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Community renewable energy in Panama: a sustainability assessment of the "Boca de Lura" PV-Wind-Battery hybrid power system

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Abstract. This paper presents a case study of a community renewable energy project implemented in the community of "Boca de Lura" located in rural Panama. This is a 2.17 kW stand-alone PV-Wind-Battery hybrid power system supplying energy to a local school also serving as a community facility. A novel sustainability assessment framework is used to examine the Boca de Lura experience and future perspectives for the power system and the project as a whole. The main challenges for Boca de Lura are discussed and recommendations to overcome some of the obstacles encountered are provided. Findings suggest that, even though the project was successfully implemented, its long-term operation is jeopardized due to non-technical aspects rather than technical ones. A potential solution is upgrading the stand-alone system into a minigrid; however, more studies and external advice are required to understand the implications for Boca de Lura, local institutions and possible national and international sponsors.

1 Introduction

It is estimated that globally over 1.2 billion people are living without access to electricity [1] and by 2040 half a billion will remain in the same conditions, concentrated mostly in rural areas [2]. Noting the importance of modern energy services to meeting many of the goals in the United Nation's sustainable development agenda, goal 7 specifically seeks to ensure affordable, reliable, sustainable and modern energy supply for all. In rural areas of developing countries, electrification can be realized via minigrids or stand-alone power systems, often more cheaply and reliably than grid extensions, particularly, where population density and electricity demand are low. Either option could serve up to 60% of capacity additions to reach universal energy access [2]. Nevertheless, these opportunities are often unattractive to private companies and not considered as a priority by most utilities [3]. Thus, community-based initiatives are often the only alternative for un-electrified communities.

Community renewable energy (CRE) initiatives have the potential to mitigate some implementation problems arising from other operator models, with benefits including [4]: (1) more engagement and acceptance of renewable energy technology (RET), leading to better integration within the community, adaptation of designs and social organisational structures; (2) derived from a shared sense of ownership, higher satisfaction with RETs and community action towards end-user education; and (3) local technical and managerial capability building and empowerment, supporting long-term system operation.

Therefore, a CRE approach to rural electrification may lead to higher electricity access rates and broader rural livelihood improvement. However, CRE projects have not been universally successful, and there are no accepted metrics for monitoring and evaluating CRE outcomes, either to confirm sustainability or to understand the factors that determine these outcomes. Moreover, some authors and practitioners have highlighted the need for more field evidence from community-based projects [3,5], especially, regarding the characteristics of successful ones [6]. Consequently, this paper presents a case study of a successful CRE initiative implemented in the community of "Boca de Lura" located in rural Panama. This project has

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Table 1. Summary of main activities for project preparation, design and implementation [8].

Phase	Dates	Sub activities
I	November 2009–June 2010	Obtaining financial resources; literature review on technological options; site visits to four potential communities; wind and solar resource assessments; selection of the Boca de Lura community as project beneficiary; pre designs.
II	June 2010–May 2011	Detailed technical design; permit requests to relevant institutions; laboratory tests on system components and generators before installation; installation at site and commissioning of the hybrid system.
III	May 2010–January 2011	Follow up measures, including technical inspections of the system and training sessions for end-users; dissemination of results to academia and the public.

Fig. 1. Boca de Lura school facilities and power plant views.

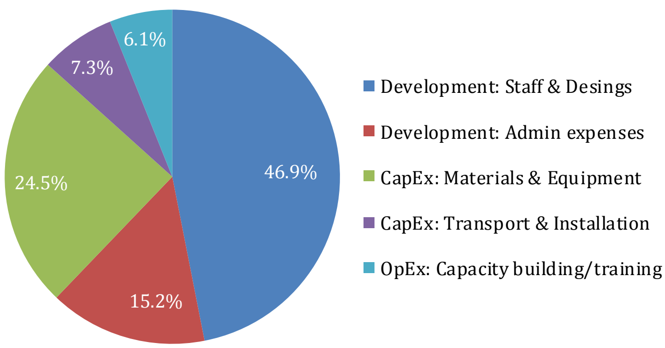

Fig. 2. Boca de Lura project costs breakdown.

received recognition at a national level for its innovation, and for its high positive social impact. Today, the hybrid power system has provided over 6 years of continuous 24/7 power supply. Thus, it is a case worth analysing to understand the success factors, and potentially replicating them in future CRE projects and programs in developing countries.

1.1 Background on the Boca de Lura project

Access to electricity in Panama has increased in recent decades passing from 81.1% in 1990 to 90.9% in 2012, but for rural areas the statistics were 67.7% and 79.8%, respectively [7]. This situation encouraged students and academics from the Universidad Tecnológica de Panamá (UTP) to develop a pilot project aiming to promote innovative solutions for off-grid communities in rural areas of Panama. Hence, a 100% renewable energy solution was devised, including: solar photovoltaics (1.17 kWp), a small wind turbine (1 kW), and chemical storage (1000 Ah). The project was implemented in three phases and took around 2.5 years before its commissioning in early 2011 [8]; see details in Table 1.

This initiative was sponsored by the National Secretariat of Science, Technology and Innovation (SENACYT) providing US $44 820 to carry out all the activities in Table 1. Later, a 2.17 kW stand-alone PV-Wind-Battery power system was designed and installed for the selected off-grid community known as “Boca de Lura”. Boca de Lura is located 30 km north of Penonome, the nearest town, in the Cocle province. There are 42 families (164 people) living within a 3 km radius and about 12 km away from the national grid. Today, the power plant provides electricity to the local primary school for 38 children, which also serves as the school teacher’s lodging and as a community facility; see Figure 1.

School buildings are used by community members and visitors for: (a) civic and cultural celebrations; (b) training provision from national institutions for adult education, e.g. on general health, and agricultural best practices in the region; and (c) as a warehouse for humanitarian aid for 14 neighbouring off-grid communities after natural disasters. This multi-objective project was recognized as successful in Panama [9]. Also, has led to the development of further projects for accessing and improving educational technology for the children in Boca de Lura [10].

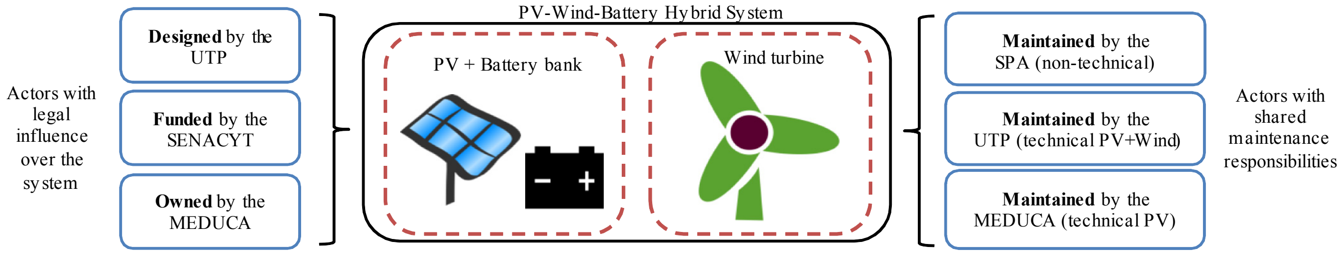

Fig. 3. Decision making structures for the Boca de Lura Energy project.

A costs breakdown following the rubrics defined in [11] is shown in Figure 2. Project development required up to 62.1%, which is reasonable in pilot ventures as learning curves usually need extra training and working hours for the management staff, engineers and technicians. The capital expenditure was a quarter of the budget. Interestingly, some experts have reported PV only projects in schools located in isolated rural areas taking about a third of total costs [12]. This is possibly explained due to the recent lower prices in the solar PV market and systems components, as well as by the absence of a back-up genset in the final solution defined by UTP engineers. The operational expenditure for commissioning and end-user training activities received the remaining of the available resources; no budget was put aside for future operation and maintenance (O&M), expected to be covered by the community.

2 Assessment methodology

Two main research activities were undertaken. Firstly, drawing on the CRE literature, a sustainability assessment framework was developed using a community capability approach to better integrate technical and social relevant factors around community-driven initiatives [4]. This framework has been previously tested on the field to assess a CRE rural electrification initiative in Costa Rica [13], and it is structured around six main capability areas. These are: (1) community governance; (2) capacity building and engagement; (3) ownership structures; (4) technical design; (5) operation, maintenance and management; and (6) follow up measures for system and project sustainability. Secondly, field research was carried out, including an internship period at the UTP's Energy Lab at the Tocumen campus, and at the Cocle campus, from March to April 2016. Six site visits to Boca de Lura over a 10 week period were also necessary for data collection. Field research included archival analysis, 28 semi-structured interviews with stakeholders, including 13 end-users, a load assessment [14] and a survey of the RE power plant.

3 Assessment results and discussion

The sustainability assessment for the Boca de Lura is briefly presented in this section. The success factors so far and the main challenges for the long-term sustainability of the RE hybrid project in Boca de Lura are organised by capability areas. Recommendations to overcome some of the obstacles encountered in this project are also provided where relevant.

3.1 Community governance

Boca de Lura is a socially active community, with four different formal social structures dynamically promoting action: the Local Community Committee, the Water Committee, the Religious Committee, and the School Parent Association (SPA). During the implementation of the RE hybrid system no energy committee was created. Instead, the SPA was appointed as responsible for the power plant. In the region, the school teacher and director (usually the same person) are non-community members, but influential within the SPA. Hence, leadership and decision making within the SPA around the power system in Boca de Lura was driven by the teacher/director from the outset. However, after commissioning, there have been several changes of teacher/director, which has diminished the leadership within the SPA, and subsequently affected decision-making capacity in the community. Additionally, the decision making for the Boca de Lura energy project can be influenced by three external actors, namely: the SENACYT, the Ministry of Education (MEDUCA) and the UTP.

Figure 3 illustrates how the interaction between the SPA and outsiders is, which influenced also the areas of ownership, technical design and O&M of the power system. There is now a need to either create a new local social structure, e.g. an energy committee, or to transfer governance to another existing social structure, e.g. the water committee, as a means of utilising the water-energy nexus for enhancing local empowerment.

3.2 Community capacity building and engagement

The community capacity building and engagement assessment reflects on how the community was mobilised and empowered to acquire necessary skills to integrate the project into the community and enhance ownership. In early 2011, there were two seminars given by UTP academics to community members as a starting point for capacity building (Tab. 1). Topics such as: RE technology fundamentals and working principles, electricity basics, safety handling of system components, and basic O&M tasks were included in the curriculum [8]. These sessions were mostly informative and no more activities were implemented in 5 years of operation. Nonetheless, it was observed that new abilities in the community have been derived from these seminars, including non-technical maintenance, coordinated by parents within the SPA. Moreover, end-users showed high levels of satisfaction with the RETs, as well as enthusiasm towards the energy

Table 2. Energy and peak load in 2011, field assessment in 2016 and projections to 2021.

Year	Energy in dry season (kWh)	Energy in wet season (kWh)	Contribution to max. demand (kVA)	Estimated peak load (kW)	Peak load driven by energy use form
2011	7.68	7.68	–	1.71 (morning)	Classroom activities
2016	4.44	4.96	3.89	0.60 (afternoon)	Workshop activities
2021	9.18	10.23	6.69	0.99 (afternoon)	Workshop activities

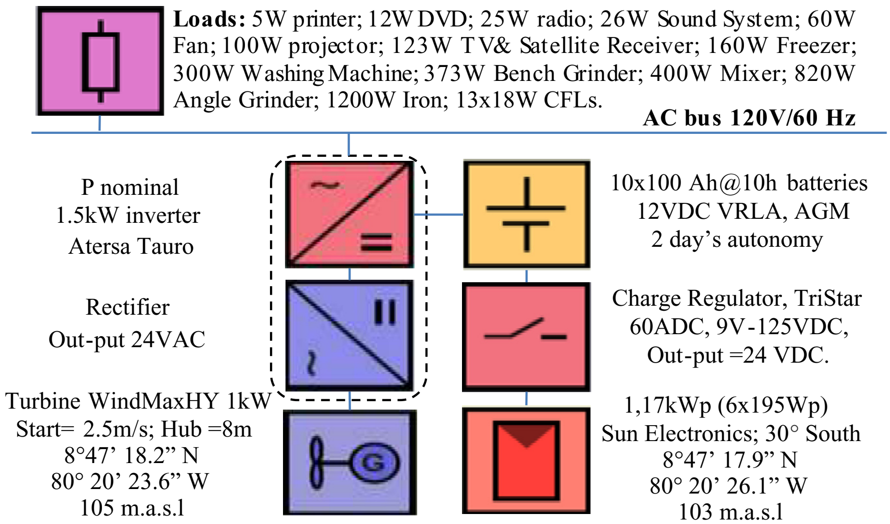

Fig 4. PV-Wind-Battery hybrid power system layout.

project. This suggests there may be room for implementing further participatory approaches and capacity building to improve current levels of engagement outside the SPA.

3.3 Ownership structures

Legal ownership of the RE hybrid power systems as well as the actors with different functions in this CRE initiative are presented in Figure 3. During field visits it was noted that the system components had an asset numberplate from the SENACYT or the UTP; however, other actors were identified as having responsibilities for O&M of these assets. The purchase of equipment was done by the UTP using funds from the SENACYT, and after installation the ownership was transferred via a donation letter from the UTP to the MEDUCA. Therefore, the community does not have legal ownership of the system. If long-term operation of the power plant is sought, then a new ownership structure should be defined, aiming to keep the ownership within the community.

3.4 Technical design

The system design process was led by engineers from the UTP (Tab. 1). The selection criteria for RE generators and system components considered: (1) availability in the local market; (2) quality of the hardware; (3) cost-benefit relationship, e.g. maintenance needs and technology complexity; and (4) budget compliance. The total cost of the 2.17 PV-Wind-Battery hybrid system in 2011 was US $11 000 (Fig. 2) and represented US $6567/kW of installed capacity. Since then, electricity is supplied in Boca de Lura for: 1 workshop; 3 class rooms; 2 teachers' bedrooms; 1 laundry area; and lighting for halls and toilets.

A load assessment carried out in March 2016 shows that the power system is currently underused with peak load of about 0.60 kW, 35% of the design capacity. This is due partly to unexpected usage patterns by locals. For instance, the design load considered 15×50 W lighting bulbs working 8 hours a day, whereas lighting is used for around 4 hours per day. Community members prefer to meet in the afternoons, thus reducing night time demand. In addition, a lighting energy efficiency retrofit was recently implemented in the school by the SPA, where 50 W bulbs were change for 18 W CFLs. A load curve was constructed based on observations of electricity consumption (by children during classes and adults during community meetings), along with power ratings of appliances. Based on interviews with end-users, an expected load increment by 2021 was also calculated. Results indicate that the system can meet the predicted demand in 2021–twice what it is today – while still only working at 58% of its capacity; see Table 2, Figures 4 and 5.

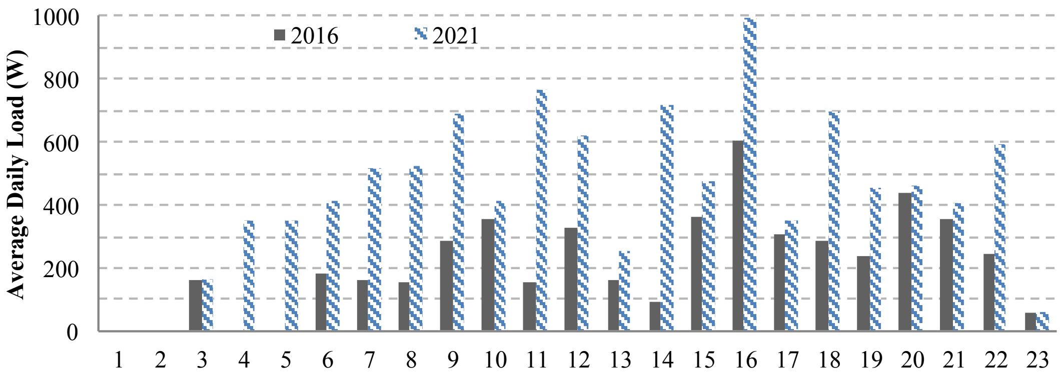

Fig 5. Load curve in 2016 and projected in 2021.

The design process and system performance during commissioning were considered to be technically successful [9]. Unfortunately, no technical capacity was transferred to the Boca de Lura community, as resource assessment, technology selection and sizing were carried out in isolation from locals. Neither, local technician were trained for assuming O&M responsibilities.

3.5 Operation, maintenance and management

Almost continuous operation of the RE hybrid power system since commissioning is reported in Boca de Lura. An exception occurred in October 2015, when a member of the SPA accidentally cut the cables from the wind turbine to the control room with a grass cutting machine while doing non-technical maintenance. As a consequence, electricity was provided only from the PV side for nearly 4 months until the system was repaired by UTP engineers. However, this situation was not considered to be critical by the community, as power supply was still covering local energy needs.

General surveillance of the hybrid system is done by the SPA, which also coordinates basic maintenance tasks. These include: ensuring the safety for children and school visitors; protecting the system from possible robbery or vandalism; and non-technical chores, e.g. cleaning of the PV modules and clearance of weeds around the power plant. These activities are done on a volunteer basis as no electricity tariff was established in this project for end-users. Consequently, there is no budget available for troubleshooting or any other future corrective maintenance. Fortunately, so far no accidents or system failures from the PV or wind generators have been experienced in Boca de Lura. On the other hand, the 1000 Ah battery bank has not required major maintenance since commissioning, and its state of charge was found to be at 95%. Even through the battery bank may be near to the end of its lifespan, it seems to function correctly so far. It is estimated that approximately US $6000 will be required to cover future replacement of the battery bank, with proper transportation and installation.

No historical data was found on energy yields from the solar or wind generators, nor on operational state of charge of the batteries. Hence, it is difficult to quantify and analyse the performance and efficiency of the power plant. Moreover, back up gensets were not considered for Boca de Lura as the original designs gave priority to 100% RE solutions. While there may be some economic or reliability benefits to integrating a genset into the hybrid power system if load grows in the future, the system is currently oversized compared to the load, and it is unfeasible because of the lack of financial resources for the O&M. Therefore, in order to manage future replacements of system components or facilitate the use gensets to improve reliability, Boca de Lura urgently needs to establish an appropriate electricity tariff as well as to develop management, fundraising and accounting capabilities.

3.6 System and project sustainability

On the plant side, as previously discussed, the RE hybrid power system is robust enough to the meet the load in the coming years due to reliability of system components; system oversizing at design; low load growth; and due to the high level of involvement by locals in protecting the system. Nevertheless, the system is highly dependent on outsiders for technical maintenance as no local technicians are available. In addition, the lack of budget and absence of spare parts compromise future system operation. In this context, it seems that its long-term operation relies on two main aspects: (1) the life span of system components (mainly the battery bank) and (2) the willingness of external actors (MEDUCA and UTP) to support the maintenance needs with their own technical staff, and to cover the associated costs.

On the project side, is seems this CRE initiative was left to survive after a successful implementation, which seems to be a common practice in community-based energy projects deployed in developing countries [15]. Follow up measures have been limited since commissioning, and no additional training or engagement activities have been developed for Boca de Lura in more than 5 years. This situation may compromise the ability of the community to independently own and operate the power system.

For enhancing the sustainability of this project as a whole, some actions to consider may include, but are not limited to:

- enhancement of community governance, e.g. creation of an energy committee or adaption and empowerment of other exiting local social structure;

– ownership transference from MEDUCA to locals, to allow better decision-making and interaction with national institutions and internationals organizations in the future;
– creation and implementation of a continuous program for technical and managerial capacity building, with locals appointed as managers and operators of the power plant;
– evaluating the status of the energy project at least once a year, to allow implementation of corrective actions for long-term project survival.

This CRE initiative was envisaged as a microgrid for energy supply to the school and some near households in 2010. While it was implemented only for the school to avoid controversies and rejection by the other community members, going back to the original idea but this time for supplying the entire community may derive some benefits. For instance: access to more incomes, resources and training opportunities for capacity building, as well as additional energy for productive uses. For this, external advice is essential, at least to initiate the preparation of proposals to be submitted to potential donors, national or international institutions. This work could be carried out by technicians from relevant public institutions, volunteers with experience on community-based projects, or university students. In particular, it is recommended that external assistance is sought to conduct a joint study with community leaders considering:
– specific strategies to implement the recommendations already provided in this study;
– possible technical upgrading options, including micro hydro and/or biomass generators;
– an estimation of associated costs, teamwork and time of execution required;
– identification of complementary local capacities required for its implementation;
– minigrid simulations of system performance and estimation of related cost of energy;
– feasible energy tariffs, subsidies and/or loans for covering capital and O&M;
– understanding of social impacts for establishing an electricity tariff in Boca de Lura.

4 Conclusions

The sustainability assessment of a community renewable energy initiative including a 2.17 PV-Wind-Battery hybrid system for Boca de Lura in rural Panama was presented. Two main success factors were identified. First, the design prioritized high quality and maintenance-free system components. Currently, the system is working below its design capacity, and projections to 2021 show that the system will be able to supply the demand. Second, high levels of involvement by the community has supported ongoing non-technical maintenance, protection of the system from vandalism, and ensuring safety to end-users. As a result, the RE system has worked over 5 years almost 24/7 without system failures or accidents. In contrast, the main challenges facing this initiative are: (1) decision-making and coordination with national institutions, as the ownership of assets remains outside the community; (2) developing local managerial and technical know-how, which are currently non-existent; and (3) access to budgets for O&M, until now, energy has been provided for free.

This research confirms that the project was successfully implemented, designed, installed, and have derived social positive outcomes for Boca de Lura, as envisaged by UTP academics and students involved in the project. However, findings also suggest that its long-term sustainability is put at risk due to legal, organisational and financial aspects rather than technical ones. UTP engineers have been able to offset the lack of local technical capabilities by providing Ad-honorem external support when required. Further, the implementation of critical actions for sustainability enhancement recommended in this study could be very challenging for locals, time consuming and require additional financial resources, which are not available. Therefore, external advice is needed to support future survival of the energy project in Boca de Lura. One viable way forward is to upgrade the stand-alone power system into a minigrid. This may allow access to financial resources and training, as well as increasing energy access for productive and humanitarian uses supporting rural socio-economic development for Boca de Lura and neighbouring communities.

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