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Review of alternative methodologies for analysing off-grid electricity supply

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ABSTRACT

Off-grid electrification is gaining importance in the developing countries where the access to electricity is often limited. The purpose of this paper is to review alternative methodologies that are used for off-grid electrification projects to identify the features of each methodological approach and to present their strengths and weaknesses. The paper reviews a large volume of relevant literature covering techno-economic feasibility studies, analytical works highlighting methodological applications and practice-oriented literature. The review identifies five methodological options, namely the worksheet-based tools, optimisation tools, multi-criteria decision-making (MCDM) tools, system-based participatory tools and hybrid approaches. The paper recommends a hybrid approach that combines two or more options to take advantage of strengths and weaknesses of different options.

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1. Introduction

The issue of providing access to electricity to almost 1.4 billion people without electricity is one of the major development challenges of recent times. Although the grid extension is the most common mode of electrification for providing electricity, the progress in this area has remained unimpressive in many countries. Accordingly, the off-grid supply is now considered as an alternative option, where renewable as well as fossil-fuel-based energies are being used either individually or in hybrid forms.

The literature on renewable energy and electricity supply for rural use is very well developed and a number of strands can be identified from this body of knowledge:

- First, the focus of most of the literature is on the technical design of the system and its cost-effectiveness analysis using some economic indicators. Given the technological diversity of renewable energies, this set of literature has often relied on the case study approach where the application of individual technologies or a combination of technologies has been considered to meet the energy demand. Some studies provide a review of the technological and economic readiness of alternative energies as well.
- Second, a number of tools have been used by various authors.
- For example, HOMER (Hybrid Optimisation Model for Electric Renewables), developed by NREL (National Renewable Energy Laboratory, USA), appears repeatedly in the literature as a preferred tool. It can handle a large set of technologies (PV, wind, hydro, fuel cells, boilers, etc.), loads (AC/DC, thermal and hydrogen), and can perform hourly simulations (see Table 1 for some applications). HOMER is an optimisation tool that is used to decide the system configuration for decentralised systems. Other software tools include HYBRID2 developed by the Renewable Energy Research Laboratory (RERL) and HOGA (Hybird Optimisation by Genetic Algorithms developed by the University of Zaragoza, Spain), which are available freely.[1]
- The use of optimisation approach has a long tradition in the energy analysis and has been extended to rural energy supply analysis by many authors. The most common application relies on linear programming due to its ease of use but more advanced applications have also been reported. In addition, computer-based dynamic economic evaluation model to assess alternative options (as in [70]) or simulation-based software for hybrid systems (as in [71]) has been reported in the literature. While some tools were technology specific [58] for an optimisation tool for wind-fuel cell hybrid), others have more generic capabilities (see [1] for a tool to assess different decentralised systems). Similarly, multi-objective evolutionary programming has been used to optimise decentralised systems (see [11] and [82] for example).
- Multi-criteria decision making and its extension to include social aspects have also found favour of analysts. Given that the decision-making often involves trade-offs amongst various competing objectives and because such decisions may change depending on the stakeholder preferences, MCDM provides an effective alternative for reconciling conflicting viewpoints.
- In addition, other methods also have been used including simple indicator-based one to more complex tools such as systems-based approaches and participatory approaches.
- Third, the practice-oriented literature (manuals, best-practice experiences, etc.) also provides some guidelines on decentralised electricity supply and in some cases recommends steps or critical factors for such projects.

[1] For a list of such tools and their characteristics see [10].

Although, various approaches can be found in the literature, each method has its own features and limitation. Moreover, any solution strategy for promoting energy access has to consider various dimensions such as the techno-economic, governance, socio-political, environmental, financial, etc. The techno-economic dimension focuses on factors such as reliability of supply, sustainability of supply, cost-effectiveness and ways of improving this, manufacturing and operating capabilities, attractiveness of the supply option to the investor, and lock-in effect and its socio-economic effect on future development. The governance dimension focuses on the institutional compatibility of the proposed solutions, regulatory effectiveness, transition management, institutional endowment, capacity building, and the institutional adjustments required for implementing the solutions. The socio-political dimension needs to consider social acceptability and affordability issues, equity aspect, gender bias, political acceptability, local income generation issues, and behavioural changes required for the adoption of energy access solutions. The environmental dimension takes into account issues such as environmental desirability of solutions including benefits and adverse effects, resource sustainability and the social implications of environmental effects.

Whether or not a methodology takes such dimensions into account, and whether the approach is appropriate for general application needs to be reviewed. The objective of this paper is to identify alternative methodological options and analyse the appropriateness of various options for off-grid electricity supply. To the best of our knowledge, no such review exists, although reviews of decentralised supply or specific technologies or tools can be found.

The organisation of the paper is as follows: Section 2 provides a review of literature of techno-economic feasibility studies. Section 3 presents various analytical approaches such as indicators, optimisation, multi-criteria decision-making and systems approach, while Section 4 reviews some project-based literature (project reports, etc.). Section 5 then considers the appropriateness of alternative options for the purpose of off-grid projects. Finally, a concluding section captures the main findings of this paper.

2. A selected review of techno-economic feasibility studies

A large volume of literature of this sort is available that focuses on various technologies and country cases. The methodology in all these studies generally follows a common approach—assessment of technological appropriateness, evaluation of economic viability and determination of financial or other incentives required to make the project viable at a given location [59]. In the following paragraphs, only a brief review of a selected set of this literature is presented.

An early study analysing the grid-connected rural electrification options in developing countries can be found in [109]. As the demand in rural areas arises mainly from the use of domestic appliances, the load factor of domestic demand tends to be low, which emerges as the main problem for grid extension. Reddy et al. [93] argued that the magnitude of energy use is not the true indicator of development but the level of energy services provided should be considered for this purpose. This requires inclusion of decentralised and energy conservation options alongside energy supply options. Their study provided a comparative costing of grid-connected, off-grid and energy conservation systems in the Indian context. This study highlighted the importance of improved technology for rural energy services and provided a detailed evaluation of grid-connected, off-grid and energy conservation options using the life-cycle costing approach. Sinha and Kandpal [105] compared the cost of electricity supply through grid extension against the cost of supply from decentralised sources for rural India. This study considered the cost of extending the grid in terms of investments