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A new integral management model and evaluation method to enhance sustainability of renewable energy projects for energy and sanitation services

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ABSTRACT

Autonomous systems based on the use of renewable energy (RE) have proven suitable for providing energy and sanitation services to isolated communities. However, most of these projects fail due to managerial weaknesses. Designing an appropriate management model is a key issue for sustainability and it is especially complex when includes different RE technologies. This paper is aimed at developing a novel management model for RE projects to provide energy and sanitation services with any kind of technology. Moreover, a new method to evaluate the sustainability is proposed regarding technical, economic, social/ethical, environmental and institutional/organisational dimensions. The case study of Pucara (Peru) is presented, in which a RE project with six different technologies was implemented and the integral community management model was designed in 2011. The project sustainability was evaluated in 2013 and results showed that the management model has succeeded to strengthen sustainability, especially in the institutional/organisational aspects.

Introduction

Energy services are crucial for eradicating poverty, improving human welfare and raising living standards (Vera and Langlois, 2007). However, providing access to these services remains a major challenge (Bhattacharyya, 2012a; Mainali and Silveira, 2013; Mainali et al., 2014; Spalding-Fecher et al., 2005) as the vast majority of the world's population, especially in rural areas, still lacks access to these services. Indeed, one in four people on the planet lacks access to basic energy services, this being a huge barrier to improving living conditions and a serious hindrance to economic and social development (International Energy Agency, IEA, 2010). Moreover, there is a generalized lack of sanitation services. UNDP (2006) concludes that water and sanitation crisis is a direct and immediate threat for poor people in development countries. Thus, providing appropriate and reliable modern energy and sanitation services using secure and environmentally sound technologies, in conformity with socioeconomic needs and cultural values, is essential to the race for sustainable development.

Autonomous systems based on the use of renewable energies (REs) have proven suitable for providing affordable, reliable, safe, and high-quality energy and sanitation services to isolated communities. Moreover, RE projects might potentially strengthen people's self-reliance and empowerment and improve the quality of their environment, including the immediate environment in their households (Johansson and Goldemberg, 2002).

In Andean rural communities RE based development projects have been implemented, both by public or private initiatives (Midilli et al., 2006). However, most of these projects have failed due to deficient managerial skills (Energy Sector Management Programme, ESMAP, 2010), as these have a big influence on systems' sustainability (Gomez and Silveira, 2012; Palit, 2013; Shyu, 2013; Yadoo and Cruickshank, 2010; Zhang and Kumar, 2011).

Thus, establishing an adequate management model is a key process when implementing any kind of technology project in rural areas. Sánchez et al. (2006) identified that the management model is the most important factor in achieving sustainability for rural stand-alone electrification projects. Defining an adequate management model may promote technology adoption, reduction of social inequalities, production increase, and redefinition of power structures and strengthening of individual and collective empowerment. Although there are numerous

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management models for rural technology projects, most of them are generally focused on one single technology or service. Among them, the most common are those privately managed, cooperatively, or by state or local municipalities or communities. These models have different characteristics in terms of ownership of the systems, level of user participation, responsibility for operation and maintenance (O&M) of systems, users' involvement in infrastructure construction and installation of equipment, management of tariff payments, etc. (Energy Sector Management Programme, ESMAP, 2001).

Furthermore, establishing a robust method to evaluate the sustainability of technology projects must be addressed as a key element within the project management cycle. Appropriate evaluations can support decision making procedures, enhance learning processes, improve management, develop capacities and strengthen coordination between stakeholders. However, the vast majority of the evaluation methods for RE projects in rural areas are focused on energy or sanitation services separately, and do not emphasise the assessment of the key elements of the management model, for instance user participation, accountability, and organisation and coordination skills.

In the Andean community of Pucara, in the region of Cajamarca (Peru), the local NGO Soluciones Prácticas (Practical Action) implemented a RE project to give access to basic energy and sanitation services. A stand-alone microhydro power plant, individual solar photovoltaic systems, solar water heaters, improved cookstoves, biodigesters and Trombe walls were installed to provide electricity, domestic hot water, upgraded cooking conditions and enhanced household heating. Since the complexity of managing several different types of technologies at a time in one single community is a big challenge, an innovative management model was needed to deal with all the energy and sanitation services at once. Moreover, the model included the drinking water system and latrines that existed already before the RE project's implementation.

This paper is aimed at contributing to the sustainability enhancement of RE projects to provide energy and sanitation services in remote rural areas by developing a novel management model able to deal with any kind of technology. Moreover, a new method to evaluate the sustainability of a wide range of technologies is proposed regarding the technical, the economic, the social/ethical, the environmental and the institutional/organisational dimensions. In particular, we will present the project of Pucara, where this integral community management model was designed in August 2011 and the project's sustainability was analysed in September 2013.

The rest of this paper is organised as follows. The section Description of the case study presents the community of Pucara and technologies of the project. The management model design is developed in the section Management model. In the section Assessment of the sustainability of the project, the methodology used to evaluate the project sustainability is presented. The section Results shows the results of the aforementioned evaluation. The results are discussed in the section Discussion and finally the section Conclusions summarizes the conclusions.

Description of the case study

This section describes the main socioeconomic characteristics in Pucara to provide the reader a better understanding of the context of the community where the project was implemented.

Description of the community

The project is located in the community of Pucara, in the northern Peruvian Andes, 3320 m above sea level and a two hour journey from the city of Cajamarca, the capital of the region. In this community there are 224 inhabitants and 29 households. There is a primary school with 30 students and two churches, but there is no health care centre, so villagers must go to another community to receive medical assistance.

The majority of the population is under the age of 25 (around 62%). The average education level is quite low, 30% of the population has not finished primary school and 6.1% are illiterate. Each family owns an average of 12 ha of land for agriculture and livestock. Whereas agricultural production is intended for family consumption, they sell the milk produced by beef cattle and receive an average monthly income of S/. 790 Nuevos Soles[a] per family.

In terms of energy expenses prior to the implementation of the project, families used to spend a monthly average of S/. 16.75 Nuevos Soles, predominantly on candles and batteries. They can collect their own firewood at no monetary cost.

Before the project's implementation, Pucara had already a community drinking water system and family latrines for all villagers. To manage these systems, a Management Board for Sanitation Services (MBSS) composed by local villagers (see the section Management model design) was established, as it is mandatory according to Peruvian law requirements.[b] Each user had to pay a monthly tariff of S/. 1 Nuevo Sol to cover operation costs. However, this tariff was just enough to cover the operator's salary, who performed basic O&M actions when needed. When any disruption appeared the MBSS had to ask the local municipality for economical support, which generally provided it with significant delays, thus leaving the community without access to these services for excessive time.

Renewable energy technologies implemented in the project

The design of the technologies that would be implemented in the project was defined according to the result of the previous energy demand and socioeconomic analyses. However, the limited budget the NGO had for this project restricted the decision-making process regarding the kind and number of systems to be implemented in Pucara.

Concerning access to electricity, off-grid RE systems were used, as they have proven suitable for rural contexts (for example, Pasternak, 2000; Chaurey et al., 2004; Dincer and Rosen, 2005; Alanne and Saari, 2006; Nguyen, 2007; Borges et al., 2007; Benecke, 2008; Lhendup, 2008; Breyer et al., 2009; Love and Garwood, 2011; Terrapon-Pfaff et al., 2014a, 2014b). A combination of a microhydro power minigrid and individual photovoltaic systems were selected.

A *microhydro power plant* produces electrical power (alternating current) through the use of the gravitational force of falling water, driving a water turbine and generator. This technology was chosen because microhydro systems are usually the lowest cost option for off-grid rural electrification (Coello et al., 2006; REN21, 2008; Williams and Simpson, 2009; Kaygusuz, 2011), the energy is continuously available (Drinkwaard et al., 2010), they have flexible power production for electrical equipment (Guitonga and Clemens, 2006), are reliable for off-grid systems (van Els et al., 2012) and the technology requires little maintenance and is long-lasting (Paish, 2002).

Individual photovoltaic systems generate electricity from solar radiation and are suitable for providing decentralized electrical services to individual homes or businesses (Jacobson, 2007) in remote areas (Chaurey and Kandpal, 2010a), have low running costs (Gullberg et al., 2005), are frequently cheaper than photovoltaic minigrids (Millinger et al., 2012), the comprehensibility of the source tends to lead to a larger acceptability of the technology (García and Bartolomé, 2010), and are typically used for providing basic electricity services to rural households (Chaurey and Kandpal, 2010b; Valer et al., 2014).

After an economic analysis, the microhydro power plant was installed to electrify only the closest 22 households, the school and both churches. As extending this minigrid to reach the farthest users would be very expensive, in this project individual photovoltaic systems

[a] Exchange rate US Dollar/Nuevo Sol is approximately 2.60.

[b] Article No. 173 of the Regulations of the General Law of Sanitation Services; Law No. 26338.