Energy for Sustainable Development 43 (2018) 203–223

Contents lists available at ScienceDirect

Energy for Sustainable Development

Review

Electricity access and rural development: Review of complex socio-economic dynamics and casual diagrams for more appropriate energy modelling

Fabio Riva [a,*], Helene Ahlborg [b,c], Elias Hartvigsson [d], Shonali Pachauri [e], Emanuela Colombo [a]

[a] Politecnico di Milano, Department of Energy, via Lambruschini 4, Milan, Italy
[b] University of Gothenburg, Department of Political Science, Box 711, 405 30 Göteborg, Sweden
[c] Chalmers University of Technology, Division of Environmental Systems Analysis, SE-412 96 Göteborg, Sweden
[d] Chalmers University of Technology, Division of Electric Power Engineering, SE-412 96 Göteborg, Sweden
[e] International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria

ARTICLE INFO

Article history:
Received 11 December 2017
Revised 6 February 2018
Accepted 6 February 2018
Available online xxxx

Keywords:
Rural electrification
Electricity-development nexus
Causality diagrams
Energy modelling
Complexities

ABSTRACT

The causal relationships between electrification and development of poor, rural communities are complex and contextual. The existing literature focuses mainly on the impact of rural electrification and electricity use on local socio-economic development, while the reverse feedbacks of various social and economic changes on electricity demand and supply have not been fully characterized. Most electricity access impact assessments assume linear, one-way effects and linear growth in electricity demand. However, the projections rarely match the reality, creating challenges for rural utilities. From a modelling perspective, the lack of attention to dynamic complexities of the electricity-development nexus prevents the appropriate modelling of electricity demand over time and, hence, informed planning for and sizing of power plants. With the goal to improve modelling of the electricity-development nexus, we undertake a comprehensive review and extensive analysis of the peer-reviewed literature on electricity access and its impact on rural socio-economic development, and vice versa. We characterize and describe the nexus between electricity access and development through graphical casual diagrams that allow us to capture, visualise and discuss the complexity and feedback loops. Based on this, we suggest guidelines for developing appropriate models able to include and simulate such complexities.

Our analysis confirms that electricity use is interconnected through complex casual relations with multiple dimensions of socio-economic development, viz. income generating activities, market production and revenues, household economy, local health and population, education, and habits and social networks. The casual diagrams can be seen as a first step of the conceptualization phase of model building, which aims at describing and understanding the structure of a system. The presence of multiple uncertain parameters and complex diffusion mechanisms that describe the complex system under analysis suggests that systems-dynamic *simulations* can allow modelling such complex and dynamic relations, as well as dealing with the high uncertainties at stake, especially when coupled with stochastic approaches.

Contents

* Corresponding author at: Via Lambruschini 4, 21056 Milan, Italy.
E-mail addresses: fabio.riva@polimi.it (F. Riva), helene.ahlborg@pol.gu.se (H. Ahlborg), elias.hartvigsson@chalmers.se (E. Hartvigsson), pachauri@iiasa.ac.at (S. Pachauri), emanuela.colombo@polimi.it (E. Colombo).

https://doi.org/10.1016/j.esd.2018.02.003
0973-0826/

Introduction

The International Energy Agency (IEA) estimates that 1.1 billion people do not have access to electricity, most of them living in rural areas (International Energy Agency, 2017). Lacking reliable access to electricity is considered a limit on people's opportunities and quality of life. The role of energy as a key driver to sustainable development is now widely recognized by the global community, as evidenced by the fact that the Sustainable Development Goals (SDGs) include access to affordable, reliable, sustainable, and modern energy for all by 2030 as an explicit target. While the relationship between electricity use and development is known from a macroscopic and macroeconomic point of view, the local dimensions of the electricity-development nexus in poor, rural contexts are not completely captured and characterized. Experiences of international institutions like GIZ and the Energy Sector Management Assistance Programme (ESMAP) of the World Bank have highlighted the multifaceted aspects of the issue. They have shown that it is not enough to simply provide people with access to electricity and "hope for local economic activity to pick up by itself" (Brüderle, Attigah, & Bodenbender, 2011, pg. 8). Indeed, the literature emphasises that electricity access should always be accompanied and sustained by other enabling activities and services, in order to contribute to greater educational attainment, more business opportunities, gender equity, and higher income at the local level (Bastakoti, 2003; Colombo, Bologna, & Masera, 2013; Khandker, Barnes, & Samad, 2013; Winther, Matinga, Ulsrud, & Standal, 2017). Against this backdrop, in this paper we review the complex nexus between electricity access and use, and socio-economic development of rural areas in the Global South.

The complexity of the problem renders the use of linear or predefined sets of relations of cause and effect to describe the issue inaccurate, since "the dynamics of growth and electrification are complex, involving many underlying forces" (Khandker et al., 2013, pg. 666). According to Matinga and Annegarn, "simple deterministic relations between electricity access and development outcomes do not reflect reality" (Matinga & Annegarn, 2013, pg. 301), while Ahlborg (2015) confirms the presence of multiple interfaces and feedbacks that shape outcomes in electrification processes. The literature also suggests that the nexus between electricity use and rural socio-economic development has dynamic components, meaning that the nexus is characterized by complex feedbacks that can reinforce or balance impacts over time (Ulsrud, Winther, Palit, Rohracher, & Sandgren, 2011). Khandker's et al. (2013) study of Vietnam's rural electrification program exemplifies how a "virtuous circle of development" emerged as significant investments in other rural infrastructure services were undertaken (viz. water supply, roads, health and education) and rural electrification contributed to greater educational attainment, more business opportunities, and higher income, which in turn improved the affordability of electricity and appliances, leading to an increase of total electricity load and more investments in rural electrification. Khandker, as well as others (Kanagawa & Nakata, 2008), suggest that electrification, if supported by enabling complementary actions, can lead to positive feedbacks on future electricity demand in a rural context.

In rural electricity planning, being able to analyse and forecast electricity demand is pivotal to the development of sustainable and reliable electricity models and plans, especially those dealing with the architecture and sizing of off-grid solutions. Inaccurate predictions can negatively impact local socio-economic development and cause unsustainable sizing processes of energy solutions, leading to negative consequences for the technical performance of the power supply (Ulsrud et al., 2011), such as supply shortages or cost recovery failures (Hartvigsson, Ahlgren, Ehnberg, & Molander, 2015). Existing energy demand models for off-grid electricity planning do not capture these complexities; indeed, they usually rely on simple estimates of the energy demand and its evolution over time. Given that such linear projections are commonly inaccurate, being able to understand and model aspects and dynamics that determine rural electricity use can lead to more robust energy planning and solutions in rural areas, as well as increase the current understanding of the energy-development nexus.

The goal of our study is therefore to:

(i) review and analyse literature which describes, explains, and discusses – through case studies, experiences on the field, and surveys – the impact of electricity access and consumption on rural socio-economic development, and vice versa;
(ii) discuss and capitalize on the literature's findings by describing the development nexus complexity through graphical representations – viz. casual diagrams (Coyle, 2000).
(iii) derive insights and set useful guidelines for developing appropriate models able to include and simulate such complexities.

With this work, we try to make explicit the many aspects that influence electricity use and demand – that "energy problems go beyond purely technical and economic issues" (Morante & Zilles, 2001, pg. 380). Our intended audiences are researchers in energy and socio-economic development, energy modellers, energy planners and policy makers involved in the global challenge of rural electrification. In particular, we aim at providing researchers and modellers with useful guidelines for developing robust long-term energy access scenarios; while we wish to provide the latter with a clearer view of the multifaceted and interrelated techno-economic and social complexities at stake, and consequent useful information for enhancing effective and sustainable electricity access polices.

Background - electricity access and rural development

State-of-the art

In this section, we report the state of the art for review studies that focus on electricity access and rural development, trying to highlight the methodological progress achieved in past years and the new emerging challenges. Review studies of the socio-economic impacts of rural electrification in developing economies and formerly colonized countries started emerging in the 1980s. Within the context of the International Labour Office's World Employment Programme's research, Fluitman (1983) reviewed the available literature on rural electrification, its effects on rural industrialisation, and its impact on such socio-economic objectives as employment and income generation. The