A Community Based Approach for Sustainable Off-Grid PV Systems in Developing Countries

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***Abstract*— The energy requirements of developing countries underpin progress towards achieving the Millennium Development Goals (MDGs). Rural electrification is acknowledged as key to providing a source of reliable, affordable and sustainable energy. Many planners and decision makers agree that the off-grid PV system has the potential to become a valued and straightforward source of electricity for remote rural communities. However, there are several challenges that need to be addressed to realize the potential of PV as a sustainable solution. These challenges are illustrated and highlighted by many reported cases of poor sustainability/longevity of PV installation in sub-Saharan Africa. This paper reviews the sustainability of off-grid renewable energy deployments in sub-Saharan Africa along with recent attempts to define sustainable energy frameworks. The specific case of off-grid PV systems for improved educational and health facilities are considered and a community based approach for improved sustainability is proposed. Case studies illustrating practical implementation of this approach in Gambia and Malawi are described.**

***Index Terms*— Distributed Energy, Off-Grid, Renewable Energy, Sustainable Energy**

I. Introduction

The provision of safe, clean, reliable and affordable energy to the rural poor of developing countries, may not be mentioned explicitly in Agenda 21 [1] or the Millennium Development Goals (MDGs) [2]; however, it is widely recognized as being an essential area of development required to underpin other higher level development objectives [3]. About 1.64 billion people live without electricity worldwide, with 80% of these people living in rural areas. In addition, 2.5 billion people use traditional fuels such as charcoal, firewood, etc. as a source of energy. Approximately 1 billion of the world's population of 6.7 billion people lives in Africa. This represents 15% of the world's population and accounts for 2% of the global economic output. Africa's population is projected to rise to 1.3 billion by 2020 [4]. Excluding South Africa, Africa has the lowest rural access to electricity of any continent; hence many countries in Africa continue to rely heavily on traditional fuels. For example, in Malawi 97% of energy comes from biomass in the form of fuel wood, charcoal, and agricultural and industrial wastes [5] compared with 78% in the Gambia [6], as indicated in Figure 1.

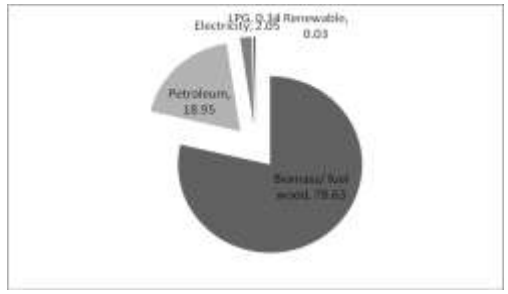

Figure 1 - Gambian Energy Mix

Only 30% of the 690 million people in sub-Saharan Africa have access to electricity. Furthermore, electricity access rates vary considerably from urban areas to rural areas, with rural access rates being particularly low [5][7]. Approximately 7% of all Malawians have access to electricity. Of those living in urban areas, 30 % have access, while only 1% of rural Malawians have access [9]. In Gambia almost 30% of the total population has access to electricity, with 50% of those living in urban areas having access, compared with only 10% of the rural population [8].

While rural electrification may be a well established need in these countries, simply maintaining the existing grid infrastructure is often the first challenge for the national Government and private sector. National electricity grids are plagued with intermittent power black outs and heavy load shedding programmes [7]. Compounding this issue, demand is increasing at the rate of 4.6% and surplus generation capacity is running out [10]. Incentives for utility companies and private sector investors to address the electricity needs of rural communities of developing countries are limited due to the significant levels of capital investment required and the risks and challenges associated with establishing sustainable market models to recover investment costs [11]. As an alternative to grid expansion, renewable energy sources (especially photovoltaic systems) have been actively supported in Africa by multilaterals, governments and non-governmental organizations over the last several decades [12]. The successes, failures and lessons learned by such initiatives are summarized by the Food and Agriculture Organization (FAO) of the United Nations (UN) who report on the application of photovoltaic (PV) technology for sustainable agriculture and rural development [13]. The authors acknowledge that PV can only meet part of rural energy needs but recognize its suitability for areas such as health care, education, communication, agriculture, lighting and water supply. The United Nations Development Programme (UNDP) have also explored the role of PV for decentralized rural electrification and recognize its potential in the powering of public services supporting rural communities, such as school lighting and power, information exchange and communications, community pumping and vaccine refrigeration [14]. The lack of indigenous technical support within these communities and their economic constraints, make the challenge of meeting the energy needs of rural African communities in a sustainable way, extremely complex. To achieve this will most likely require a wide portfolio of energy solutions involving different generation mixes and control methods; however, the role of PV technology in delivering decentralized rural electrification, with its relatively low operational and maintenance costs, in addition to its natural application in these climates, makes it particularly suited to the delivery of sustainable community scale solutions in Africa.

This paper discusses the sustainability challenges of PV for community solutions in rural sub-Saharan Africa and proposes a sustainable deployment model.

II. Sustainability issues for off-grid stand alone PV systems

Stand alone PV, micro-hydro and micro-wind systems have been widely adopted in developed nations as an effective method of complementing available grid power, often incentivized by Governments and regulators to encourage uptake and increase penetration of renewable technologies as a mechanism for offsetting carbon emissions. There is an opportunity for such technologies to provide a relatively cost effective method of opening up access to electricity for the rural poor of developing countries. The World Bank identified the four main reasons for including stand alone renewable energy initiatives in rural electrification programs as: (i) least cost economic solution; (ii) environmentally sustainable; (iii) contributing to Millennium Development Goals and renewable energy targets; and (iv) ability to bring service faster than awaiting grid supply [15].

Several studies have investigated the sustainability of PV systems in recent years. [16] observes that despite high initial installation cost of PV systems, in many occasions the service and maintenance costs are not taken into account at the inception of the PV systems installation. At the national Government level, the financial capacity of developing countries to repay low interest development loans subsidizing rural electrification relies on widespread community engagement. Just as with developed nations securing the uptake and continued use of these new technologies can be challenging; without this, the return on investment, in both monetary and societal terms, falls short. Developing a consumer base requires an understanding of community requirements and expectations, and their capacity to sustain a consistent level of engagement. Only then can practical market models, supported by effective policies, and implemented through good governance and regulation, be developed to widen access to, and encourage the uptake of these sustainable energy solutions. This paper focuses on methods of establishing and sustaining community engagement.

The Solar Electrification by Concession Approach in Limpopo Province and Eastern Cape in South Africa [18] faced many difficulties because it did not give proper consideration to local community needs, expectations and capacity at its inception. The project had deployed 6,000 Solar Home Systems (SHS) by the end of March 2000 however 1,400 SHS were repossessed by Shell-Eskom due to default payment by the users. These default payments were not due to the consumers' inability to pay, but their refusal. It is purported that the main project failures were poor design and a lack of local empowerment. The loading capacities of the SHS were not properly communicated to the end users. These systems were designed to accommodate minimal lighting loads only. Users expected grid supply power quality and capacity to meet cooking demand and provide unlimited lighting. The resulting end user dissatisfaction led to many refusing payment. In addition, transfer of basic maintenance skills was not considered at the design phase of the project, with users unable to even replace a lamp.

The Mutale Local Authority pilot project [19] involved the installation of 582 PV systems. Only 13 survived in good working condition. 20 PV arrays were stolen and 549 PV systems were recorded as faulty. The main project failures were identified as: severe underestimation of support requirements, including the provision of no indigenous training in basic PV systems maintenance; failure to safeguard the security of the equipment; and failure understand the financial capacity of locals to meet maintenance contributions.

There is a widespread need for more quantitative data on real maintenance costs associated with PV systems and costs and benefit analysis to inform impact assessment and sustainability analysis [17].

The UNDP/GEF solar project in Zimbabwe 1992 [20] had a number of aims addressing the enhancement of the long term sustainability of PV systems. The project was concerned with poverty alleviation and addressing climate change. The installation of more than 9000 SHS (45 Wp) in rural homes, health centres and schools by the end of 1997 was considered a means of improving the quality of life for the rural people while minimizing carbon emissions. Upon assessment of the project, it was found that the project had deployed more than 2000 SHS in different rural areas in Zimbabwe. However, a lack of accountability and auditing resulted in no recorded data being available for any cost-benefit analysis or impact assessment. There was not even sufficient information available to establish how many systems remained operational.

The case studies described above are not isolated cases and have led to a poor perception of PV technology in many areas. Anecdotal evidence in Malawi states 50% of PV systems fail within a year of their installation. Clearly the long term sustainability of a PV solution depends on much more than the standard and integrity of its technical design and installation; careful consideration must be given to the socio-economic and cultural context of the environments in which these systems are installed and continue to operate.

III. Sustainable energy

The term sustainability within the broad context of development has been defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [21]. The concept of sustainable energy development has been defined as "energy development that will require electricity services that are reliable, available and affordable for all, on a sustainable basis, world-wide" [22]. The same author identifies the following areas (or pillars) of sustainable energy development.

- Technical sustainability
- Economic sustainability
- Institutional sustainability
- Environmentally sustainable
- Social sustainability

This illustrates the need for technological developments to remain aligned with the social, economic, institutional and environmental needs and constraints of poor rural communities. It is notable that the engineering approach must transcend simply the technical sphere when developing sustainable energy solutions.

This criteria has been addressed in the (The Renewable Energy for Sustainable Rural Livelihoods workgroup) SURE and (Intermediate Technology Development Group) ITDG frameworks which provide a strategic approach to the development of rural energy solutions [23]. The SURE framework focuses on the suitability of a technology to the local rural communities, while the ITDG framework model assesses environmental resource, social development, economics and institutional requirements. The authors argue that there is a huge challenge in the way renewable projects are managed. Additionally, true and effective sustainable energy development can only be achieved through an inclusive and participatory approach involving all industry stakeholders, including; Government, regulators, manufacturers, suppliers, installers, investors/donors, educators and consumers. Among the technical and socio-economic barriers and constraints that makes the challenge of sustainable energy development so complex, and which often contribute to the failure of renewable energy projects, are weak or inadequate regulatory frameworks, lack of financial support mechanisms, political risks, inadequate institutional capacity to implement projects and limited awareness and appreciation of the potential role of renewable technologies in sustainable development. In addition, various studies on renewable energy models in Southern Africa have shown that socio-political factors play similar roles to economic and technical factors in terms of sustainability of renewable energy projects.

The World Bank has extensive experience in the support of energy infrastructure projects and has also addressed the issue of sustainable off-grid electrification [24]. The recommended principals and practices highlight key elements of rural electrification project design as: practical technology choices, least cost design, appropriate delivery mechanisms, community involvement, maximizing productive applications, exploring international co-financing, Government ownership and consistency with rural electrification plan.

The authors utilized the Delphi methodology to assess the two renewable energy framework models and subsequently developed a framework integrating both SURE and ITDG models. The authors conclude that technological choice should always be a function of indigenous participation and structural arrangements, and should also take into account effective institutional arrangements for the benefit of the local people.

IV. Community based approach for sustainable PV systems

The integrated framework for sustainable energy and rural electrification, as illustrated in Figure 1, have been applied to the specific case of a community scale PV systems designed for education and health public service facilities. The environmental sustainability of PV systems is inherent in the technology.

Figure1: Sustainable community PV system

The integrated methodology mentioned above was implemented to establish sustainable community based energy solutions (utilizing PV technology) for schools and health clinics in rural areas in Malawi and Gambia. The four areas of sustainable development which this integrated methodology was used to address, are outlined below:

Technical sustainability: The design process of the PV systems include assessing peak load, average daily load, solar resource, days of autonomy to determine the technical specification of the PV array, battery technology, charge control and inverter electronics. This design process is well established and described in detail in many texts. Here it is assumed that a high standard of technical design are a pre-requisite of technical sustainability but not necessarily guaranteed. The technical sustainability is equally influenced by ensuring appropriate use, correct maintenance and access to properly trained engineering support in the event of failures.

Economic sustainability: The economics of PV are often discussed in terms of market based situations, investment recovery and general affordability. In this context the upfront investment for the PV system is assumed with the justification for subsidized investment generally provided by a requirement for improved education/health. The authors' definition of economic sustainability centers on the post installation recurring costs.

Institutional Sustainability: In this context, institutional sustainability concerns the organizational structures bearing influence on the local community. These include Government (particularly local government structures), health and education policy and administration and traditional village authority structures.

Social Sustainability: This concerns the general interaction of the community with the PV installation, in particular its engagement, participation, ownership and the accountability of the local users.

The proposed approach to achieving sustainability in these areas is based on community focused system design and a community ownership model. These two core aspects of the sustainable model and the 'influence links' to the key sustainability areas are illustrated in Figure 2.

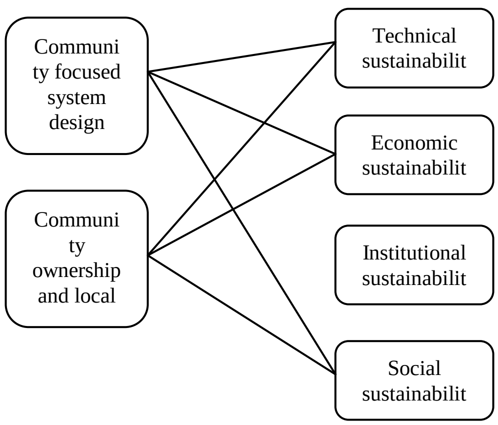

Figure 2: Community based model

A. *Community Focused System Design*

Standard practice has been to design a PV system for the core requirements of a school or health installation, directly benefiting the users of these services. The proposal here is that system design must be viewed from a wider community perspective to maximize potential benefit and exploit income generation opportunities.

Inputs to the design process include: PV system design standards, locally available technology, budget, core load requirements, additional load implications of wider community use and the income generation activity.

Technical sustainability is influenced by standards based design and the use of locally supplied technology for ease of maintenance. Economic sustainability is influenced by the design to allow for income generation with minimal additional infrastructure. Social sustainability is influenced by design to maximize participation and access to the wider community.

B. *Community Ownership*

Positioning the electrical system as a community resource allows for greater engagement and participation from the wider community. Although health and education facilities are owned by the responsible government agencies it is common practice for local communities to play an active part in sustaining and maintaining these facilities. The proposed approach is to foster a sense of ownership which encourages the community to recognize the electrical infrastructure. While the PV system is may not be the legal property of the community it should be regarded as a resource that improves the lives of the community, and which will deteriorate and fail without their care. The proposed model for community ownership is via an Energy Committee. The committee would be formed through acknowledged local process and represent the community's responsibility for the maintenance, security and responsible use of the system. The committee works in partnership with the responsible health and education employees to ensure the core functionality is prioritized but that wider community access and income generation can be promoted and managed in a coordinated manner. Appropriate community sensitization and training is central to establishing a functional energy committee.

Key to the success of the local energy committee is the support that is available to them for technical support and ongoing knowledge transfer. In addition to the need for additional training, the energy committee will need regular refresher training, encouragement, and perhaps an incentive, to actively fulfill their roles. In the event of technical failures, the committee will also require trusted advice and access to maintenance engineers.

The energy committee influence technical sustainability by ensuring appropriate use, providing basic maintenance, security and recognizing the need for maintenance engineers. Economic sustainability is influenced by the committee assuming responsibility for income generation and the growth of a maintenance fund. Institutional sustainability is influenced by providing appropriate community representation working with the approval of education/health administration and traditional local authorities. A local representative formally taking responsibility for the system influences social sustainability as does the facilitation of wider community access. Local support is essential for technical sustainability in the event of maintenance issues. Continued knowledge transfer and capacity building of the energy committee influence the social sustainability.

V. Case Study and Results

In the following sections the community based approaches to rural electrification are discussed from the Malawian and Gambian context.

A. *Community Rural Electrification Development*

The Community Rural Electrification Development (CRED) project in Malawi has installed PV systems in 2 primary schools and 3 health posts in rural areas of Chikwawa district. The sustainable deployment model was utilized as described below.

1) *Community based system design*

The core functionality required by the school was evening lighting. Additional evening lighting was included for community purposes. A low powered inverter was included to allow mobile phone charging. The core functionality required by the health post was lighting in the treatment room and vaccine refrigeration. Again, additional lighting was included for community purposes and mobile phone charging provided for.

2) *Community Ownership*

Community sensitization meetings were held with representation from all community stakeholders: traditional authorities, village elders, faith groups, education and health representatives and the general public. A community energy committee was elected and trained in basic electrical principals, safety and maintenance. The community energy committee were trained and then tasked with encouraging appropriate community access, regular maintenance, security and income generation. Energy committees were also encouraged to maintain a logbook record of all activities. An agreement with a local health NGO allowed the employment of a local field worker who was trained to provide support to the energy committees. The field worker met the committees fortnightly and collated the activity monitoring data and provided a point of contact for advice and support, with further technical support being available in the main town if required. From the records maintained over the first 14 months since the system was installed, a total of income MKW90,000 (£360), directly attributable to the PV system, was generated, 272 community meeting were held, and a total of 748 evening study classes were conducted reaching a 10,730 students.

At the time of writing, the systems have been operational for eighteen months. Technically the systems have been trouble free with the exception of one faulty charge controller. This was recognized by the energy committee and reported to the field worker who in turn contacted the supplier to replace this item, financed by the revenue generated by the committee via the system. Economic support is available from income generation activities centering on mobile phone charging and cold drink sales have been established and well accounted maintenance funds continue to grow. Significantly, the level of income generation is currently on track to allow battery replacement for these systems after four years. Institutional support for the community energy approach has been forthcoming from the health and education authorities, and local MPs have formally supported the energy committee activities. The social benefits are apparent in the number of additional school hours available due to the provision of lighting in classrooms in the evening, and also the possibility of evening meetings involving various community groups, which encourages widespread community interaction.

B. *Gambia Solar Project*

The Gambian Government is focused on the provision of an efficient, reliable and affordable energy delivery system that is sustainable and environmentally friendly. However, the ability to upgrade existing central generation and network infrastructure to meet demand requires investment and institutional support from foreign organizations.

It is reported that approximately 40% of energy generated is lost due to high technical losses and un-metered connections [25] compared to in the region of 5-10% in developed countries. Renewable energy promotion and deployment is high on the agenda of the Gambian Government, with relevant policies and bodies (Gambian Renewable Energy Centre) being introduced to do so. However, the rate of uptake and market penetration within the private sector has remained relatively low for many of the reasons and barriers outlined in this paper. In addition, while a Government strategy for rural electrification exists, which involves both grid extension and distributed off-grid solutions for the more remote locations, this too has stalled. Despite conducting independent feasibility studies to assess consumer needs and capacities, and investigating suitable market models designed to recover investment costs, the Government has not yet been able to secure the necessary development funding. It is unlikely that the rural electrification plans will meet the population's demands in the foreseeable future unless a more sustainable development can be formulated. Furthermore, there are some remote areas that have no real prospect of accessing electricity as these communities fall outside the Governments current plans for electrification.

The Gambia Solar Project has installed rural PV systems in seven schools, one health post and one laboratory for working animals, at a rate of one or two installations per year since 2006. Having completed PV installations in schools for an entire educational cluster, impact data will be collated to assess the socio-economic impact that providing lighting and power to the local schools has on the wider community. It is envisaged that this may form the basis of a case study that may ultimately feed into larger scale Government funding proposals, demonstrating the return on investment of such installations, in both social and economic terms, to potential investors and/or donor organizations.

1) *Assessing System Requirements*

A key approach to system design incorporated assessing the requirements through discussions with local teaching staff, clinic staff, village elders and the Parent Teacher Committee.

School schemes: With the aim of schools serving as community hubs where extended schooling, community meetings and evening recreation for the community could take place. System requirements were defined as; lighting for 2 classrooms and the head teacher / staff area; and power for mobile phone charging/

Health Post: The Health Post serves many of the surrounding communities and required provision of a medical refrigerator for vaccinations and lighting to conduct emergency procedures in the evening if necessary.

Laboratory: As primarily subsistence farmers these rural communities rely heavily on their farm animal, and as such a rural veterinary clinic was established to ensure the wellbeing of these working animals. The electrical requirements for the laboratory included; lighting and power for microscope, phone and laptop charging, and a small refrigerator.

2) *Promoting Community Ownership*

The PV systems are donated by the University of Strathclyde and ownership is then assumed by the community schools, the clinic and the laboratory. Local support and knowledge proved invaluable in the overcoming barriers to deploying the systems. In addition, the inclusive nature of the design and installation phases also succeeded in fostering the sense of community-based ownership required to ensure the sustainability of these systems.

3) *Monitoring and Quantitative Data Capture*

It is clear from previous lessons learned in the deployment of rural schemes that the benefits are only accrued when the systems are fit for purpose and used for the purpose for which they were designed. Quantitative and qualitative technical and socio-economic data gathered from the local communities and the region's educational directorate will be collated. This will provide an insight into the community-wide impact these community-owned systems can achieve for a given level of system investment and design standard. This study will consider examination results pre and post installation; analysis of each installations fault / useage log; the income generation subsidizing system and school maintenance from small phone charging businesses; information on battery charge/discharge cycles and consumption history. This will serve to optimize designs for user requirements.

VI. Discussion

The importance of rural electrification to the development of countries in Sub-Saharan-Africa is clearly established in the literature. The use of PV to provide off-grid electrical supply has proved attractive to Governments, NGOs, International Agencies and individual rural inhabitants. The technical design, delivery and short term success of PV systems is well understood and eminently achievable. However it is the long term sustainability of off-grid PV systems, as illustrated by many case studies, that presents a sizeable challenge.

In this paper current thinking on sustainable approaches to rural energy has been reviewed. The specific case of an organization seeking to improve education or health facilities in a rural location has been considered and the key aspects of sustainability for such an installation have been identified. The principle of a "community energy" approach has been developed and the core components of this approach have been described. A case studies of typical deployments in Malawi and The Gambia, illustrate this community energy deployment model. Socio-economic data indicates strong community engagement, evident in their participation in maintenance and security. Income generation via mobile phone charging and cold drink sales subsidize maintenance funds, which at the current rate, are projected to fund battery replacement after 4 years.

Not only is a sustainable deployment model necessary for this type of PV system but a comprehensive method of assessing the impact of the improved energy supply is also required. Current work and future publications will explore methods of impact assessment for community PV solutions that map easily to typical social development frameworks and MDG delivery assessments. To date, all Malawian and Gambian PV systems remain operational bringing the communities increased access to education, business opportunities and knowledge.

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