Energy for Sustainable Development 20 (2014) 36–48

Contents lists available at ScienceDirect

Energy for Sustainable Development

Rural electrification options in the Brazilian Amazon
A multi-criteria analysis

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ARTICLE INFO

Article history:
Received 2 September 2013
Revised 17 January 2014
Accepted 21 February 2014
Available online 19 March 2014

Keywords:
Rural electrification
Multi Criteria Analysis
Brazilian Amazon

ABSTRACT

Worldwide, approximately 1.2 billion people still lack access to electricity. Recognized by the Brazilian Government as a citizen's right, access to electricity was extended to almost 15 million people since 2003 as a result of the "Luz Para Todos" (Light for all — LPT) program. However, considerable parts of the Amazon region still lack access to electricity services, largely due to the long distances that need to be covered and to challenging topography. This paper explores electrification using selected renewable sources, both for new installations and for hybridization of existing diesel generators. We present results from a multi-criteria analysis that explores trade-offs associated with electrification options. Techno-economic, environmental, social and institutional criteria and attributes are explored. We find that renewable and hybrid systems present a number of advantages for application in isolated areas of the region.

Introduction

In 2003 electricity access was recognized as a basic human right in Brazil. Since then, the government has undertaken an extensive effort to provide electricity to the entire population (Gomez and Silveira, 2010). The current Brazilian rural electrification program, 'Light for All' or 'Luz Para Todos' (LPT), was designed to achieve universal electricity access in the country. By December 2012, approximately 3 million families, representing roughly 14.7 million people, had received access to electricity (ANEEL, 2012a, 2012b). It is estimated that over 400,000 new jobs have been created directly or indirectly. For this effort, the Brazilian government allocated significant resources with federal government contracts reaching R$ 14.5 billion, equivalent to approximately 6.3 billion US$ (Ministerio de Minas e Energia, 2013).

Most of the progress to date has been accomplished by the concessionaries[1] through grid-extensions. However, significant effort is still needed to reach the goal of universal access to energy services. Over 350,000 new connections are to be made during the years 2013–2014 (ANEEL, 2012a, 2012b), and new connections are constantly being required from rural communities (e.g. in 2011 alone, approx. 360,000 new connections for rural households where requested by rural communities (ANEEL, 2011)).

In the Amazon region,[2] where most of the connections are requested, grid extension is, in many cases, no longer an economically feasible option. This is due to the long distances between the communities and the grid, as well as a relatively challenging topography. After reaching all the communities close to the national grid, each new community connected represents a substantial cost (Di Lascio and Barreto, 2009). Off-grid solutions are therefore now perceived as an integral part of the rural electrification policy in Brazil. Technologies including small-scale hydropower, biomass based power generation, wind, solar cells, and hybrid systems are considered as potential solutions to achieve universal electrification goals in the region (Ministério de Minas e Energia, 2011a).

Where connecting to the national grid is not an economically feasible option, concessionaries have tried to meet the LPT targets using primarily diesel fuelled micro grids (Gómez and Silveira, 2011). Diesel solutions are chosen mainly due to low capital cost, a consolidated supply chain in the region and a working subsidy system for the purchase of Diesel (Di Lascio and Barreto, 2009). Lower capital cost implies a clear advantage for concessionaries, as low up-front costs are small compared to the costly fines that are applied to the concessionaries

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[1] LPT is currently based on a government-supported private sector concession model. Concessionaires, the main providers of electricity in the country, are required to fully supply electricity services to citizens living in their concession area, guaranteeing low tariffs for low-income population (Brazilian Presidency, 2002, 2010). The government provides financial support to the concessionaires in the form of both connection and consumption subsidies.

[2] For the purpose of this study, the Amazon region is defined as equivalent to the North region in the official macro-region division of the country. As a result, our study covers Acre, Rondônia, Roraima, Amazonas, Pará, Amapá, and Tocantins states. The Brazilian Amazon region is characterized by a very low population density, that is, about 4 inhabitants per square kilometer in comparison with a national population density of about 22 inhabitants per square kilometer (IBGE, 2011).

http://dx.doi.org/10.1016/j.esd.2014.02.005
0973-0826/

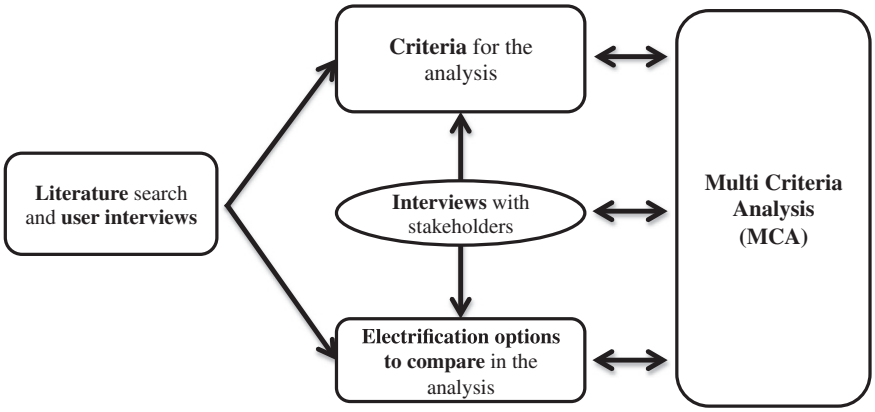

Fig. 1. Schematic of research methodology.

that do not reach LPT connection targets. However, maintaining the diesel system has been proven to be very costly for the concessionaries due mainly to the high fuel costs. In fact, the transportation of fuel to those remote locations may take several days by boat (Di Lascio and Barreto, 2009). The result is that the cost of diesel for isolated communities, once the transportation costs are considered, may be two or three times greater than prices charged at gas stations (Silva et al., 2010).

In addition, in many cases where concessionaries have not yet complied with the obligation to provide universal electricity access electricity is provided with small private diesel generators. Similarly, these solutions are preferred for the low capital cost, and for the consolidated supply system of diesel in the region. However fuel cost for these small systems are extremely high as they are often powered by fuel from the black market, without any subsidies from the government. It is not uncommon that energy generated by privately owned diesel generators is informally sold to neighbors, with no quality, price or environmental controls (Schmid and Hoffmann, 2004). Also, where electricity access is not available, approximately 80% of the households use candles and kerosene lamps to have basic lighting services (IDEEAS PSA, 2006). Both the usage of private diesel generators and basic lighting systems such as kerosene lamps have negative impacts on the economy of rural families, on the local ecosystems and a direct health impact[3] on users (Rosa, 2007).

This research focuses on identifying and highlighting some of the main positive and negative aspects of using different renewable and conventional energy solutions for providing energy services to the rural population of the Amazon region.

Methodology

A schematic of the methodology is presented in Fig. 1. The initial step of this work includes a techno-economic analysis of existing electrification solutions used in the Amazon. Derived from national strategy documents, analyses of past projects and interviews with regional stakeholders, five promising energy solutions have been chosen for this work's comparative approach (Table 2). Based on weights obtained from an interview process, a simple multi-criteria analysis was undertaken and each of the chosen systems has been evaluated. This enabled the comparison of the different electrification options across individual criteria as well as a composite index.

Finally, we suggest tentative conclusions, assessing the appropriateness of each option in the Amazonian context. A list of pros and cons for each electrification option is drawn from the analysis thereby highlighting both positive and negative aspects of the considered solutions.

[3] Especially when those systems are located near or inside the houses.

Multi Criteria Analysis

The MCA (Multi Criteria Analysis) methods aim to improve the quality of decisions involving multiple criteria by making choices more explicit, rational and efficient. This is accomplished through (Hobbs and Horn, 1997):

- Displaying trade-offs among candidate attributes. These are linked to clear criteria, that are valued to define an objective so that planners, regulators and the public can understand the advantages and disadvantages of alternatives
- Helping people to reflect upon, articulate and apply value judgments, resulting in a ranking of alternatives
- Moving the discussion away from alternatives and towards fundamental objectives and corresponding trade-offs.

Implementing one instance of this methodology requires the identification of various assessment criteria. These elements are assigned weights and aggregated into corresponding macro criteria, which in turn receive relative weights. Finally, the resulting alternatives are prioritized and ranked (Amer and Daim, 2011).

In this analysis we aggregate criteria with a simple weighting to derive single values for 'macro' criteria, and those in turn are given weights to arrive to the final index of the analysis. This methodology enables the comparison of alternatives both on single-criteria (e.g. fuel cost) as well as the macro criteria of the analysis (e.g. economics) while showing a final weighted aggregate index. Finally the transparent assignment of weighting allows quick sensitivity analyses.

Following interviews with decision makers listed in Table 4 and a limited contextual literature review (Afgan and Carvalho, 2002; Amer and Daim, 2011; Daim et al., 2009; Ilskog, 2008; Nutt, 1979), 16 criteria were identified as most relevant (Table 1). The 16 criteria are aggregated into 5 macro-criteria, namely: Technical, Economic, Environmental, Social and Institutional.

A simple weighting methodology is applied (Fig. 2). Criteria are weighted (with a weight W_i [%]) to form the respective macro-criterion. The macro criteria are in turn weighted to reach the final index of this analysis. All the parameters are normalized in percentages so as to be aggregated in the final index (0% to 100%).

Albeit limited, this approach makes it possible to derive comparisons of electrification options on criteria, macro-criteria and on the final composite index which expresses an overall judgment for the options in the region. It has to be emphasized that this final index is not intended to indicate the "best" solution over the possible alternatives, but to help contextualize relevant pros and cons when supporting decision-making.

The weights W_i for the analysis have been chosen pursuing a participatory approach: questionnaires had been filled out in order for the interviewed decision makers (DMs), listed in Table 4, to express their