipes etc., they face considerably less severe financial constraints than micro grids. Furthermore, a micro grid is much more technically complex, requiring technical knowledge to manage, maintain and operate it, particularly since voltage regulation is often done by hand (Maier 2007). This problem of a lack of technological capabilities has often been identified in the literature (see for example Murphy 2001; Sauter and Watson 2008), as a barrier to technological leapfrogging in the context of rural electrification, micro grids being an example of such leapfrogging compared to traditional grid-based electrification. Clearly, then, capacity building within the community is always an important success-factor, regardless of the presence or absence of other enabling conditions for collective action.

7. Micro-grids as CPR in the Research Literature: Findings and Gaps

The body of literature treating electricity as a CPR and applying theories of collective action in this context, as has been mentioned before, is quite limited. Nonetheless, there are a few publications that have taken similar approaches.

Maier (2007) explicitly uses a common property recourse perspective to analyse reasons for successes and failures of 27 community-based micro hydro micro grids in Northern Pakistan which had been implemented by the Aga Khan Rural Support Programme. As almost none of the systems studied are equipped with load controls and electricity access is unmetered, Maier finds that communities collectively agree to limit their electricity use to certain appliances, such as tube lights, radios, mobile phone charging and TVs, while, in most cases, banning the use of all other electrical appliances, in order to protect the grid from overloading. Maier finds that in all functioning projects studied there is a community organisation charged with the management, maintenance and operation of the micro grid, which also coordinates the consumers' own contribution to the maintenance of the installation. Furthermore, they have all developed various forms of penalty schemes for consumers who fail to pay their tariff or contribute their share of maintenance work. It is important to note that these rules in many cases have been developed by the communities themselves in reaction to the need to adapt to the constraints of the micro grid system. These constraints, according to Maier, exhibit all the typical characteristics of CPRs, i.e. jointness (or subtractability), excludability and indivisibility. He concludes that communities 'are able to set up institutions that govern the use and ensure the maintenance of the plants and that in many ways function better than state- or private-based models.' (*ibid.*: 72).

Greacen (2004) also suggests that electricity in community-based micro hydro micro grids, in this case based on 59 projects in Thailand, can be treated as a CPR. His analysis mostly focuses on financial, technical and regulatory factors affecting the long-term sustainability of village electrification projects. He finds that grid arrival is by far the most common reason for abandoning the system, however, nine of the 24 villages with grid connection maintained their system in order to be able to supply their own electricity in the case of grid blackouts. Other common technical issues include equipment failure, mostly involving the generator, shaft and bearings, as well as low voltage. He also recognises that the mismatch between generation capacity and demand patterns in the villages leads to blackouts and brownouts, and directly causes equipment damage, which therefore represents a CPR problem. Rather than elaborating how experiences from other instances of collective action could be used to overcome these issues in the existing projects, Greacen suggests that current limiters, which technically limit the maximum current that can be drawn by each household, could sufficiently solve this problem, i.e. he arrives at a technological fix for the problem, rather than an institutional approach. He therefore does not extend the CPR analogy to the whole micro-grid and its management, maintenance and operation as a complete resource system, but rather limits the analysis to electricity only as the resource itself, hence leaving room for a more comprehensive analysis.

In an analysis of the economic impacts of five community-based micro hydro micro grids in rural Kenya, Kirubi (2009) also studies some aspects of collective action in this context. After determining the CPR nature of electricity in a micro grid he focuses on the contested effect of heterogeneity of the group (condition G7 in Agrawal's framework) on the sustainability of collective action. In the literature on collective action heterogeneity has been described as beneficial, detrimental and neutral to collective action and Kirubi sets out to determine which of these effects can be observed in the context of community energy in Kenya. He finds that heterogeneity of economic interests is initially beneficial to collective action, but also finds that heterogeneity of endowments within the group can lead to problems associated with elite capture. While this is certainly an interesting and important result, it fails to recognise other important group characteristics, such as shared norms or past experiences, and their role in collective action. As his study is more concerned with the impacts of rural electrification on economic impact, a broader examination of enabling conditions for collective action could not have been expected.

Finally, Jenny *et al*. (2006) analyse collective action in the context of a community-based solar PV micro grid in Cuba. The village they are studying has developed a series of rules governing the use of appliances in response to overloading of the grid, showing a similar ability to learn and adapt as presented by Maier (2007). Jenny *et al* (2006) specifically look at the role of sanctions in the sustainability of this project and find that a high probability of being detected and the severity of the sanctions play a large role in rule compliance. In addition, they also find that social norms are an important factor in rule compliance. Even though the authors don't specifically refer to the enabling conditions in the literature it is clear that they have focused on conditions G3 and I1-I4 of Agrawal's framework, relating to shared norms and the design and enforcement of rules.

Based on this review of existing literature two things become clear. First of all, it is useful to treat electricity as a CPR, particularly when studying community-based micro-grids. Secondly, and most importantly for the rationale behind this paper, there exists a clear gap in the literature when it comes to the application of the well-established set of enabling conditions introduced in Section 5 above. While a few authors have considered very limited subsets, or even just one of the enabling conditions, as part of studies on community-based rural electrification more broadly, there still is scope for a more focused and in-depth study. This paper contributes towards filling this gap, by first conducting a careful analysis of all 33 enabling conditions in the context of community-based micro-grids in order to determine a subset of the most potentially relevant conditions. This will lay the necessary foundations for future research on how the existing theory of enabling conditions for the creation of sustainable institutions for CPR management can be used to understand and analyse off-grid electricity networks as man-made resource systems and increase their chances of long-term success.

8. Application of the Framework

While Agrawal's framework of 33 enabling conditions for collective action is very exhaustive, this also makes it particularly difficult to implement methodologically. As a result it is useful to reconsider one by one all the conditions introduced in the framework based on the type and extent of research that will be required in order to determine their role in explaining the long-term sustainability of community-based micro grids in rural areas of developing countries. These are dealt with below under the headings taken from Figure 5.1 above. Based on this consideration it will then be possible to narrow the framework down to a more focused set of conditions, which are particularly suitable for the analysis of the types of social, cultural and institutional factors which the literature review presented in this paper has shown to require further analysis.

Group Characteristics

A few of the conditions identified within this category are self-evident in the context of CBMG. While neither of the two sources (Wade 1988; Baland *et al.* 1996), which list small group size as an enabling condition for collective action give an actual number for what constitutes a small group it nonetheless seems to be a given in this context. For example, the 27 Nepalese case studies analysed by Maier (2007) typically involve 71 households, clearly a small group. A review by the author of 12 existing CBMGs in Kenya using hydropower has also led to this conclusion, as the typical project involves between 50–200 households. Similarly clearly defined boundaries are also a natural condition of CBMG, as the boundary of the group is simply defined as the extent of the mini-grid. Furthermore, the condition of shared norms does not apply in this context as these are only a requirement, according to Baland and Platteau (1996), if the group size is large. Since community-based micro grids specifically target comparatively poor rural areas, the conditions of low levels of poverty, as specified in the framework, cannot be fulfilled. On the contrary, poverty levels are likely to be high in any rural off-grid context in the developing world. Heterogeneity of endowments and homogeneity of identities and interests have been studied by Kirubi (2007) who finds that heterogeneity of economic interests and endowments is positively related to collective action success. The presence of productive uses for electricity, often by comparatively wealthier community members, is a good proxy for this as those economic elites have a higher economic interest in access to electricity and can hence act as facilitators of collective action. This, as mentioned earlier, of course also creates a risk of elite control or capture, which can be problematic. Homogeneity of interests refers to a similarly high interest in reliable electricity supply by all users, which needs to be determined. The interdependence among group members are of particular interest in Wade's (1988) analysis of collective action in which he looks at the relative power of sub-groups and the extent of mutual obligations within the group. These dynamics, e.g. between productive uses and household uses of electricity, must be understood in the context of CBMG.

Resource System Characteristics

In a micro grid, the characteristics of the resource system are relatively straightforward to define within this theoretical framework. Small system size and well-defined boundaries are given for reasons analogous to those outlined regarding the group characteristics. Low levels of mobility of the resource are also present by definition, as electricity is not mobile at all. It cannot leave the resource system, i.e. the micro grid. Possibilities of storage of resource benefits will depend on the particular micro grid design, i.e. whether batteries are present or, in the context of hydro power, how much water can be stored above the penstock. This is linked to the final resource system condition concerned with predictability, which in this case can be defined as the reliability of the electricity supply and will likely be a crucial factor on determining long-term success.

Group and Resource System Overlap

Due to the nature of a micro grid, the location of the resource system and user group is identical leading to a perfect overlap between user group and resource location. Low levels of user demand, at least initially, will also be likely but the importance of gradual change in levels of demand should not be underestimated, as rising demand must be met by system upgrades. Research has shown, however, that such slow change in levels of demand are likely to be observed, as recently electrified households don't simply move up the 'energy ladder' but continue to use a variety of energy sources (Campbell *et al*. 2003; Hiemstra-van der Horst and Hovorka 2008). High dependency by users on the resource system in this context means that the stakes involved for the community are high enough to properly maintain and manage the micro grid. This further underlines the importance of productive uses for electricity, which need to be encouraged and supported from the very beginning, as such productive uses increases dependency on the system and also help to generate the economic benefits necessary to maintain the system in the long run. Finally, fairness in allocation of benefits is at the core of the common pool resource problem faced in a micro grid. This condition will be defined by the design of the micro grid in question. For example if no meters or current limiters are in place everyone connected has equal access but needs to coordinate with everyone else in order not to overload the system.

Institutional Arrangements

Institutional arrangements are at the very centre of this analysis as they offer the greatest opportunity to create enabling conditions from the outset. Rules need to be simple and easy to understand meaning that the electricity consumers, i.e. the members of the community, need to be able to understand them and must agree with them. This is similar in its argument as the requirement for locally devised access and management rules, which have been devised using democratic processes actively involving community members. In the context of a micro-grid this is especially important when it comes to tariff setting. They also need to be adjustable through these processes if necessary. When there is no metering the rules governing who can consume how much electricity at what time of the day need to be agreed upon in this manner as well, i.e. restrictions on consumption are matched to resource generation. As with any rules they must be easy to enforce, e.g. through the use of electricity meters or a ban on the use of certain appliances, such as, for example, irons. If rules are broken there must be graduated sanctions, which also are agreed upon by the community and effectively identify and, if necessary, exclude free riders. As such exclusion processes can easily lead to conflict, there needs to be low cost adjudication, for example in the form of a village committee. Finally, and crucially, monitors and other officials must be accountable to users through democratic processes in order to avoid problems of elite capture.

External Environment

A number of these enabling conditions in this category, again, are predetermined in the case of micro-grids. There is low cost exclusion technology as free-riding households can simply be disconnected, and new households need to be connected to the grid before they can start consuming electricity. There also are, by definition, low levels of articulation with external markets, although this can potentially change with the arrival of the national grid, which very often leads to the abandonment of the micro grid by the community (Maier 2007). This then also rules out the condition regarding a gradual change in articulation with external markets. Since the micro grid can only be either off-grid or connected to the national grid its relationship with external markets is somewhat binary, making this condition less relevant. A further condition that is less applicable in this context is supportive external sanctioning institutions. It is unlikely that an external institution would be interested in sanctioning behaviour in a micro grid not connected to the national grid. As a result this is not a major concern in the context of CBMG. Nested levels of appropriation, provision, enforcement, and governance, however, could be a useful tool to avoid elite capture. There also need to be appropriate levels of external aid, both financially and in terms of capacity building. This will take some time for adaptation to new technologies. Finally, the central government should not undermine the local authority of the community-based organisation in charge of the micro grid, i.e. it should not impose restrictions on their authority.

Key conditions

Considering these elaborations regarding the applicability of Agrawal's framework to the context of CBMG it becomes clear that there are useful ways in which each group of conditions could be applied. Yet, the conditions concerned with the institutional arrangements not only stand out because they all can be applied to CBMG, but also because the literature review presented earlier in this paper, as well as the brief review conducted as part of this section, indicates that these conditions are least understood. Furthermore, because they are largely concerned with issues of institutional design, they can be influenced early on in the conception of CBMG projects and can even be altered in existing projects in order to enhance sustainability. Finally, they provide a very coherent set of conditions, as they are all very much linked and dependent of each other. The first requirement is for rules to be simple and easy to understand (I1), which in part can be achieved by devising the rules regarding access (and hence electricity consumption) and management locally, ideally through democratic processes (I2). In order for these rules to be useful, however, they must be relatively easy and, ideally, cheap to enforce (I3). Enforcement is only of use if graduated sanctions exist (I4). These need to be adapted to the local context and be strict enough to strongly discourage free riding, yet allow some flexibility in the case of unforeseen and temporary (income, health, family etc.) shocks to individual households. In order to determine these circumstances and deal with potential conflicts the presence of low cost adjudication is critical (I5). Finally, in order to make this whole arrangement work and to avoid some of the problems related to elite capture pointed out earlier in this paper, those involved in the operation and management of the system must be held accountable to the users (I6), which means that the institutions must be underpinned by democratic processes. In future research it will therefore be most useful to limit the theoretical framework to those six conditions in order not only to gain new knowledge and insight but also to arrive at useful, practical and implementable policy recommendations.

It should be noted, that these institutions should not be seen so much as rigid structures that strictly regulate behaviour, but rather constantly evolving frameworks enabling progress and action. Mehta *et al*. (1999) correctly identify and criticise the weakness of rigid institutions as they are often defined by collective action theory to deal with uncertainty, in particular ecological, livelihood and knowledge uncertainty. In the context of CBMG all three forms of uncertainty are, however, ever-present. Climate change, for example introduces ecological uncertainty into systems using renewable energy; the use and presence of electricity affects livelihoods introducing another layer of uncertainty; and the low initial levels of knowledge surrounding use, management and maintenance of electricity systems leads to yet more uncertainty. The institutions responsible for the CBMG should therefore be flexible enough to respond to these uncertainties by, for example, building upon long-lasting, pre-existing institutions within the community. This aspect of institutional design will be an interesting and useful starting point for future research.

9. Policy implications

As a result of applying the framework proposed in this paper it will hence be possible to determine which enabling conditions for collective action need to be sought out and supported where absent, in order to increase the chances of success for community-based micro grids in East Africa. A set of best practices for institutional arrangements of CBMG projects can be developed for intergovernmental and non-governmental organisations to support the most important enabling conditions and avoid situations where the absence of suitable institutions makes CBMG less likely to succeed.

In addition, the application of the proposed framework will provide a way to *ex-ante* evaluate the suitability of a community for operation and maintenance of a mini-grid, based on the extent to which prevailing local conditions align with the ideal conditions determined in this research. This, of course, is not to say that community-based approaches will always be assumed to be the best solution. In fact, varying degrees of community involvement or private sector driven models might be more suitable in some cases. The ability to determine a community's suitability to own, operate, manage and maintain a micro-grid in a structured way as part of the project development process will reduce the chance of expensive mistakes being made and increase the effectiveness of rural electrification efforts. Maier (2007), for example, finds in his analysis of 27 CBMGs in Northern Pakistan that after about ten years one third of the micro grids were no longer functioning. Greacen (2004), similarly, finds that of the 59 micro hydro micro grids built in Thailand between 1982 and 2001 less than 50 per cent were still operational by 2003. Assuming that such failure rates are not unusual it becomes clear that being able to determine the viability of community-based approaches upfront and, where possible, creating suitable enabling conditions for their success is very useful as it has the potential to significantly lower the failure rates.

10. Conclusion

This paper has introduced a way to determine factors affecting the long-term sustainability of community-based micro grids that goes beyond the widespread analysis of technical and financial issues. Treating the electricity in a grid-independent micro grid as a common property resource opens up the analysis to the application of the well-established body of literature concerned with enabling conditions for collective action in the presence of CPR. Determining which of the 33 enabling conditions collated by Agrawal (2001) are best able to explain successes and failures of community micro grids enables the formulation of policy recommendations and best practices which will be able to increase the effectiveness of future off-grid electrification efforts in the developing world. Ultimately this has the potential to contribute towards efforts to bring modern energy services to significant parts of rural populations without electricity access.

The first application of this analytical framework will be part of a doctoral thesis, which aims to investigate the key enabling conditions for collective action in the context of community-based micro grids in rural Kenya. The focus will be on the institutional arrangements and how they have influenced the long-term sustainability of these micro grids. This first application will test the framework's validity and provide the information needed to further adapt and develop it so it can be used in analyses in other East African countries as well as elsewhere.

Bibliography

Agrawal, A. (2001) ‘Common Property Institutions and Sustainable Governance of Resources’, *World Development*, 29.10: 1649–1672

Anderson, R., Jackson Ræstad, M. and Sainju, P. (2012) ‘Cost-Benefit Analysis of Rural Electrification', *Norplan Policy Brief,* (December): 1–6

Araral, E. (2009) ‘What Explains Collective Action in the Commons? Theory and Evidence from the Philippines’, *World Development* 37.3: 687–697

Baland, J-M., Platteau, J-P. and Olson, M. (1996) *Halting Degradation of Natural Resources : Is There a Role for Rural Communities?*, Rome: Food and Agriculture Organization of the United Nations

Barry, M-L., Steyn, H. and Brent. A. (2011) ‘Selection of Renewable Energy Technologies for Africa: Eight Case Studies in Rwanda, Tanzania and Malawi', *Renewable Energy,* 36.11: 2845–2852

Bazilian, M., Nussbaumer, P., Eibs-Singer, C., Brew-Hammond, A., Modi, V., Sovacool, B., Ramana, V. and Aqrawi, P-K. (2012) ‘Improving Access to Modern Energy Services : Insights from Case Studies.’ *The Electricity Journal*, 25.1: 93–114

Beyene, F. (2009) ‘Collective Action in Water-Point Management: The Case of Pastoral and Agropastoral Communities in Eastern Ethiopia', *Natural Resources Forum,* 33.3: 175–188

Bhattacharyya, S. C. (2013) ‘Financing Electrification and Off-Grid Electricity Access Systems', in S. Bhattacharyya (ed.) *Rural Electrification Through Decentralised Off-Grid Systems in Developing Countries*, Green Energy and Technology, London: Springer London, 227–252

Bilek, A. (2012) ‘Revitalizing Rural Communities through the Renewable Energy Cooperative', *Series on the German Energy Transition (3 of 6)*, Washington, DC.: Heinrich Böll Stiftung

Blomquist, W. and Ostrom, E. (1985) ‘Institutional Capacity And The Resolution Of A Commons Dilemma', *Review of Policy Research,* 5.2: 383–394

Bomberg, E. and McEwen, N. (2012) ‘Mobilizing Community Energy', *Energy Policy,* 51: 435–444

Bravo, G. and Marelli, B. (2008) ‘Irrigation Systems as Common-Pool Resources. Examples from Northern Italy', *Revue de Géographie alpine/Journal of Alpine Geography*, 96.3: 15–26

Brent, A. C. and Rogers, D.E. (2010) ‘Renewable Rural Electrification: Sustainability Assessment of Mini-Hybrid off-Grid Technological Systems in the African Context', *Renewable Energy*, 35.1: 257–265

Campbell, B.M., Vermeulen, S. J., Mangono, J. J. and Mabugu, R. (2003) ‘The Energy Transition in Action: Urban Domestic Fuel Choices in a Changing Zimbabwe', *Energy Policy,* 31.6: 553–562

Casillas, C. E. and Kammen, D. M. (2011) ‘The Delivery of Low-Cost, Low-Carbon Rural Energy Services', *Energy Policy,* 39.8: 4520–4528

Cox, M., Arnold, G. and Tomás, S. V. (2010) ‘A Review of Design Principles for Community-Based Natural Resource Management', *Ecology and Society,* 15.4: 38

Davis, G., MacKay, R., MacRae, M., Nicolson, L., Currie, C., MacPherson, R., Banda, E., Tembo, K., Ault, G., Frame, D. and Picken, S. (2011) ‘Supporting Community Energy Development in Malawi - A Scoping Study for the Scottish Government', University of Strahtclyde (lead), Community Energy Scotland, IOD Parc and University of Malawi Polytechnic

Deichmann, U., Meisner, C., Murray, S. and Wheeler, D. (2011) ‘The Economics of Renewable Energy Expansion in Rural Sub-Saharan Africa', *Energy Policy* 39.1: 215–227

Eberhard, A., Vennemo, H., Shkaratan, M. and Rosnes, O.(2011) *Africa’s Power Infrastructure*, Washington D.C.: World Bank, http://elibrary.worldbank.org/doi/book/10.1596/978-0-8213-8455-8

Fabricius, C., and Collins. S. (2007) ‘Community-Based Natural Resource Management: Governing the Commons', *Water Policy* 2: 83–97

Foley, G. (1992) ‘Rural Electrification: The Institutional Dimension', *Utilities Policy*, 2.4: 283–289

Greacen, C.E. (2004) ‘The Marginalization of "Small Is Beautiful": Micro-Hydroelectricity, Common Property, and the Politics of Rural Electricity Provision in Thailand', PhD thesis, Berkeley: University of California

Greenslade, T. B. (2003) ‘The Hydraulic Analogy for Electric Current', *The Physics Teacher* 41.8: 464

GVEP (Global Village Energy Partnership) (2011) ‘The History of Mini Grid Development in Developing Countries', *GVEP Policy Briefing,* London: GVEP International

—— (2012) Developing Energy Enterprises in East Africa, London: GVEP International

Hardin, G. (1968) ‘The Tragedy of the Commons', *Science* 162.13: 1243–1248

Hiemstra-van der Horst, G., and Hovorka, A. J. (2008) ‘Reassessing the ‘energy Ladder’: Household Energy Use in Maun, Botswana', *Energy Policy* 36 .9: 3333–3344

Holland, R., Perera, L., Sanchez, T. and Wilkinson, R.(2001) ‘Decentralized Rural Electrification: Critical Success Factors and Experiences of an NGO', *ReFocus,* 2.6: 28–31

IEA (International Energy Agency) (2012) *World Energy Outlook 2012*. Paris: International Energy Agency

Ilskog, E., Kjellström, B., Gullberg, M., Katyega, M. and Chambala, W.(2005) ‘Electrification Co-Operatives Bring New Light to Rural Tanzania', *Energy Policy,* 33.10: 1299–1307

Ito, J. (2012) ‘Collective Action for Local Commons Management in Rural Yunnan, China: Empirical Evidence and Hypotheses Using Evolutionary Game Theory', *Land Economics,* 88: 181–200

Jenny, A., Hechavarria Fuentes, F. and Mosler, H-J.(2006) ‘Psychological Factors Determining Individual Compliance with Rules for Common Pool Resource Management: The Case of a Cuban Community Sharing a Solar Energy System', *Human Ecology,* 35.2: 239–250

Kerr, J. (2007) ‘Watershed Management: Lessons from Common Property Theory', *International Journal of the Commons*, 1.1: 89–109

Kirubi, C. G. (2009) ‘Expanding Access to Off-Grid Rural Electrification in Africa: An Analysis of Community-Based Micro-Grids in Kenya', Berkeley: University of California

Kishore, V. V. N., Jagu,D. and E Nand Gopal. 2013. 'Technology Choices for Off-Grid Electrification', in S. Bhattacharyya (ed.) *Rural Electrification Through Decentralised Off-Grid Systems in Developing Countries,* Green Energy and Technology, London: Springer London, 39–72

Krithika, P. R. and Palit, D. (2013) 'Participatory Business Models for Off-Grid Electrification', in S. Bhattacharyya (ed.) *Rural Electrification Through Decentralised Off-Grid Systems in Developing Countries,* Green Energy and Technology, London: Springer London, 187–225

Maier, C.(2007) Decentralized Rural Electrification by Means of Collective Action - The Sustainability of Community-Managed Micro Hydels in Chitral, Pakistan, Berlin Geographical Paper 33, Berlin: Centre for Development Studies, Freie Universität

Mehta, L., Leach, M. and Newell, P. (1999) *Exploring Understandings of Institutions and Uncertainty: New Directions in Natural Resource Management*, IDS Discussion Paper 372, Brighton: Institute of Development Studies

Monroy, C. R. and San Segundo Hernández, A.(2005) 'Main Issues Concerning the Financing and Sustainability of Electrification Projects in Rural Areas: International Survey Results', *Energy for Sustainable Development,* 9.2: 17–25

Murphy, J. T. (2001) 'Making the Energy Transition in Rural East Africa: Is Leapfrogging an Alternative?', *Technological Forecasting and Social Change,* 68, 2: 173–193

Olson, M. (1965) *The Logic of Collective Action. Public goods and the theory of groups*, Cambridge M.A.: Harvard University Press

Ostrom, E. (1990) *Governing the Commons : The Evolution of Institutions for Collective Action*, Cambridge: Cambridge University Press

—— (1992) *Crafting Institutions for Self-Governing Irrigation Systems*, San Francisco: ICS Press

Pellegrini, L., and Tasciotti, L. (2013) 'Rural Electrification Now and Then: Comparing Contemporary Challenges in Developing Countries to the USA's Experience in Retrospect.' *Forum for Development Studies*, 40.1: 154–176

Quinn, C. H., Huby, M., Kiwasila, H. and Lovett, J. C. (2007) 'Design Principles and Common Pool Resource Management: An Institutional Approach to Evaluating Community Management in Semi-Arid Tanzania', *Journal of Environmental Management,* 84.1: 100–13

Rolland, S., and Glania, G. (2011) *Hybrid Mini-Grids for Rural Electrification: Lessons Learned*, Brussels: Alliance for Rural Electrification (ARE)

Sarker, A. and Itoh, T. (2001) 'Design Principles in Long-Enduring Institutions of Japanese Irrigation Common-Pool Resources', *Agricultural Water Management,* 48.2: 89–102

Sauter, R. and Watson. J. (2008) T*echnology Leapfrogging: A Review of the Evidence, a* Report for DFID, Brighton: SPRU, University of Sussex

Schlager, E., Blomquist, W. and Tang, S. Y. (1994) 'Mobile Flows, Storage, and Self-Organized Institutions for Governing Common-Pool Resources', *Land Economics*, 70.3: 294–317

Schmidtz, D. and Willott, E. (2003) 'Reinventing the Commons: An African Case Study', 37 *UC Davis L Rev 203,* Heinonline,http://heinonlinebackup.com/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/davlr37&section=17

SE4All (2012) Sustainable Energy for All - A Global Action Agenda, New York: United Nations

Sebitosi, A., Pillay, P. and Khan, M. (2006) 'An Analysis of off Grid Electrical Systems in Rural Sub-Saharan Africa', *Energy Conversion and Management,* 47.9-10: 1113–1123

Terrado, E., Cabraal, A., Mukherjee, I. (2008) Designing Sustainable Off-Grid Rural Electrification Projects: Principles and Practices, Washington, D. C.: The World Bank

Theesfeld, I. (2004) 'Constraints on Collective Action in a Transitional Economy: The Case of Bulgaria's Irrigation Sector', *World Development,* 32.2: 251–271

UNDP (2011) Towards an 'Energy plus' Approach for the Poor : A Review of Good Practices and Lessons Learned from Asia and the Pacific, Bangkok: UNDP-APRC

Wade, R. (1987a) 'The Management of Common Property Resources : Collective Action as an Alternative to Privatisation or State Regulation', *Cambridge Journal of Economics,* 11.2: 95–106

—— (1987b) 'The Management of Common Property Resources: Finding a Cooperative Solution', *The World Bank Research Observer*, 2.2): 219–234

—— (1988) Village Republics : Economic Conditions for Collective Action in South India, Cambridge: Cambridge University Press

Watson, J., Byrne, R., Morgan Jones, M., Tsang, F., Opazo, J., Fry, C. and Castle-Clarke, C. (2012) What Are The Major Barriers To Increased Use Of Modern Energy Services Among The World's Poorest People And Are Interventions To Overcome These Effective?, Systematic Review, Collaboration for Environmental Evidence, http://www.environmentalevidence.org/SR11004.html