Applied Geography 72 (2016) 1–13

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

The benefits of geospatial planning in energy access — A case study on Ethiopia

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ARTICLE INFO

Article history:
Received 10 November 2015
Received in revised form
18 April 2016
Accepted 20 April 2016
Available online 11 May 2016

Keywords:
GIS
Energy planning
Energy access

ABSTRACT

Access to clean and affordable modern energy is crucial to fostering social and economic development and to achieving the Sustainable Development Goals. Efficient policy frameworks and effective electrification programs are required in order to ensure that people are electrified in a sustainable manner. These programs differ from country to country depending on geographic and socioeconomic conditions. Electrification planning process must consider the geographical characteristics of the resources as well as the spatial dimension of social and economic drivers of energy demand in order to find the most optimal energy access solution. Geographical theory and Geographic Information Systems (GIS) in particular can play a significant role in electrification planning, since they are capable of managing the data needed in the decision making process and may integrate and assess all possible options. This paper focuses on considering these characteristics by applying a recently developed GIS based methodology to inform electrification planning and strategies in Ethiopia. The paper illustrates two major aspects of energy planning; 1.) how the optimal electrification mix is influenced by a range of parameters — including population density, existing and planned transmission networks and power plants, economic activities, tariffs for grid-based electricity, technology costs for mini-grid and off-grid systems, and fuel costs for consumers and 2.) how the electrification mix differs from location to location. For a certain level of energy access, on-grid connections would be optimal for the majority of the new connections in Ethiopia; grid extension constitutes the lowest cost option for approximately 93% of the newly electrified population in this modelling effort with 2030 as time horizon. However, there are some remote areas with low population density where a mini-grid (ca. 6%) or a stand-alone solution (ca. 1%) are the most economic options. Depending on local resource availability, these systems deploy varied combinations of solar, wind, hydro and diesel technologies.

1. Introduction

Around 18% of the world's population lack access to electricity, the large majority of whom reside in rural regions of developing countries. Providing universal energy access has become a fundamental humanitarian goal, which is vital to ensure economic and social development (IEA, 2014a). Universal access to electricity by 2030 is one of the key goals of the UN Sustainable Energy for All (SE4All) initiative (SE4ALL, 2015). Universal access to sustainable, affordable and reliable energy is highlighted in the 7th Sustainable Development Goal (SDG). Special importance in given to expansion and upgrading of technology to supply energy services to developing countries (UNDESA, 2015a). While the need for increased electrification rates in developing countries is widely recognised in national policies (WHO, 2009; IEA, 2011), there are diverging views on how to achieve those. Development of effective electricity distribution has several geographical dimensions thus giving different outcomes in terms of spatial distribution of development. Energy system evolution is inherently linked to geographical characteristics of an area, such as local resources availability, distance from roads and power infrastructure, economic activities and settlement structures. Commonly, one electrification option, such as grid

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http://dx.doi.org/10.1016/j.apgeog.2016.04.009
0143-6228/

extension, mini-grid or stand-alone connection, is preferred over another for various reasons depending on perspective, background, financial capacity and competence of the implementing body. The spatial organisation of the different options at hand result in different degrees of spatial differentiation thus influencing inequality within and among countries (Balta-Ozkan, Watson, & Mocca, 2015; Nijkamp, 1980). Therefore, energy planning needs to relate not only to the thematic energy related SDG but also consider how energy systems influence inequality within and among countries as outlined in the 10th SDG (UNDESA, 2015a).

Electrification planning and thus the resulting technology choices often depart from an understanding of the spatial structure and distribution of the population and economic activities. These choices are based on as accurate as possible estimation of the societal needs and economic demands versus the costs of electric infrastructure investments. However, existing proxies such as population density prove inadequate to estimate costs at a national level since the latter are motivated by additional geospatial attributes, which are mentioned throughout this study.

The general paucity of reliable energy-related information, socio-economic and geo-referenced data in Africa hampers analysis and planning (Pollet, Staffell, & Adamson, 2016). Access to such information and data is however crucial for assessing, planning, implementing and monitoring basic energy services delivery. The use of ground level geospatial data is quintessential to identify the most effective electrification strategy for universal energy access. However, such geospatial data are often non-inexistent, fragmented, or inconsistent and their use for strategic planning at national levels remains in an early stage.

The integration of energy system models and Geographic Information Systems (GIS) and the development of combined tools is fundamental to better understand the spatio-temporal dynamics of energy planning. This paper applies such a methodology drawing on GIS tools and remote sensing data to fill data gaps in national databases, such as renewable energy resources, actual costs of diesel at the point of consumption, population density linked to energy demand and transmission infrastructure (Mentis et al., 2015).

Ethiopia is chosen as a case study for spatial electrification planning as the country's per capita electricity consumption is among the lowest globally. Ethiopia's current per capita use amounts to 52 kWh – dismal compared to neighbouring Egypt (1743 kW h/cap) or the USA (13,246 kWh/cap) (SE4ALL, 2015). Increasing cost effective and affordable access to electricity and the services it provides is paramount for meeting SDG 7. Also, the local renewable energy potential is significant in size. The wind and solar power potential in the country are noteworthy (IRENA, 2014; Mentis et al., 2015). However, the country is struggling to provide its citizens with access to electricity as it has one of the lowest rates of electricity generation per capita in the world and supply falls short of demand resulting in load shedding, black outs and a reliance on private generators. To illustrate, just over 26% of the country's population has access to electricity (24 million out of 92 million in 2012). In rural areas this figure drops to 10% (IEA, 2014b).

The structure of the paper is as follows: This introduction is followed by a description of the existing applications of GIS tools in energy and electricity planning and renewable energy assessments. The literature review serves to underline the need for a comprehensive geospatial electrification planning approach, which is described in detail in Section 2. That section first lists and describes the datasets needed for such a GIS based electrification assessment. Thereafter, an electrification analysis is carried out using urban and rural energy access targets.[1] Section 3 presents the results of this work. Section 4 discusses the findings of this study and Section 5 wraps up the paper with conclusions regarding next steps and possible enhancements.

1.1. GIS for energy systems and energy planning

Energy system planning is essential in order to match demand and supply, where cost minimization is a primary objective. Moving from centralized electricity generation and costly transmission and distribution, hence expensive to connect the currently unconnected, towards fluctuating, decentralized and cost effective renewable energy production necessitates considerable modifications of energy infrastructure (Resch et al., 2014). Even though local approaches to electrification are inherently motivated by geospatial questions and challenges, the integration of GIS and energy system analysis and planning tools is still in its infancy.

The availability of tools such as GIS and enhanced computing power has facilitated multivariable and multiscale analyses and integration of spatial data to study the impact of geographical issues such as neighborhood effects, clustering and increased and or decreased spatial inequality. Studies of spatial variability in disciplines such as remote sensing (Quattrochi & Goodchild, 1997), landscape ecology (Turner, 1989), geomorphology (Phillips, 1988), hydrology (Blöschl & Sivapalan, 1995), population and economic geography (Archila Bustos, Hall, & Andersson, 2015) have used GIS as a tool for analysis since the 1980s.

In the context of our study there are several recent studies on energy planning and renewable resource assessment, spanning from local (Calvert & Mabee, 2015; Gormally, Whyatt, Timmis, & Pooley, 2012; Miller & Li, 2014; Palaiologou, Kalabokidis, Haralambopoulos, Feidas, & Polatidis, 2011; Quinonez-Varela et al., 2007) national studies (Aydin, Kentel, & Sebnem Duzgun, 2013; Bekele & Tadesse, 2012; Sahai, 2013; Siyal et al., 2015) to regional studies (Archer & Jacobson, 2013; ESMAP, 2015; IRENA, 2014; Mentis et al., 2015; Sørensen & Meibom, 1999) taking the spatial dimension into account. However, these studies do not consider explicitly the spatial effects. Several concepts from geography can be applied within the context of energy planning. Distribution systems for energy have a clearly spatial dimension and can influence regional inequality (Ye & Wei, 2005). The level of regional inequality differs across the spatial scale as discussed by (Turner, 1989). (Wei, 2015) conclude that most studies are conducted on subnational level across administrative units but to a less degree between nations.

In most cases, planning energy distribution systems is essentially reduced to the choice between centralized or de-centralized systems. Centralized distribution systems focus on a structure exploiting economies of scale at large generation and transmission and distribution infrastructure (Künneke, 2008). However, the growing sensitivity to environmental issues, the development of information and communication technologies, as well as the fall in the minimum efficient scale following the introduction of new distributed solutions have been powerful drivers in the transition to decentralized and deregulated systems with a modal split consisting of different solutions (Pollitt, 2008).

According to the literature review, the usage of GIS is mainly focusing on generation of spatial data used as input in scenario development for energy systems. The outcome is helping us to understand how spatial data such as population density, solar reflection, the division between rural and urban settlements influence the optimal solutions to energy access. Our study provides, not only the development of aspects using spatial data to generate

[1] KTH Division of Energy Systems Analysis collaborated with the International Energy Agency in order to contribute to the Africa Energy Outlook, 2014. Current electrification rates and electrification access targets were provided by IEA.