RURAL ELECTRIFICATION TRAJECTORIES

Anjali Nursimulu, Ecole Polytechnique Fédérale de Lausanne,
Energy Center, Station 5, CH-1015, Lausanne, Switzerland,
+41 21 693 2441, anjali.nursimulu@epfl.ch

Overview

Renewable-energy (RE)-based rural electrification is essential for achieving Sustainable Energy for All (S4All). According to the International Energy Agency's 2016 World Energy Outlook, over 95% of the population who do not have access to electricity—about 16% of the global population—and without access to modern and clean cooking facilities—more than 38% of the global population—are predominantly in the rural areas of sub-Saharan Africa and developing Asia. The welfare impact, measured in terms of social and economic benefits, of rural electrification has been widely discussed. But, despite some progress, the electrification rate is being outpaced by population growth in rural areas, in a large part due to a lack of financial viability of projects.

In this paper, we explore the boundary conditions for RE-based on-grid, mini-grid and standalone rural-electrification solutions, focusing on the drivers of successful RE-based mini-grid development. Specifically, the strategic considerations for deploying renewable energy-based mini-grids are radically different from off-grid standalone solutions such as solar home systems or solar lamps. RE-based mini-grids require economies of scale to be financially viable and sustainable. By means of a diffusion modeling framework, the paper contributes an informed understanding on the potential rural electrification trajectories using mini-grid and, in so doing, highlights migi-grid scale-up and upscaling (connecting mini-grids to the grid) opportunities.

Methods

The paper add network effects to the Bass diffusion model, a well-established technology adoption model, to assess the diffusion time of energy services within mini-grids and, thereby, to evaluate the performance of mini-grids in terms of economic and financial viability, and sustainability. We consider both direct network effects—particularly demand-side scale economies—and indirect network effects, such as collateral activities for, say, operations and maintenance. We define rural network archetypes on the basis of different network dimensions such as the heterogeity of consumers' willingness and ability to pay for energy services across nodes, and the presence and density of hubs.

Results

Through quantitative analysis of temporal and structural patterns of adoption of energy services in these rural network archetypes, we provide decision-relevant insights on:

- The importance of incremental mini-grid development in view of optimizing up-front costs and managing financial risks
- The benefit of bundling mini-grid development with other projects to generate sufficient network effect; otherwise projects may fail or it may be difficult to scale-up mini-grids
- The importance of decoupling end-user tariffs and project financial viability, e.g. through market mechanisms that align economic and financial performance
- The need to take a blended view of grid, mini-grid and off-grid solutions, using level of energy services and not electrification rate as performance metric.

Conclusions

Within a single and comprehensive diffusion framework, we obtain actionable insights for sustainable rural electrification. The analysis is aimed at diverse users, including project developers and operators, investors and policy-makers. Policy makers can make use of the analysis to identify key and local priorities to improve access to energy services. For example if network effects are strong, the government should encourage capacity building and guarantee an effective supply chain, e.g., for spare parts. For developers and operators, an understanding of the temporal and structural dynamics of energy services can help optimize the project development over time, such as incremental addition of PV modules and services. The framework can thus be used for improving mini-grid risk management. The network-based diffusion framework can be extended to other mini-grid projects, such as RE-based hybridization of so-called brownfields (diesel-based mini-grids). It also applies to the context of decentralization of energy system in developed nations, e.g., to indentify viable business models for aggregators and/or smart service providers, where network effects are important.