DECENTRALIZED RENEWABLE OFF-GRID SOLUTIONS VERSUS GRID EXTENSION IN DEVELOPING REGIONS – NECESSARY CRITERIA FOR A SPATIAL ANALYSIS OF KEY DRIVERS

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Abstract

Despite advancing electricity producing technologies with and without renewable energies and international efforts to mitigate energy poverty, rural electrification remains still an unresolved issue in many parts of the developing world.

With the high learning curves of renewable energy technologies and the abundance of solar irradiation, wind and hydro resources, solutions seem to exist. However, several years of developing aid with many pilot projects, investments and research show that the lack of providing electricity is a more complex issue. One aspect, which received inadequate consideration until today, is the spatial reference. Spatial information discloses a new dimension of the understanding of local situations, which consequently helps to distinguish the appropriate electrification scheme for each place. Geographical information systems can then be used as a tool to process the existing data so as to obtain large-scale insights for distinguishing between off-grid electrification and grid extension from a geographical point of view.

Motivation

Providing access to electricity is still a major challenge in developing countries worldwide. Globally 1.3 billion people, especially in rural, remote areas live without electricity [1], [2]. The traditional approach to solve this issue is the extension and development of transmission grids with mainly fossil fuel-based centralized power generation, or the usage of expensive carbon-intensive small diesel generators. Grid extension requires high initial investments and a well-organized political planning structure [3]. In less developed regions, electricity provided by the main grid is often a very unreliable source due to load shedding and additional unplanned interruptions. Furthermore, the transmission grid often only covers regions with high electricity demand, i.e. high population density. As a result, rural electrification rates remain low compared to urban electrification rates in many countries (Tab. 1) [1].

With the rising cost competitiveness of renewable energy and storage technologies decentralized off-grid solutions (solar home system, pico system, mini-grid – depending on available local purchase power) based on solar, wind, and hydro power present a viable alternative to grid electricity worldwide [4]. Especially remote regions with scattered populations and small settlements could profit from decentralized solutions. However, exact knowledge of relevant criteria and parameters is necessary to identify the techno-economic-optimized, sustainable electrification option [5].

This paper presents a multi-criteria catalog as a starting point for a geospatial analysis to define key drivers for grid extension and decentralized off-grid solutions.

Table 1: Number of people without access to electricity by region (million). [1]

	Rural	Urban	Total	Share of population
Developing countries	1,081	184	1,265	24%
Africa	475	114	590	57%
Developing Asia	556	62	628	18%
Latin America	23	6	29	6%
Middle East	16	2	18	9%
World	**1,083**	**184**	**1,267**	**19%**

Spatial assessment is necessary for regional and land use planning, as well as for structuring basic services like the provision of electricity.

In particular, the focus on the effect of renewable energies requires the understanding of spatial relationships between resources and electricity demand clusters, as the advantage lies in the geographical proximity of energy producer and consumer, referred to as “prosumer”. The importance of space-based analysis grows with the rising share of renewable energy – as resources vary in their spatial abundance. As a consequence, with decentralized solutions the transmission of centrally generated electricity is no longer a prerequisite for electricity provision in rural remote areas.

Approach

The development of a multi-criteria parameter catalog is the first step integrated in the comprehensive analysis carried out within the PhD project “Comparison of Off-Grid Electrification versus Grid Extension: Influencing Parameters and The Role of Renewable Energies from a Geographic Point of View” (Fig. 1).

To assess the advantages and disadvantages of the implementation of renewable off-grid solutions and grid extension, a multi-criteria parameter catalog needs to be defined. Relevant geographical parameters include natural resource availability, land cover and topology, and amongst others, population distribution, available local purchasing power and existing grid infrastructure. These data are compiled to define thresholds and exclusion criteria for each parameter. For each data source different spatial resolutions depending on data availability are used.

The objective is to visualize local specifics and spatial relations on a most resolved basis. This helps to design appropriate national electrification development plans adjusted to local conditions. In addition, political aspects such as national electrification policies and renewable energy frameworks on a country level are included. Combining these parameters, the costs for grid extension are simulated and contrasted to the costs for off-grid solution in a further step.

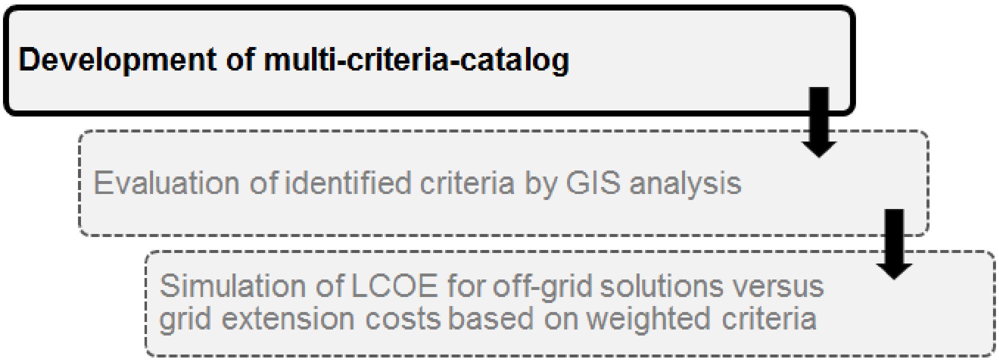

Figure 1: Development of the multi-criteria-catalog as prerequisite for further research steps.

Results

Literature research indicates the complexity of variables when it comes to defining relevant criteria for the comparison of off-grid electrification versus grid extension. Several approaches classify variables into technical, economic, social, environmental, and policy sections [6].

However, in these analyses the exact spatial aspect is mainly disregarded, even if this parameter significantly influences the analysis. For policy development it is of utmost importance to understand existing spatial correlations and structures to design adequate mechanisms to achieve full electrification. For this reason policies and targets are developed mostly based on a weak understanding of the relevant parameters regarding the feasibility and the costs of renewable off-grid solutions versus grid extension. Until now only studies on a country or regional level are carried out addressing the given issues [7],[8],[9],[10],[11],[12].

The main characteristic missing here is the linking of the available spatial information, which is the key to identify exact regions where off-grid electrification is and will continue to be the best alternative for the provision of electricity access. Therefore a multi-criteria catalog was developed to structure available information (Tab. 2).

The first section of the multi-criteria catalog investigates in “Remoteness”. Here the distinction between urban and rural areas is used in combination with analyzing the distribution of villages and towns and the respective time needed to reach the next major urban center regarding the local infrastructure. In addition, population density at each point is included. This is important regarding the structure of energy islands (i.e. geographically isolated locations with energy demand) and the estimated grid length to connect these to a grid and/or transport resources like diesel fuel or heavy fuel oil to supply local diesel grids.

On this basis, the second section "Electricity Demand" is established. Here, the current electricity access rate is considered. Also, local economic activity is taken into consideration and scaled with the respective population.

Table 2: Multi-criteria catalog to distinguish advantages and disadvantages of on- and off-grid electricity supply.

1. Remoteness
• Distribution of towns and villages
• Population density and structure
• Travel time
• Urban / rural area distinction
2. Electricity Demand
• Electricity access rate
• GDP/poverty level
• Population density
• Tourism
3. Existing Electricity Generation and Transmission Schemes
• Transmission line course
• Quality of service (load shedding, limited supply)
• Transport losses
• Central electricity generation plants (capacity, type)
4. Natural Resource Assessment
• Resource availability (solar irradiation, wind speed, hydro power potential)
• Land cover
• Digital elevation model (DEM)
5. Non-spatial Parameters
• Policy structures (e.g. electrification objectives, renewable energy targets)
• Investment incentives
• Ownership structures of plant operators and transmission line infrastructure
• Attractiveness for investors (e.g. ease of doing business index, corruption index)

For yet non-electrified or insufficient electrified regions a low demand is assumed first with a steadily increasing rate to cover the steps of electrification from supplying electricity for basic needs (e.g. light on a household level) to public services supply (e.g. health centers and schools) and the productive use of electricity [13], [14].
Furthermore, tourism activity is taken into consideration, as it influences the electricity demand in certain regions significantly. The electricity demand is the key indicator for the off-grid system sizing.

In the next section "Existing Electricity Generation and Transmission Schemes" are considered with its exact locations**.** The analysis of the coverage, status quo and development plans for generation and transmission is essential for the calculation of extension costs and definition of "off-grid" areas. The age of the existing energy infrastructure and the respective capacities also need to be taken into account. In addition, the quality of service (e.g. load shedding and unplanned interruptions), and transport losses have to be included.

With the focus on the changing development patterns of electricity systems with the raising share of renewable energies a "Natural Resource Assessment" allows the correct depiction of technological potentials for the respective energy sources and technology. Focusing on renewable energies, the spatial analysis is essential to identify the best source at each location – for example hydro power potential is spatially more constrained than solar resources, yet mostly more economic when available. Transmission grid extension costs also vary with changing surface structures, which can be assessed by using a digital elevation model and land cover data.

At last, also "Non-spatial Parameters" are considered as criteria, though this information is only appended to the prior spatial modelling results. These include policy structures and other organizational factors impacting on the decision between off-grid electrification and transmission grid extension. This section also includes a stakeholder analysis of all involved groups.

With the development of the parameter characterization a comprehensive overview is given on decisive elements regarding electrification costs with renewable off-grid solutions in contrast to grid extension. An understanding of the relationship between different aspects such as the remoteness and accessibility and their related costs is essential for the planning of further electrification strategies in developing countries.

The results are the basis for a subsequent GIS-based spatial analysis which leads to defined regions in which the renewable off-grid solution presents the most economical solution to the lack of electricity now and in the future. Gaining knowledge in these areas will therefore ameliorate the policy development and shows the advantages of decentralized renewable electricity systems especially in rural areas worldwide and allows a comparison of different developing tracks.

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