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Sustainability Dimensions of Rural Electrification Programs with Photovoltaic Systems

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Abstract:

This paper aims to identify the key characteristics that affect the sustainability of rural electrification programs with photovoltaic systems. This paper selected sixteen articles on rural electrification programs with Photovoltaic Systems deployed around the world. The programs were evaluated in terms of characteristics, that influences sustainability. The characteristics identified were organized into three primary groups called dimensions. It's classified into: policy, quality systems and program management. The analysis of the characteristics of each dimension yielded a set of items (questions) that will be used to develop an evaluation method of fuzzy multicriteria sustainability of rural electrification programs with Photovoltaic Systems. The last step of this research will be the application of this method in the rural electrification program in East Timor.

Key words

Rural electrification, photovoltaic systems, program sustainability.

1. Introduction

Energy is one of the determining factors for the country development. The provision of electricity to remote regions is a dilemma for developing countries. The investment cost is not always feasible because it is not attractive for power utilities. Thus, remote areas are not included in energy projects. Consequently, people live in rural areas no longer have access to electricity. This fact contributes to social instability. Despite of electricity lack, farmers prefer to stay in the field rather than moving to cities where electricity is available. The permanence of the people on rural areas are influenced by cultural issues and attachment to farms and livestock [1].

The provision of electricity to remote communities isolated via expansion of the power grid is not always the best option to meet the energy needs of the rural sector. This is due to the high level of population dispersion, low energy demand existing in these regions and, in some cases; it has related to the difficulty of accessing remote communities. The network expansion of these communities has been considered unfeasible due to large amounts of funds that need to be invested by the government.

For these cases, photovoltaic appears as an alternative technology for generating electricity, providing energy for individual household that is not priorities in the conventional network extension planning. The application of photovoltaic systems for rural electrification is considered one of the most technical and economic alternatives to meet the energy needs.

There are many social benefits of the projects and programs of rural electrification. Solar Home System provide essential services such as illumination, operation of the radio, television and pumping water in areas, where, are not served by the conventional electric network.

Solar Home Systems are considered mature technologies on technical view to be disseminated. However, to deal with this technology in rural electrification programs it is necessary to take into account the infrastructure and local organizational system, methodology development projects, human resources and institutional bodies responsible for projects regulation and supervision.

Many of the rural electrification programs conducted around the world with renewable energy, concerned to photovoltaic systems presented some sustainability problems. However, these problems can be solved from

the systematization of the knowledge obtained in the implementation and operation of these systems.

East Timor is officially called by Democratic Republic of East Timor, and it is one of the youngest countries in the world located in southwest of Asia. It has an area of approximately 15,000 square kilometers and a population of one million inhabitants. Currently, it holds the 134° position from the list of 187 countries that were assessed in relation to human development, according to a research conducted by the Programs of the United Nations Development (PNUD) and is considered the least developed country in the Asian continent [2].

Some years ago, the country faced problems of power supply. The energy generation from conventional power plants is not enough to provide energy to the entire population. Only a few part of the population has access to electricity. In 2005, [3] about 22% of households had access to electricity. The electricity consumption of rural communities reached about 2% of electricity generated in the country and 95% of rural households have no access to electricity. The Timor-Leste Government has planned expansion of the energy sector intending to increase the electrification rate in the country from 20% to 80% over the next 20 years.

The country's energy matrix is composed of conventional and renewable sources. The electrical power supply in urban areas is supplied by conventional power plants. The distribution of energy to the communities is realized through the expansion of conventional electric network and constructing new thermal power plants. The electricity generation in rural areas is based on renewable energy sources. The photovoltaic systems are the predominant component of the program instead of small hydroelectric and Biogas plants.

The government rural electrification program, [4] proposes to provide energy to 50 thousand households in remotes areas through solar home systems. From this number, 9 thousand of the households were already electrified. Each household has a solar home system that comprise a single 50 Wp panel, 30 Watt compact fluorescent lamps and a 12 V 60 Ah battery on which a charger controller of 6 Ampere was mounted. The system is the same for all users, and it must be used only for lighting purposes for a period of 3 to 4 hours during the night. The investments on these equipments are estimated at 7 million American dollars.

However, there is no significant information about the sustainability of the program developed in the country. The secretary of state of energy is responsible for implementing the program. On the other hand, it has been facing some problems related to making decision concerning to the program problems. There is no available information about the amount of deployed systems that are still in operation. In addition, there are no resources provided for maintenance and also it is not guaranteed that the families served by the program are those that should be attended according to technical and social criteria, aiming the program sustainability.

The government program invests a lot of resources while the goals set in the national energy policy are not guaranteed to be reached.

The literature searches for articles that discuss the rural electrification of many developing countries, especially the strategies to solve rural electrification problems.
The aim of this paper is to identify the key characteristics that affect the sustainability of rural electrification programs with photovoltaic systems. The dimensions and characteristics will form the basis for a method of sustainability assessment of rural electrification programs with photovoltaic systems.

2. Methodology

The sustainability of rural electrification programs with photovoltaic systems (REPP) has been studied in three primary steps. Figure 1 shows the steps and substeps that have been developed in this study.

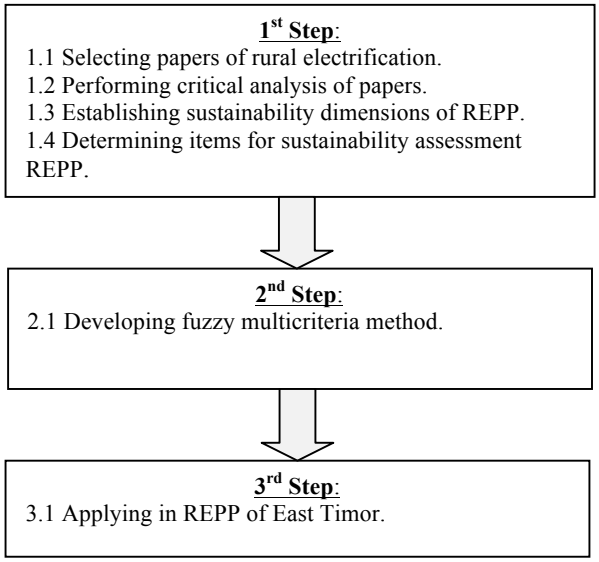

Figure 1- The Methodology Steps

The first step used in this papers which reported the various rural electrification programs based photovoltaic (REPP) implemented in the world. The second step consist on the development of a method to carry out fuzzy multicriteria sustainability assessment of REPP. The third step will consist in assessing the sustainability of the REPP East Timor. This paper presents the results obtained from the development of the first step of the research.
The substep 1.1 utilized the information on REPP's deployed around the world in relation to diversity of climatic, socioeconomic and cultural. The experiences of these rural electrification programs allowed to identify the necessary dimensions for the sustainability of such programs. Table 1 presents the papers which were selected for the development of step 1.1.

Table-1 Rural Electrification Program characteristics

Author / year	Country	Program features
1.Zhang, Kumar, 2010	China	The author [5] mentioned about the financing program, the

		equipment quality control, the adoption of Community funds and scaling up the system to meet the future demands of rural Chinese communities.
2.Els, Vianna, Pinho, 2011	Brazil	The author [6] comments about the rural electrification program process implementation, in which involved the community participation on energy management under local agency supervision.
3.Hong, Abe 2011	Philippines	The author [7] evaluates the implementation of photovoltaic plant to energy supply for rural communities and evaluated the management of the project and the satisfaction level of the end users.
4.Tsikalakis, Tomtsi, Hatziargyriou, at. al. 2 011	Africa	The author [8] commented that the rural electrification program implemented in Africa financed by government investment and the assigns tasks and responsibilities of local communities to manage the system.
5.Bhattacharya, Ohiare, 2011	China	The author [9] mentioned that the rural program electrification in China is invested by central government, and the local government is responsible for the system management. The cooperation between both governments leads to the program success.
6.Carrasco, Narvarte, Lorenzo, 2012	Maroco	The author [10] investigated the rural electrification implemented in isolated communities in Marocos. Many issues were identified during the project implementation, such as lack of reliability of the equipments and related to maintenance procedures. These factors affected the success and sustainability of rural electrification project in Marocos.
7.Javadi, Rismanchi, Sarraf, at. al. 2012	Malaysia	The author [11] mention that the rural electrification policy must be addressed issues concerning on local characteristic, and socio-economic characteristics of the communities as priority of the program.
8.Mahama, 2012	África (Ghana)	The author [12] mentioned about the composition of rural electrification investment program. The investment is composed of people training cost and related to the equipment maintenance costs.
9.Obeimaier, Szklo, Lebre, at. al. 2012	Brazil	The author [13] evaluated the energy consumption on rural household, and analyzed how the energy consumption is affected by the family income.
		Finally, it showed that low-income families need financing subsidies in order to keep the system operation and in order to maintain the program sustainability.
10.Schillebeeckx, Parikh, Bansal, at. al. 2012	Thailand	The author [14] stated that rural electrification program should take into consideration the quality control of the equipment, and the participation of communities in the management and operation of power generation systems in rural communities of Thailand.
11.Lahimer, Alghoul, Yousif at all, 2013	Malaysia	The author [15] identified the challenges faced in many projects in isolated systems. It highlighted the importance of proper selection of technologies that meet the energy demand of isolated communities.
12.Luo, Guo, 2013	China	The author [16] commented about the main concepts about rural electrification. The Chinese government provides part of the investment for the system maintenance and the systems installed in rural areas are under management of the local government.
13.Mainali, Silveira 2013	Nepal, Afghanistan	The author [17] compared the energy costs from various renewable sources in order to select the most economical option technology for generating electricity to rural communities.
14.Poudel, 2013	Nepal	The author [18] commented that the government policy tends to remove gradually the rural electrification program subsidies and the use of the appropriated technologies to best meet the energy demands of rural communities of Nepal
15.Rahman, Paatero, Poudyal, at. al. 2013	Bangladesh	The author [19] stressed that the application of generating energy system in rural areas must be selected based on site criteria's. Furthermore, the program should provide investment on maintenance purpose, beyond the availability of spare parts. All the installed systems need to be monitored periodically.
16.Rahman, Paatero,, Lahdelma 2013	Bangladesh	The author [20] addressed on the technologies for renewable energy sources implemented in rural areas. The program offers training courses to the users aiming to sustain the system performance and establishes an institutional agency for rural electrification that is responsible for the projects supervision implemented in rural areas of Bangladesh.

The substep 1.2 was developed a critical analysis of the information reported in the articles of Table 1. The objective of the analysis was to identify good practices and opportunities for improvement. The good practices are actions that contributed positively to the implementation of REPP. The opportunities for improvement are situations reported as potential causes of difficulty in the implementation of REEP and can be improved in the implementation of other REPP's.
The substep 1.3 consists of grouping good practices and opportunities for improvement related the same topic. This activity was aimed at identifying the set of topics covered, which will constitute the dimensions that affect the sustainability of REPP.
The substep 1.4 good practices and opportunities for improvement that belong to the same dimension (topic) were treated to obtain items (questions) that can deliver the assessment of this dimension of sustainability and serve as a basis for the development of the fuzzy multicriteria method.

3. Results

The articles presented in table 1 were analyzed from the perspective of the criteria that influence the sustainability of rural electrification programs with photovoltaic systems. The criteria identified in the articles analyzed are presented in Table 2

Table 2 – The Sustainability criteria

Author / year	Sustainability criteria
Zhang, Kumar, 2010	- Selection of technologies - Quality control - System Maintenance - Management of the installed systems - Scaling up System - Financing
Els, Vianna, Pinho, 2011	- Capacity building - System Management - Selection of communities - Maintenance procedures
Hong, Abe, 2011	- Appropriate system sizing - System Management - System Maintenance - User satisfaction
Tsikalakis, Tomtsi, Hatziargyriou at. al. 2011	- Community self-management - Financial support - Cooperation of stakeholder in the program
Bhattacharyya, Ohiare, 2012	- Financial assistance - Management scheme
Carrasco, Narvarte, Lorenzo, 2012	- Subside cost for maintenance - System Management
Javadi, Rismanchi, Sarraf, at. al. 2012	- Appropriate energy Policy - Financial assistance - Selected communities
Mahama, 2012	- Subsidy for low-income users - Promote capacity building for the consumers
Obeimaier, Szklo, Lebre, at. al. 2012	- Mutual cooperation among agencies - Understand users energy demand - Financial assistance
Schillebeeckx, Parikh, Bansal, at. al. 2012	- Standards of quality control - Community cooperation - Selected communities
Lahimer, Alghoul, Yousif, at. al. 2013	- The project attend the basic needs of communities in rural areas. - Assessment on energy needs
Luo, Guo, 2013	- Rural electrification policy - Maintenance - Management
Mainali, Silveira 2013	- Economical technology selection - Financial subsidy - Reasonable energy cost
Poudel, 2013	- Clear objective of the program - User satisfaction - Power quality
Rahman, Paatero, Poudyal, at. al. 2013	- Financial support - Self –management - Generation and demand balance - Selected communities - Monitoring activities
Rahman, Paatero, Lahdelma, 2013	- Rural electrification Policy - Community management - Selected communities - Financial auditing - Availability of spare parts

Table 3 presents the best practices identified in Articles of table 1 and identifies the good practice, which subsequently will form the dimensions that affect the sustainability of REPP.

Table 3 - Set of good practices and actions identified

Policy	The government policy aims to promote the use of renewable energy technologies to meet the basic energy needs of rural communities [21]
Technology electricity generation (scaling)	Collective PV system, biogas, wind energy, solar PV individual. The PV plant and biogas are considered more viable alternative technologies for rural electrification. The solar system is in the classification of 59% acceptability biogas and 41% [22] Powers installed 10 Wp to 50 Wp [23], 22000 Wp 280 Wp [24]. World Energy Council (WEC) states that energy consumption for needy people is 300-500 kWh per year [13]. Solar panel life time according to manufacturer (20 years), battery (5 years), charge controller (10 years). But in real practical solar panel (7-10) years, battery (1.5-3) years [15].
Systems acquisition	Tender, direct purchase, donation kit. Quality equipment, qualified installers. [23] Equipment Certification, Technical Specifications Compatible [21]
Financing	International Agency, private companies, the user, the government [21] 90% government investment and 10% of the community [5]
	Community group, local government, private

Management program features	businesses, users [5] Monitoring by periodic visits, Georeferenced satellite and mobile [25]. Wireless sensors [5] 90.8% of system failures due to poor quality of the component [5] Audit [26] Financial control [25], inter sectorial involvement, government and private institution[27]
Maintenance	Community group, local government, user [28] Of four months [15] The values assigned to system maintenance 1-3% of the cost of the system [29] and 1-10% of the cost of the system [21]. 26.5% of the overall cost of the program [29] User, financing agency, government (federal, state, municipal), mixed [5], collective fund [21] Periodic visits [24] Frequency of maintenance is four months [15] Parts inventory on site, agency, supplier of parts [26]
Training	Training of users, training of local technical team [23] Creation of training centers [30]
Users satisfaction	Research, interviews [31] Stability and energy quality, maintenance and spare parts acquisition [21], reasonable price, local technical assistance, [19]. Historical maintenance, data base [24]

The results analysis from tables 2 and 3 identified three dimensions that affect the sustainability of photovoltaic systems. The analysis consisted of sorting and grouping criteria that characterized one aspect of the sustainability of many rural electrification programs studied. The dimensions are:
- Dimension 1 - Policy, Budget source;
- Dimension 2 - PV Systems characteristics;
- Dimension 3 - Program management.

The dimension 1 shows criteria of a macro, such as electrification policy adopted by the government, the goals, the budget amount and origin of the resource for the sustainability of the program
The second dimension deals with the qualitative aspects of the equipment and sizing of photovoltaic systems. This group show evidence if in the project design, component specification, procurement, spare parts, distribution and installation quality control are envolved.
The third dimension addresses the management aspects of the system from the process of choosing and registering beneficiaries, maintenance of systems to continue in operation until the efficiency of the program, to ensure that each resource is invested in serving the best program policy possible way.
The analysis of rural electrification programs according to the methodology applied rise questions that should be part of the methodology of analysis of sustainability of programs.

Dimension 1
What is the policy of the program?
Are the goals of program established?
Are there any budget available for the program?
What are the percentages of the budget?
What is the origin of the financing resource?
There are any subside funding for the next program?

Dimension 2
Does the rural electrification program uses photovoltaic?
Is there any standard sizing for photovoltaic system?
Which the power capacity range is?
What is the specification of each component of the system (battery, regulator, panel and loads)?
The all products purchased are certified by international standards?
What is the form of equipment and services acquisition (procurement)?

Dimension 3
How the process selection of the beneficiary is?
How about the process selection of the locality?
Are the status of users and the service history of the systems recorded on the database?
How much the percentages budget for the maintenance provided by the program?
Who performs the maintenance of the systems?
How often the maintenance is required?
Where the funding sources for systems maintenance comes from?
The program offers training on the operation and maintenance of the systems?
How about the replacement of the damaged components?
Is there any mechanism for monitoring users satisfaction?
Are the users satisfied with the installed system?
What is the percentage of the systems that are in operation?
How to monitor the systems performance?
What agency is responsible for the management of the system (purchase, installation, maintenance and selection of beneficiaries)?
What agency is responsible for auditing the management of the program?

4. Conclusion

The study selected sixteen papers that are concerning on rural electrification programs with photovoltaic systems deployed in several developing countries. The characteristics of each program were grouped in good practices and opportunities for improvement which influence on programs sustainability.
The study also identified three main factors that affected the sustainability of programs. The first dimension is political issues the second is systems quality, and the third is efficiency management program.
These dimensions determine the program's sustainability and raise a number of items (questions) in each dimension. These items serve as basics references for the future development method assessment for the rural electrification programs sustainability.

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