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A Review of Factors Influencing the Success of Community Renewable Energy Minigrids in developing countries

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Abstract

Minigrids are expected by the UN Sustainable Energy for All (SE4All) initiative to play a significant role in ensuring universal energy access. Despite this, there are a range of technical, organisational, social and financial barriers to their successful deployment, including lack of community integration, unrealistic user expectations and poor local maintenance capabilities. Community Renewable Energy Minigrids (CREMs) are expected to increase community engagement and therefore potentially mitigate some of these problems, improving outcomes when compared to minigrids with other ownership and operation structures. CREMs are also likely to offer other important socioeconomic benefits and improved rural livelihoods. However, a range of challenges for existing CREMs are reported in the literature. Specific barriers include the need for extensive liaison (e.g. community engagement), technology choice risks, controversies around governance of benefits and, often, non-existing technical and organizational local capabilities. At this stage, it is not clear which implementation models or community capabilities are required to overcome these challenges. This paper will present a review of recent experiences, exploring the factors that influence the success of CREMs, which might require special input and attention by practitioners, donors, and community activists in order to deliver a sustainable and successful CREM.

1. Introduction

Universal energy access remains an unresolved challenge. An estimated 1.3 billion people worldwide had no access to electricity in 2013 (IEA, 2013) and projections using business-as-usual assumptions predict limited progress by 2030 (UNEP, 2013). Minigrids[1] are expected by the UN SE4All initiative to play a significant role in ensuring energy access for all. For example, 42% of the 250 GW of additional generation capacity required to reach 100% electrification globally is expected to be met by minigrids (OECD/IEA, 2010). However, minigrids have yet to be deployed at a scale commensurate with this role (Hazelton, *et al.*, 2014), and are often perceived by practitioners as delivering a second-rate interim option for rural electrification (Practical-Action, 2014).

The implementation of minigrid projects is challenging. A range of owner-operator models have been attempted in practice, involving utility, private and community organizations, with some models involving a hybrid of these. While each model has strengths and weaknesses, in accordance with the capabilities of the actors, some of the common

[1] Minigrid refers to as a decentralized power generation, distribution and demand management network up to 500kW of installed capacity and 110-220-380 VAC for a domestic, public or commercial use to cover basics and disperse community electricity provision (ARE, 2011).

barriers to achieving successful deployment relate to (Dutt and MacGill, 2013, Bhattacharyya and Palit, 2014, Hazelton, *et al.*, 2014):

- inaccurate load assessment, resulting in incorrect system sizing,
- lack of community participation,
- unrealistic user expectations,
- unsuccessful organisational and ownership structures, and
- poor local maintenance capabilities.

Community-based minigrids, where the renewable energy (RE) technology is owned, operated or maintained by local members (Community Renewable Energy Minigrids, CREMs[2]) are expected to increase community engagement (Rae and Bradley, 2012, Seyfang, *et al.*, 2013), and therefore mitigate some of these issues by allowing:

- better technology assimilation within the community, improving technology acceptance, adaptation of designs and organisational structures,
- enhanced local technical capability building and empowerment, supporting long-term system operation,
- streamlined decision-making processes, derived from a shared sense of ownership and encouraging community action.

As a result of the above, CREMs may improve outcomes compared to minigrids with other ownership and operation structures, and therefore help to solve the electricity provision dilemma in off-grid areas. Additional benefits may also be derived from the application of CREMs, such as: fostering local socioeconomic development, i.e. from direct and indirect local income generation (DFID, 1999, Philippe, *et al.*, 2011, Ortiz, *et al.*, 2012), and diversification of livelihood systems (Niehof, 2004, Bruce and Watt, 2008). Unfortunately, there is also field evidence of barriers and challenges for CREMs, including:

1. The need to ensure there is extensive liaison between project staff, organizations and stakeholders, e.g. community engagement (Walker, 2008);
2. Establishing financial and technical viability is a challenge, in particular, data collection and the sharing of information is deficient (Hicks, *et al.*, 2014);
3. The diversity of designs and the absence of subject expert advice reduces the possibilities of incorporating knowledge and experience, e.g. generator selection criteria, sizing and hardware compatibility and estimating maintenance costs (Walker, 2008, Dutt and MacGill, 2013);
4. Challenges relating to financial governance and distribution can be a source of disagreement which may lead to conflict on how this can be distributed among locals, stakeholders and neighbouring communities, e.g. revenue investment and subsidies (Bristow, *et al.*, 2012).

Another significant challenge relates to the selection of ownership structure when a new CREM is considered. Community leaders usually do not know about the existing options, or the implications of CREM when compared to other options, e.g. utility-run minigrids, which still have a high prevalence in Africa (Franz, 2013). Selection of a community approach (e.g. charities, cooperatives, development trusts) versus a hybrid model

[2] For the purpose of this study, we use the term community to mean both community of interest and place. A community of interest refers to as a group of people sharing the same interest despite their location, e.g. a cooperative (Hick, *et al*. 2014). A community of place can be seen as a group of individuals with a shared sense of place, identity, localism and values (Rae and Bradley, 2012). Although there is no a consensus on the definition among different actors on what a CREM is, we follow the notion of a "…*project where communities (of place or interest) exhibit a high degree of ownership and control of the energy project, as well as benefiting collectively from the outcomes (either energy-saving or revenue-generation), p. 978*" (Seyfan, *et al*. 2013).

(e.g. public-private partnership, shared stakes private-community) will impact the levels of complexity in terms of organization and interaction with outsiders and other local actors. In some cases, political agendas can also enforce restrictions, increasing local hostility towards the energy initiatives. A central barrier for CREMs is the lack of local technical, managerial and organizational capabilities; however, this may be a common factor in isolated, un-electrified communities, regardless of the operator model embraced.

Therefore, in order to better understand and exploit the potential of CREMs, it is vital to have a better understanding of the factors influencing project success, particularly when a CREM model is adopted in isolated off-grid rural areas. This paper will present an outline of recent experiences exploring these factors. The focus of this review will be on experiences from developing countries; however, selected examples from industrialised countries are also included where relevant. The results of this review are summarised in section 2, followed by a discussion of the main outcomes in section 3.

2. Success factors for long-term operation of CREMs

A selection of reports has been reviewed, aiming to find information about success factors for CREMs. RE systems such as solar PV, biomass, hydro, wind or hybrid configurations were all considered. Priority was also given to evidence-based case reports from international organizations and academia, mainly drawing on experiences in developing regions. In this section, the findings are presented, grouped according to project phase: preparation, design, implementation, monitoring and evaluation. Figure 1 summarises these factors, which, if considered together, can contribute to the success of a CREM.

2.1. Preparation Phase [includes 5 factors]

Community building: In the preparation phase, it is necessary to establish a suitable community for the project, which should include consensus regarding boundaries & limits, shared needs, values and organizational options. For this purpose, community leaders often need to consult with local government and NGOs to establish clear boundaries between neighbouring communities (geographically and in terms of energy provision). In Peru, proactive and consistent involvement from Parents' Association, teachers and an O&M committee (WISIONS, 2010) led to successful community building and implementation of PV-pico hydro systems in 10 communities. During the preparation phase, an off-grid and disorganized community can benefit beyond the development of a CREM, as new social structures required to carry out the energy initiative might emerge. Building new local connections or strengthening existing ones can not only increase the sense of belonging among community members, but may also enable them to tackle external pressures jeopardizing the sustainability of the community itself. The mini hydro CREM of the PACOS (GE/T/P) in Malaysia (Schnitzer*, et al.*, 2014) was found to build a stronger sense of affiliation.

Local actor identification: Clear identification of the different roles and responsibilities of community members (Gül, 2004) is important in order to facilitate: the integration of common interests in project planning; allow room for prioritizing actions to mitigate collective concerns; and support the formation and legal structure of the village committee. For CREMs, 10 roles that can be used to facilitate project planning and community engagement have been identified: captive consumer, active consumer, service user, green investor, local beneficiary, protestor, supporter, participant, technology host and energy producer (Walker and Cass, 2007). In the preparation phase, collection of stakeholder information is necessary, such as socio-economic data, users' ability to pay and users' expectations (Franz, 2013).

Sense of ownership: Field evidence suggests that sense of ownership is a critical factor for developing a shared vision towards solving specific community energy needs and for establishing a firm decision-making structure (Kumar, *et al.*, 2009, Ortiz, *et al.*, 2012, Terrapon-Pfaff, *et al.*, 2014). Transparency and open dialogue with and from community leaders is not only crucial to analysis and selection of a suitable ownership model that responds to local needs, but can also result in a sense of ownership from the outset, and increased levels of responsibility which will secure the long-term and success of system operation. If a hybrid ownership structure is adopted, e.g. community-private, it has been found that it is important for the community to make all major decisions concerning minigrid implementation and operation (Franz, *et al.*, 2014) in order to retain this sense of ownership.

Capability building measures: Field observations have shown that capability building is another critical factor in small scale energy interventions in developing countries (Franz, 2013, Terrapon-Pfaff, *et al.*, 2014). The two main issues that need to be addressed are (Gül, 2004): 1) training of nominated staff for management, and operation and maintenance (O&M) (technicians and business planners); and 2) the establishment of regional maintenance centres. Assessment of knowledge and available local skills for operation and O&M should be used to develop a capability building and development plan. Local NGOs can be used to support and monitor training and capability development, which was successfully done in PACOS (GE/T/P) in Malaysia; (Schnitzer, *et al.*, 2014). Local skills and capacity building measures must be developed strategically, and in a timely fashion, so that skills gained do not tend to dissipate after commissioning (IEA, 2003). After commissioning, further training may be required for interconnection of the microgrid to form a regional minigrid, or grid connection, see the Baglung District in Nepal (Pokhrel, *et al.*, 2013).

Continued engagement measures: Community engagement can mitigate risks related to social integration of RE systems (WB, 2008, Hazelton, *et al.*, 2014). For instance, in WBREDA, India, villages contributed land to host the power plants and created cooperatives for supporting the distribution system paths, selecting customers and communicating expectations between stakeholders. These engagement efforts were found to have significant positive impacts for keeping the minigrid operational and enhancing local economy. The provision of technical know-how and investigation of technology issues alongside people in remote communities is a significant component of the successful projects in the Northern Territory (CAT, 2015). It should be noted that engagement activities can be salary, time and resource intensive, and appropriate budget allocation from the total investment required for the CREM must be included (WB, 2008).

In the preparation phase, two aspects should be highlighted. First, a sense of ownership plays a significant role, because it positively influences the other factors. Second, it should be noted that there is a connection between the "continued" capability building and engagement measures, as they may complement each other.

2.2. Design Phase [includes 5 factors]

Strategic project planning: Strategies to avoid or mitigate possible issues that may arise during implementation of the CREMs must be considered in advance. Lessons learned from experiences in Asian energy developments (Bhattacharyya and Palit, 2014, Schnitzer, *et al.*, 2014) have revealed the need for planning the CREMs in terms of:

- Penalty and theft policies, including customer disconnection for non-payment;
- Ecological conservation measures, e.g in mini-hydro projects, watershed protection to avoid logging can be fundamental to protect the river flow;

- Contract negotiation with local producers to prevent running out of feedstock in biomass projects; and
- To plan for replicability, since successful project design can be a duplicated for the benefit of a wider range of communities with similar characteristics.

For example, in eight Latin American countries (Guatemala, El Salvador, Honduras, Nicaragua, Ecuador, Peru, Bolivia and Paraguay), an effective standard design (either PV or PV-Wind) was successfully implemented in over 600 remote villages, improving the living conditions of 300 000 people (EUROSOLAR, 2013). Although replicability in terms of the technical design in particular, can be beneficial, the implementation activities should be seen as case-specific and dynamic, allowing the creation of new or an adaption of existing social structures for on-going problem solving and continued learning (Ortiz, *et al.*, 2012).

Realistic project implementation schedules are also needed, as project setbacks or delays such as natural disasters e.g. heavy storms, landslides or floods, can affect considerably transport and engineering work, which occurred in a micro-hydro project in Southern Mindanao in the Philippines (WISIONS, 2010) and in PACOS, Malaysia . Social safety and environmental considerations are also important, for instance, to manage lead-acid batteries and compact fluorescent lamps (CFLs) which must be recycled or disposed of safely (WB, 2008).

<u>RE technology selection & sizing</u>: Appropriate technology choice should consider the distance to the grid, size of demand, resource availability, income level, equipment availability and community organization (WB, 2008). Consultation with regulators is required to ensure compliance with existing regulations (Franz, 2013). System sizing will impact the financial viability and determine the O&M practices to be assumed. Therefore, it is important to adequately estimate load characteristics, including expected uses of energy (WB, 2008). Load uncertainty has been highlighted as a major risk for minigrid systems, leading to over or under sizing of systems (Hazelton, *et al.*, 2014). System design must also consider non-technical losses such as: illegal tapping of lines, meter tampering, collusion of the meter reader with the customers (Philippe, *et al.*, 2011). Inadequate documentation of systems, carrying out system designs in isolation, and failure to understand the system and its limitations also pose barriers to successful system design, and have led to minigrid failures in Fiji (Dutt and MacGill, 2013). Technology compatibility and system controllers are extremely important when integrating RE technology with existing diesel gensets (see the children's hospital in Tabarre, Haiti (ARE, 2013)).

<u>Operator model selection</u>: A CREM may be operated by local technicians, private contractors, or a utility. A clear understanding of the local market can improve operator model selection and project design, e.g. in DESI Power in India over 100 communities were surveyed prior to selecting and establishing 5 biomass projects. If a CREM will be operated by local technicians, know-how and support from not-for-profit existing social structures can improve capacity, which proved beneficial at the Njombe Diocese Mission in Tanzania (Klunne and Michael, 2010). In CREMs where local technical capacity is inadequate, the RE technology may be owned by the community, with different private contractors selected by the village to provide installation plus a number of years of O&M.

<u>Technical operation planning</u>: Sustainable operational planning must include best practice strategies such as: 1) planning and budget allocation for regular site visits; 2) visual inspections with immediate trouble shooting; 3) investigation of consumer theft; and 4) checking operator logs. Technical maintenance tasks should be carried out by local trained technicians or a private contractor keeping one lineman and one operator at each microgrid

site. The operation contract must incorporate follow up measures and renewal of the maintenance contract on the basis of user's satisfaction level.

Financial and commercial viability: Project documentation must be sound and complete at the financing stage for bankability purposes (Franz, 2013). Sufficient coverage and hence customer base to establish an affordable tariff for connection and monthly energy service is vital to secure financial viability. In addition, to reach the highest percentage of people with lower incomes is critical to secure positive socio-economic impacts. For example, in the Phakeo rural village grid electrification project in Laos - where many villagers live on less than 2 USD per day- the project reached 100% of community members resulting in improved lifestyle, quality of life and boosted the local economy (ARE, 2013).

2.3. Implementation Phase [includes 3 factors]

On-going O&M and troubleshooting: As a general practice, regular technical and financial O&M objectives should be pursued by the operator (Philippe, *et al.*, 2011). However, in CREMs a particular challenge is the potential lumpiness of some O&M expenditure such as in the case of major unexpected equipment failure (Dutt and MacGill, 2013). Cash flow schemes and the availability and proximity of spare parts must take into consideration the possibility of unforeseen breakdown and the need for urgent repairs. Non-technical maintenance in cooperation with community members, e.g. volunteering on a daily basis, is also vital to sustain the energy service, as issues that surface during visual inspections can be reported to technicians (Schnitzer, *et al.*, 2014). If people made no monthly contributions to deal with such challenges, for O&M as agreed before commissioning, thus fund-raising strategies must reviewed as soon as possible and, if necessary, involve local authorities to address the issues e.g. the municipality (WISIONS, 2010).

Diligent tariff collection: Tariff collection is central to keeping a CREM running. If there are a small number of consumers, it is possible to send collectors out to users with higher frequency, see DESI Power in India (Schnitzer, *et al.*, 2014). A community member can be employed to visit customers to generate interest, offer services to new potential clients as well as provide follow up assistance. This role can be commission-based (POLLINATE-ENERGY, 2015).

Final user education: An education component must be included to provide an understanding of how to best use the system. Information on demand-side management, rights and responsibilities as consumers and disconnection policies should be included (Gül, 2004, Philippe, *et al.*, 2011). It has been suggested that attendance to training should be mandatory for users and can be specific to the expected final energy use, e.g. (WISIONS, 2010) documents a hairdressing salon, case study in rural Namibia. Awareness raising and motivation building events for local entrepreneurs and local authorities was found by Ortiz, *et al.* (2012) to have a central function facilitating the introduction of energy services at a community level after a comparative analysis of implementation strategies in Peru (stand-alone wind) and Tanzania (solar PV). Additionally, training activities for current and new users can strengthen community integration and engagement.

2.4. Monitoring & Evaluation Phase [includes 3 factors]

Energy service reliability check: Effective monitoring and verification should include at minimum system monthly generation tracking and a clear channel to receive consumer complaints if the system is not working as expected. If a private provider was selected, then down time and system operational status must be checked according to the original design and contract conditions, including unmet demand growth. In some cases, overall technical system performance and on-going local capability development can be supported by academics in the same country where the CREM was implemented; e.g. Boca de Lura community in Panama (Him-Díaz, 2013). A database on problems and failures can facilitate service and reliability improvement and focus future research efforts (Dutt and MacGill (2013) .

Level of user satisfaction: Customer satisfaction is another critical factor for CREM success. In general, if performance, availability and service levels are high, then customers' satisfaction is high (Terrapon-Pfaff, *et al.*, 2014). Customer satisfaction is generally higher when the alternatives to a CREM are undesirable, e.g. kerosene and diesel, in which case users may become enthusiastic supporters, as seen in Husk Power Systems (HPS), India. Non-technical aspects of project design and implementation can also play a role in user satisfaction, e.g. ensuring that social and cultural conflicts arising from the CREM implementation are addressed. For instance, common animal sheds proposed for a biogas electric power project implementation for rural communities in Moneragala, Sri Lanka were not accepted by locals because it was contrary to their traditions. To overcome this issue, some possible solutions were trialled with individually-owned animal sheds, which have proved to be a success factor in this project (WISIONS, 2010).

Tangible health, social and economic benefits: CREM implementation can lead to real socio-economic and health outcomes for the community. Experiences from Ethiopia (Müggenberg, *et al.*, 2011), Jordan (ARE, 2013), India (Schnitzer, *et al.*, 2014) and Latin America (EUROSOLAR, 2013) illustrate these benefits:

- General health improvement. Community refrigerators can store anti-venom or general vaccines, as well as integrating water pumps and purifiers into the microgrids to deliver drinking water. Protection against wild animals by having access to household and village lighting, including minimizing the risk of snake bites at night. Provision of reliable public lighting also increases the security in military conflictive areas.
- Gender empowerment. Women can be hired to operate the CREM and be encouraged to actively participate in further entrepreneurship training.
- The birth of new local enterprises. A practical example would be where people used to travel kilometres to acquire food and other provisions at the nearest city, then one entrepreneur can use the energy opportunity to start new local business such as: photocopier services, running a refrigerator for ice making and food preservation, hairdressing salons, and electronics repair services.
- Increased commercial productivity. Local industry may increase incomes as a result of a quality improvement of final products or by extending their portfolio of products and services, enabling them to be competitive in more profitable markets.

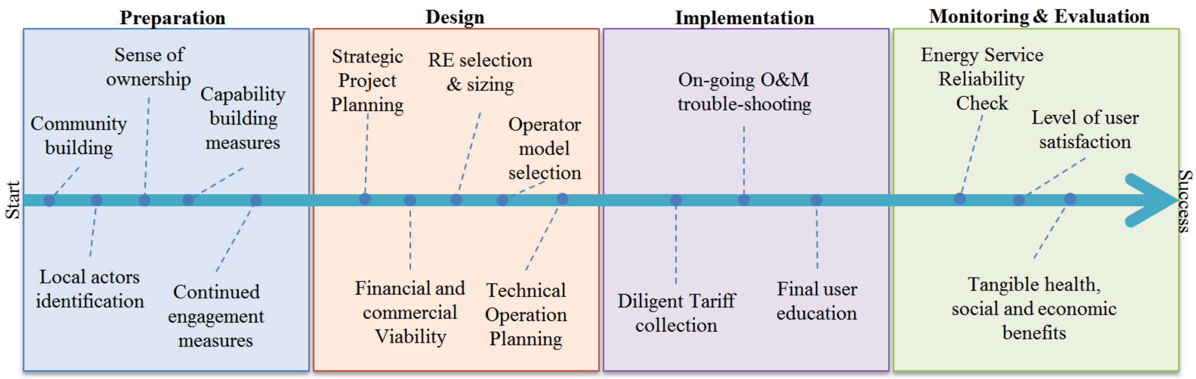

Figure 1. The path toward a successful CREM

3. Discussion and conclusion

Minigrids are expected to make a significant contribution to solving the energy poverty issue worldwide. There is also increasing recognition of the role of community-led development. The United States Agency for International Development has refocused its donor efforts *"... toward realizing a vision of development that is locally owned, locally led and locally sustained (pg.iii)"* (USAID, 2014).

In addition to increasing rural energy access, Community Renewable Energy Minigrids, CREMs, have been shown to derive additional benefits for local development. In particular, CREMs may be beneficial for changing social attitudes towards RE technologies, improving energy reliability and costs, increasing local income generation, community empowerment and local capability building. The latter outcome can ultimately have the most impact, as development of a community's capabilities might maximize system technical sustainability, as well as lead to new projects in other sectors; e.g. water, education, health, and agroindustry.

However, a number of challenges have been identified for CREMs. Obstacles can be seen from two perspectives: for existing and new projects. For current CREMs, lack of extensive local engagement, efficient information channels among stakeholders, and effective means of dispute resolution, have been identified as barriers that can put at risk the project as a whole. In addition, once the funds are available in the community to implement the RE system, the long-term financial operation can be in danger if the owners overlook lessons learned from previous CREMs, such as inadequately estimating O&M costs, or setting an inappropriate energy price. Controversies around governance of revenues have also revealed that additional know-how is still required in terms of organization and negotiation for social structures in charge of CREMs.

On the other hand, for future projects, it is important for community leaders to carefully analyse the benefits and costs of different ownership and operation models. In general, the implicit complexity of hybrid structures, when compared to CREM approaches, will demand higher levels of local managerial, technical and operational capabilities, which at times are not accessible.

This study set out to identify reported success factors in CREMs recently deployed in developing countries. From the selected case study literature, critical factors influencing the success or failure were identified. These are summarised in Figure 1, with most relevant causes playing a pivotal role to the success of CREMs as follows:

1. Sense of ownership: the higher the sense of rights and responsibilities towards the RE system, the higher the likelihood of achievement;
2. Community capability building: effective and continued training efforts must include at a minimum, capabilities for social organization, legal structure creation, project management, financial management and technology operation management;

3. RE technology selection and sizing: an accurate load assessment, together with adequate system sizing and configuration, is fundamental as it will impact positively on the financial viability and allow implementation of effective O&M practices and costs;
4. On-going O&M and troubleshooting: often CREMs need to survive in remote and low population density areas. If the operation is not supported by local people with volunteer and other in-kind contributions for non-technical maintenance and follow up activities, O&M can be compromised by this remoteness; and
5. Energy service reliability: poor technical system performance, e.g. fewer hours of access and availability, unexpected blackouts and power quality issues, will lead to unmet overall user expectations. If service levels are high, then customer satisfaction is high and tangible positive outcomes can be achieved.

It has been stated that *"one of the main gaps in the literature relates to inadequacy of information about successful mini-grid examples (p, 395)"* (Bhattacharyya and Palit, 2014). Furthermore, there is no common framework of analysis and appraisal for CREMs (Kumar, *et al.*, 2009, Bhattacharyya, 2012). In addition to improving understanding of factors influencing success in existing CREMs, the findings from this study can be used to inform project planning and design to maximise the sustainability of future projects, and form a basis for future research.

The preliminary findings suggest that: 1) we need to know more about appropriate ownership-operator models for CREMs under different rural settings in the developing world; 2) it is necessary to understand effective community capability building processes, as the challenges and requirements for capability building and engagement are skills not well understood or covered in the literature; and 3) there is a need to develop suitable sustainability assessment frameworks supporting the monitoring and evaluation of CREM outcomes. This review will serve as a basis for future work, in order to establish suitable implementation models and the requirements for success of CREMs in different contexts.

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