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Review

Long-term energy planning and demand forecast in remote areas of developing countries: Classification of case studies and insights from a modelling perspective

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ABSTRACT

More than half a billion people will still lack reliable and affordable electricity in 2040 and around 1.8 billion may remain reliant on traditional solid biomass for cooking. Long-term energy planning could help to achieve the energy access targets in developing countries, especially in remote rural areas.

Different studies exist on long-term rural electricity and thermal energy planning, but the different foci, terminology and methodologies make it difficult to track their similarities, weaknesses and strengths. With this work, we aim at providing a critical analysis of peer-reviewed studies on long-term rural energy planning, to help researchers in the field move across the diverse know-how developed in the last decades.

The work resulted in the analysis of 130 studies and categorisation of 85 of them that focus on electricity, thermal energy, and oil supply in rural areas, under a number of rules clearly defined in the first part of the paper. We classify the studies in two consecutive steps, first according to their type and afterwards according to the methodology they employ to forecast the energy demand, which is one the most critical aspects when dealing with long-term rural energy planning.

The work also provides specific insights, useful to researchers interested in rural energy modelling. Few studies assume a dynamic demand over the years and most of them do not consider any evolution of the future energy load, or forecast its growth through arbitrary trends and scenarios. This however undermines the relevance of the results for the purpose of long-term planning and highlights the necessity of further developing the forecasting methodologies. We conclude that bottom-up approaches, system-dynamics and agent-based models seem appropriate approaches to forecast the evolution of the demand for energy in the long-term; we analyse their potential capability to tackle the context-specific complexities of rural areas and the nexus causalities among energy and socio-economic dynamics.

Contents

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1. Introduction

Electrical and thermal energy use and consumption will grow fast in developing countries (DCs). Based on its New Policies Scenario, the International Energy Agency (IEA) estimates a rapid growth of the energy demand in sub-Saharan Africa and in rural and urban India in the next 25 years [1]. According to the U.S. Energy Information Administration, in the non-OECD regions, the total energy demand is expected to exceed the OECD regions' one by 89% in 2040 [2], especially in Southeast Asia, China and India. This expected growth of energy demand is mainly attributable to the ongoing energy access-oriented policies and actions. Indeed, to ensure universal access to modern energy, the World Bank estimates that 2.6 billion people will have to be electrified by 2030, and 4.4 billion served with modern cooking services [3]. Increasing the access to sustainable energy supply in rural contexts is therefore expected to largely contribute to the achievement of the global energy access goals, since people still living without electricity and modern energy fuels will live predominantly in rural areas [4,5]. In this context, the need to develop sustainable and appropriate approaches to electricity and thermal energy planning clearly emerges.

As always in energy planning, a sustainable and reliable approach is advised. The latter may influence the architecture and the sizing of the implemented solutions, particularly where economic resources are scarce, as Kusakana discusses [6]. Much of the planning relies on good estimates of the energy demand and its evolution with time. Wrong predictions could negatively impact the local socio-economic development and cause an inappropriate sizing of local energy solutions, leading to supply shortages or cost recovery failure, as argued by Hartvigsson et al. [7]. Cabral et al. [8,9] and Kivaisi [10] expressed this concept well by highlighting the need to pay attention to the evolution of the electricity load when planning electrification programmes, since the marginal costs of energy services vary among supply alternatives (*i.e.* small photovoltaic (PV) systems for low loads and grid-extension for high loads). In the scientific literature, we found different examples of studies that prove how the energy planning process is highly dependent on the estimation of the energy demand. We report the example of Fuso Nerini et al. [11], who demonstrated how the total discounted cost (capital and O&M costs) for household in the years 2010–2030 for reaching different tiers of electricity access (*i.e.* different levels of energy demand to satisfy) in the village of Suro Craic is very sensitive to the energy demand, since it can vary from few hundreds to thousands dollars per household. Further, Brivio et al. [12] demonstrated that in Photovoltaic-batteries-based off-grid systems, the optimal size of the components is sensitive to the load evolution pattern, especially the capacity of the battery energy storage system. In his system dynamic model applied to a hydroelectric-based project in rural Tanzania, Hartvigsson et al. [7] showed how the power supply capacity of energy systems for rural areas should be considered accurately based on the long-term forecasts of electricity demand, since a demand larger than the installed capacity can generate lack of power availability that may affect the willingness of people to stay connected and the utility revenues. Again, Van Ruijven at al. [13] developed a bottom-up model to assess trends in electrification over the next decades in DCs and they demonstrated how the potential of mini-grid technologies is highly dependent on the demand level and population density.

Due to highly uncertain dynamics, strong non-linear phenomena, socio-economic complexities behind the diffusion processes of energy technologies (*e.g.* social networks, people willingness and availability to pay), time-adjustments of technology perceptions and low quality and availability of data affecting such remote contexts, the long-term forecasting of energy demand in rural areas is a complex issue. This is the reason why studies on rural energy planning usually tackle demand forecasts by relying on multiple scenarios that follow regional policies or international guidelines (*e.g.* the OECD Environmental Outlook [13] or multi-tier categorisation proposed by the World Bank [11]).

This work reviews long-term rural electricity and thermal energy planning studies on the basis of the application and the insights they provide, rather than their structural characteristics. The aim is to provide a synthesis of strengths and weaknesses, fields of applicability and insights which do not depend on the views of the authors or the specific terminology employed. Moreover, as a novelty, we try to combine the analysis of both the "demand" and the "supply" aspects of the rural energy planning studies, stressing the need to consider the two parts of the planning as linked and interdependent. For this purpose, we follow an approach that classifies the studies firstly in accordance with specific sub-categories suggested by the literature (*viz.* spatial coverage, planning horizon, energy carrier, decision criteria mathematical models and energy uses), and secondly in accordance with the methodology they employ to forecast the evolution of the energy demand. Indeed, the aspect of long-term energy demand analysis and modelling within long-term rural energy planning is a poorly discussed and addressed topic in the reference literature. In this work, and we aim at opening a discussion about its importance in the field by trying to derive some useful insights and guidelines for tackling the issue in rural contexts of DCs.

The work intends to inform diverse groups of audiences, from researchers to energy planners, with different sets of information, levels of technical knowledge and involvement in the implementation aspects.

Section 2.1 reports the rationale and methodology we employed to carry out the review. Section 2.2 proposes a multi-criteria classification for the energy planning case studies and a description of the papers reviewed, while Section 3 analyses the methodologies to forecast the evolution of the energy demand employed in rural energy planning case studies and it proposes guidelines for