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Evaluation of choices for sustainable rural electrification in developing countries: A multicriteria approach

Md. Mizanur Rahman[a,b,*], Jukka V. Paatero[a], Risto Lahdelma[a]

[a] Department of Energy Technology, Aalto University School of Engineering, FI-0076, Finland
[b] Rural Electrification Board (REB), System Operation Management, Dhaka-1344, Bangladesh

HIGHLIGHTS

- Rural electrification involves a large number of socio-cultural issues in addition to technical and environmental considerations.
- Decision makers need to choose the appropriate options by considering many criteria.
- Many off-grid projects failed due to noncomplying of societal issues.
- Multicriteria based decision choice can safeguard the projects from these issues.
- SMAA analysis can select the alternatives based on merits.

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ABSTRACT

Rural electrification (RE) can be modelled as a multifactorial task connected to a large number of variables: decision makers need to choose the appropriate options by considering not only the techno-economic competitiveness but also socio-cultural dynamics and environmental consequences, making the task intricate. Many rural electrification projects have failed due to lack of attention to the issues beyond financial and technical dimensions. This paper presents a standardized approach for decision making concerning the extension of electricity services to rural areas. This approach first determines whether the supply provision should be grid expansion or off-grid on the basis of levelized cost of delivered electricity. If the grid expansion is found nonviable over off-grid options then a multicriteria decision aiding tool, SMAA-2 (Stochastic Multicriteria Acceptability Analysis), will evaluate off-grid technologies by aggregating 24 criteria values. While applying this approach, the delivered costs of electricity by the grid in remote areas within the 1–25 km distances vary in a range of 0.10–7.85 US $/kW h depending on the line lengths and load conditions. In the off-grid evaluation, the solar PV (photovoltaic) and biogas plants are found as the most preferable alternatives with 59% and 41% acceptability in their first rank, respectively.

1. Introduction

Rural electrification is an essential element in bringing about social and economic developments of the under-privileged rural population. Currently 1300 million people around the world do not have access to electricity, and 85% of them live in rural areas (IEA, 2011). Rural electrification is characterized with many challenging factors such as low load density, poor load factor, rough terrain, and high capital and operating costs. The main economic activity in rural areas is agriculture, which limits productive uses of electricity, and consumers are often poor (Mohan, 1988). The low load densities result in high cost for each unit of electricity, but it should be affordable for relatively poor customers. This dilemma makes rural electrification a complex task than an urban electrification project (World Bank, 2008). In fact, rural electrification needs to involve rural community and societal dynamics instead of just implementing a technical matter of stringing lines (Barnes, 2007).

Rural electrification requires effective prioritization and planning to enable economic choices of technology considering socio-economics and environmental consequences. A large number of off-grid rural electrification projects have failed because the focus was given on technical installation without paying sufficient attention to the long term sustainability (Kumar et al., 2009). Case

* Corresponding author at: Department of Energy Technology, Aalto University School of Engineering, FI-0076, Finland. Tel.: +358 408579889; fax: +358 9 47023419.
E-mail addresses: mdmizanur.rahman@aalto.fi, mizanur1970@gmail.com (Md.M. Rahman).

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studies indicate that off-grid supply acts as a pre-electrification option, with the community continuing to aspire for grid connection. Consequently, many off-grid electrification projects are discontinued due to access to grid lines after implementing off-grid projects (Palit and Chaurey, 2011). Reddy and Srinivas (2009) observed that the choice of technology for rural electrification is influenced by various actors and factors; policy and institutional framework at the macro level and household's socio-economics at the micro level.

Appropriate and multifactorial decision choices are, therefore, an integral part of long term sustainability of rural electrification projects. Kumar et al. (2009) proposed a decision making approach for planning and formulation of off-grid vis-à-vis grid connected rural electrification projects. Tshewang (2008) presented a weighted score system where a number of features (technical, regulatory, environmental and social) related to rural electricity supply options have been considered. Elisabeth (2008) argues that rural electrification success is allied with as much as 39 indicators under five dimensions namely technical, economic, social, environmental and institutional sustainability. Ilskog and Kjellström (2008) evaluated a rural electrification case using 31 indicators, with all the indicators having the same weight and each indicator scored on 1–7 scale, while 7 representing the best performance. Cherni et al. (2007) proposed a decision support system to determine an appropriate set of energy options which can provide sufficient power to fulfil local demands whilst improving users' livelihood in terms of five factors. Lahdelma et al. (1998) developed stochastic multicriteria acceptability analysis (SMAA) tool for aiding decision makers (DMs) to rank different alternatives based on criteria values. SMAA method can even handle alternatives which possess uncertain, inaccurate or missing information (what often happens for rural electrification cases) (Tervonen and Lahdelma, 2007). SMAA method has been successfully applied in a number of real life decision making problems, for example, decision support for selecting cargo site at airport hub (Menou et al., 2010), site selection for waste treatment facilities (Lahdelma et al., 2002), and choice of technologies for cleaning polluted soil (Hokkanen et al., 2000). Rural electrification decision making process is obviously a multifactorial problem; however, the multicriteria approach has not been adequately incorporated in rural electrification projects. In this study, we propose a multifactorial approach by incorporating SMAA method to support decision making on sustainable rural electrification process and we also illustrate this approach to a rural village. This approach and data processing techniques can be applied in any site attributed by rural features for evaluating decision choices in extending electrification.

2. Methodology

The proposed approach first determines whether the electricity supply provision should be grid expansion or off-grid on the basis of levelized cost of delivered electricity. If the grid expansion is not found viable, then SMAA tool evaluate different off-grid alternatives considering 24 criteria under five sustainability dimensions. This paper showed the procedures for determining the cost of delivered electricity for both grid and off-grid options and for finding the critical line length (or circuit-km[1]) for grid expansion against different off-grid alternatives. This paper also proposed, and described the criteria values and their weight preferences those to be applied in SMAA tool. The proposed criteria sets are well representative of general requirements for sustainable expansion of rural electrification. Among total 24 criteria, 10 cardinal criteria values are generally applicable in rural areas, however, applicability of remaining 14 ordinal criteria values are subject to refine by endorsing the local DMs' views.

[1] *Circuit-km* is the line length in km required for extending the grid electricity services.

2.1. Grid or off-grid

Though it is evident by many case studies that off-grid renewable energy systems can play a vital, cost-effective role to supply electricity to the rural areas, these off-grid options are not mutually exclusive options to serve a rural area. The national or regional utility companies have often structured their grid-extension plan without excluding villages which might have potential for off-grid supply. Therefore, for the long term sustainability of off-grid system, it is required to know whether the off-grid system will be vulnerable to the future grid extension. To get relieve from this dilemma, the World Bank recommended a decision making process for examining different alternatives (Fig. 1).

The viability of grid extension depends on a number of factors such as distance to the load, anticipated load, distribution losses etc. Checking of the viability of grid expansion can be done by comparing the costs of delivered electricity against the off-grid supply costs. At any location, the costs of delivered electricity from the grid comprise of three components i.e. (a) cost of generation at the bus-bar of the generation plant, (b) cost of transmission, and (c) cost of distribution to the clients' meter.

2.1.1. Delivered cost of electricity through grid extension

2.1.1.1. Cost of generation at the plant bus bar. The levelized cost of energy generation is the preferred tool to compare different power generation technologies of unequal economic life, capital cost, efficiencies (or heat rates), and fuel costs (Short et al., 1995). The levelized cost of electricity generation ($LCOE_g$) can be calculated according to the formulae presented below (NREL, 2012).

$$LCOE_g = \frac{\sum_{i=1}^{m}[CRF_i \times I_i + E_i\phi_i^{HR}C_i^{FC} + \beta_i I_i]}{\sum_{i=1}^{m} E_i} \quad (1)$$

here i represents the power generating plant (1, 2,…., m), m is the total number of power generating plants serving to the central grid, E_i is the annual electricity output at the bus bar (kW h) of

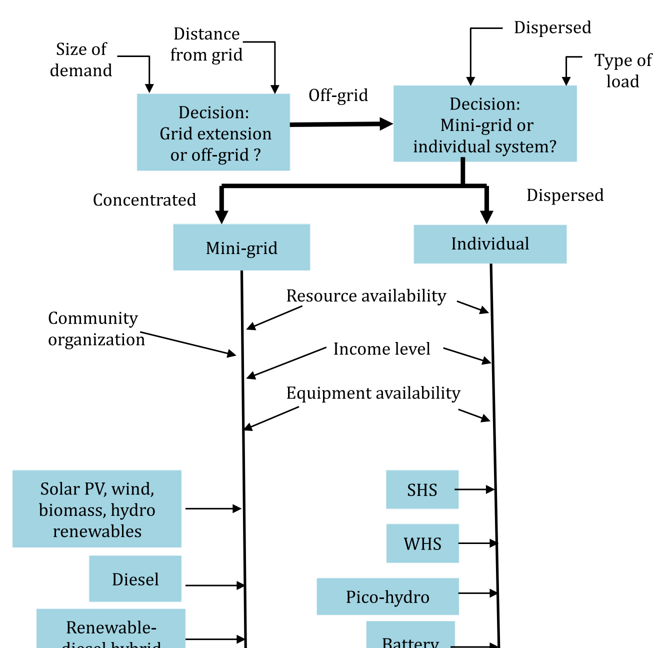

Fig. 1. Off-grid rural electrification decision making process (World Bank, 2008).