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Electricity planning and implementation in sub-Saharan Africa: A systematic review

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A R T I C L E I N F O

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A B S T R A C T

Universal electricity access is an important development objective, and the focus of a number of key global UN initiatives. While robust electricity planning is widely believed to be a prerequisite for effective electrification, to date, no comprehensive overview of electricity planning research has been undertaken on sub-Saharan Africa, the world region with the lowest access rates. This paper reviews quantitative and qualitative electricity planning and related implementation research, considering each of the 49 sub-Saharan African countries, the four regional power pools and the sub-continent as a whole. Applying a broad understanding of electricity planning and a practical limit of 20 reviewed articles per country and region, 306 relevant peer-reviewed journal articles are included in this review. A general classification scheme is introduced that classifies the planning literature along the addressed value chain depth, number of different analysed criteria and number of evaluated decision alternatives. The literature is found to be strongly clustered in a few countries, with less than 5 identified relevant articles in 36 of the 49 countries. The total amount of articles per year is clearly increasing over time, addressing technology choice, operation, distribution and implementation analyses. Although including different high-level criteria in analysing electricity systems is common, the literature is only starting to use formalised multi-criteria decision making (MCDM) tools. The review indicates that 63% of relevant articles favour renewable energy technologies for their given problems. Frequently mentioned success factors for electrification in sub-Saharan Africa include adequate policy design, sufficient finance and favourable political conditions. While considerable regional and methodological literature gaps are apparent, the literature in this review identifies a rich and fruitful ground for future research to fill these gaps.

1. Introduction

It has frequently been argued that access to electricity is a crucial prerequisite for socio-economic development [1–4]. In the context of developing countries, it has been shown to be associated with higher literacy rates [2], improved health care [5], enhanced employment opportunities [6] and productivity advancements [7]. Acknowledging electricity's crucial role for combating global poverty more generally, the UN aims to achieve universal energy access by 2030, via its "Sustainable Energy for All" initiative.

While several regions in the world are yet to achieve universal electricity access, the gap in reaching this goal remains most significant in sub-Saharan Africa. According to 2012 World Bank figures, only 15% of its rural and 35% of its total population have access to electricity. Consequently, more than 630 million people in the region are currently un-electrified. In comparison, South Asia, the world region with the second lowest electricity access figures, has a rural electrification rate four times as high as sub-Saharan Africa. Furthermore, the urban bias in electrification measured as a ratio between rural and urban electrification is 3.5 times greater in sub-Saharan Africa than anywhere else in the world [4].

Mandelli et al. (2014), in their well-written comprehensive data and policy review paper on energy in Africa, provide a variety of key insights for successful energy-driven sustainable development in Africa. They conduct in-depth analyses of African energy systems, present primary energy potential data and discuss a variety of different policy options in great detail [8]. Scholars have furthermore agreed that a systematic approach to electricity planning is a *sine qua non* for successful large-scale electrification (see for instance [9–14]). However, despite its salient rural electrification shortage, Rojas-Zerpa and Yusta (2014) suggest that sub-Saharan Africa has received considerably less scholarly attention than South Asia with regards to using modern electricity planning techniques [9]. To date, no academic paper has systematically structured and reviewed the wider African electricity planning literature.

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This paper seeks to fill this gap by reviewing a wide range of quantitative and qualitative literature on electricity planning and related implementation analysis in sub-Saharan Africa. In doing so, it pursues two principal goals. First, the paper aims to support and encourage future research on the topic. It explores relevant electricity planning and/or implementation literature, or the lack thereof, for each of sub-Saharan Africa's 49 countries. In addition, it also reviews the comparative literature featuring more than one country, as well as literature on regional power pools and sub-Saharan Africa as a whole. A systematic approach to literature searching ensures that articles with few previous citations are not overlooked. The paper characterises each article reviewed by using a range of criteria, including: regional scope, temporal development, kind of electricity producing technologies addressed, value chain depth, decision criteria employed, alternatives studied and methodological approaches utilised. Wider trends in the sub-Saharan electricity infrastructure literature are identified, and a number of existing gaps are revealed. A brief overview of the substantial findings in the literature presents crucial success factors for electrification mentioned in the reviewed articles, as well as the extent to which researchers tend to find renewable energy systems (RES) or non-renewable energy systems (non-RES) more promising to address sub-Saharan Africa's electricity needs. As a rich and informative literature on the different methodologies used in energy planning already exists [9–13,15–19], this paper will not review the characteristics of such methodologies per se.

Second, the paper presents a novel classification scheme for the energy planning literature in general in order to improve the structure of discussing energy planning approaches. Review papers on energy or electricity planning have not produced an explicit, widely used framework for characterising energy or electricity planning approaches. Instead, they have tended to focus on purely identifying the methodological concepts used in a given paper rather than actually objectively characterising the employed method. The latter should be independent of how the researchers named their method used. This has led to different, and at times contradictory, ways of classifying the literature [9–13,15,16,18,20]. For example, the concept of mathematical optimisation has been classified as separate from multi-criteria decision making (MCDM) approaches [9,12], compatible with, but distinct from MCDM [13], as one of many possible instances of MCDM [10,15,20], and as one of two types of MCDM [18]. This paper avoids the dangers of producing such conflicting results by classifying energy planning approaches based on mutually exclusive characteristics that can be applied universally beyond single methodological concepts.

Section 2 discusses the review methodology. It first presents a comparably broad definition of electricity planning, which is used throughout this paper. Furthermore, Section 2 details the review approach used in this paper and presents the literature classification scheme which allows a characterisation of energy planning research. Section 3 provides the literature review results. The literature is discussed in terms of regional distribution, temporal development, technological scope, value chain depth, decision criteria, decision alternatives and methods in turn. Recommendations for successful electricity planning in Africa apparent from the reviewed literature are presented in Section 4, while Section 5 offers a conclusion which summarises the key achievements and gaps of the African electricity planning literature.

2. Review methodology and energy planning classification

2.1. Definition of electricity planning

Electricity planning, or more generally, energy planning, has been defined in greatly varying degrees of comprehensiveness. Some scholars have chosen relatively narrow definitions. For example, Hiremath et al. (2007) state that "[t]he energy-planning endeavor involves finding a set of sources and conversion devices so as to meet the energy requirements/demands of all the tasks in an optimal manner. This could occur at centralized or decentralized level" ([14] p. 730). Hence, energy planning is seen as a process directed towards solely finding an optimal, usually cost-minimal, supply mix for a given centralised or decentralised demand. Subsequently, however, the extent of energy planning has been considerably widened. Both Loken (2007) and Rojas-Zerpa and Yusta (2014) have argued that energy planning problems involve multiple decision criteria so that a simple global optimum often does not exist [9,10]. However, both works mirror [14], by mostly focusing energy planning on finding suitable energy supply options. Other scholars have produced yet more encompassing energy planning definitions. In some cases, these have been summarised under the term integrated energy planning. Bhattacharyya (2012), in his review paper on off-grid electricity planning, writes that "a successful implementation … requires a careful planning of all related stages, which goes beyond just the technology choice or component selection decision" ([12] p.690). Other stages along the value chain he deems important for energy planning are obtaining good demand estimates, appropriate energy delivery and adequate implementation mechanisms. Bhattacharyya saliently highlights the importance of ex-post analysis in energy planning to derive valuable lessons learned for future projects. Mirakyan and De Guio (2013) offer a similarly broad definition in their review of integrated energy planning. It again features the multi-criteria nature of energy planning, its applicability at different units of analysis, its spread across different value chain stages including energy generation, transmission, distribution and use, as well as the relevance of ex-post analyses ([13] p. 290). Further work on integrated energy planning corroborates such comparably broad definitions [21].

In order to review African electricity planning as comprehensively as possible, this paper follows a broad definition of electricity planning similar to the integrated energy planning literature. Electricity planning is seen as an integrated approach of analysing an economically, technologically, environmentally, socially and/or politically suitable equilibrium between electricity demand of a given unit of analysis and different available supply options across at least one element of the electrification value chain (see [13]). This definition has comparably broad implications for scale, depth and approach of the electricity planning articles included in this review. First, it is applicable on different scales, ranging from local remote to national and international applications [9,12,14]. Therefore, articles dealing with the electrification of a remote rural village are included in the review, as are analyses of the national electricity infrastructure or the Africa-wide transmission network. Second, following [11–13,21], this paper considers the electricity planning exercise to span different value chain elements. Specifically, it includes studies in the review which address at least one of the 5 value chain stages of obtaining demand estimates, selecting electricity producing technologies, planning operations, designing transmission and distribution of electricity, or ensuring an enabling environment for successful implementation of electrification in an African context. Third, the above definition explicitly includes both ex-ante design exercises of new electricity systems and ex-post analysis of existing systems which derive lessons for electricity planning [12]. Hence, articles which qualitatively assess the past electrification of an African town are included in the review, much like those which use a quantitative approach to design a suitable future supply mix for a given demand. Relevant quantitative methods are single-objective optimisation [9,18,19], MCDM [10–12,15,17,20], life-cycle assessments (LCA) [14] or model simulations [12]. Qualitative research includes evaluations of project implementations [22], non-technical analyses of generation technologies or specific energy policy analyses [8,18,20].

Despite this encompassing definition, specific content limits apply. Articles that solely address energy potentials are not included (see [8] for a review) as they are commonly exogenous to electricity planning. The same applies for strict engineering technology design work such as