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Electrification planning using Network Planner tool: The case of Ghana

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ABSTRACT

In this study, the Network Planner, a decision support tool for exploring costs of different electrification technology options in un-electrified communities, was used to model costs and other inputs for providing electricity to 2600 un-electrified communities in Ghana within a 10-year planning period. The results show that the cost-optimized option for majority of the un-electrified communities will be grid connection, accounting for more 85% of the total un-electrified communities in each region. The total cost of electrification (which includes initial and recurring) at 100% penetration rate totalled US$ 696 million with a breakdown as follows: US$ 592 million for grid electrification, US$ 47 million for off-grid electrification and US$ 58 million for mini-grid compatible communities. Sensitivity analysis shows that model scenarios with higher electricity demand and higher household penetration rate generally recommend a larger percentage of communities for grid electrification, rather than off-grid or diesel mini-grid. One important aspect of this modelling approach is that it predicts costs for different electricity generation technologies for each of the communities involved and thus gives the planner the freedom to explore the most cost-effective technology based on existing conditions in the community and price trend of electrification inputs during the planning period.

Introduction

One of the significant drivers of socio-economic development of a country is access to electricity (Duer and Christensen, 2010; Kanagawa and Nakata, 2007). Access to electricity contributes to improvements in health delivery, education, environmental sustainability and agricultural development including crop irrigation, agro-processing and preservation of farm produce (Haanyika, 2008; Sokona et al., 2012). Despite this enormous importance, about a quarter of the world's population live without access to electricity. The worst trends in access to electricity are found in sub-Saharan African and South East Asia (Pachauri et al., 2012). Projections by the International Energy Agency (2011) indicate that by 2030, about 49% of the people in sub-Saharan Africa would not have access to electricity. In spite of the electricity access challenges in sub-Saharan Africa, Ghana has made a remarkable progress in its own electricity access rate.

Generally, increasing access to electricity has proven difficult and expensive in sub-Saharan Africa, where population is projected to be growing at a faster rate (Mulder and Tembe, 2008). Due to high the cost of investment into electricity infrastructure, policy makers and planners need tools to develop strategies for lowering the electrification cost in order to meet the economic demand of the region (Loken, 2007). In Ghana, electricity utility agencies mostly focus on the intensification of electricity access to urban and peri-urban areas already covered with existing grid network and rural areas within reasonable distance (not more than 20 km) from the existing electricity grid network. Rural electrification is generally considered to be not cost effective due to factors such as low population density coupled with high dispersion of households, low demand and persistent poverty (Mulder and Tembe, 2008; Zomers, 2001).

Even though electricity from grid extension has proved to be the most favoured approach to rural electrification in Ghana, it may not necessarily be the best option in terms of cost. In many cases off-grid connections act more as a pre-electrification option, with the community continuing to aspire for grid connection because of fixed duration and limited supply of power from off-grid projects (TERI, 2009). Off-grid technologies therefore have a role to play in the context of rural electrification. However, it is important to analyse the factors that should influence the choice of technology so that both can complement each other without competing for the same scarce financial resources.

Generally, the choice of electricity technology in the context of rural electrification is influenced by various actors and factors – prevailing policy and implementing agencies, distributors, service companies, financing institutions and household socio-economics (Reddy and Srinivas, 2009). Even though both grid-connected and stand-alone options have their own advantages and disadvantages, the underlying principle for choice of a particular mode is adopting the least cost

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[2] Author information: The late Prof. Abeeku Brew-Hammond, who co-authored this paper died during the review of this paper. May his soul rest in perfect peace.

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technology options and with minimum maintenance requirements as far as possible (Palit and Chaurey, 2011). The technical feasibility may depend on several factors such as terrain of that location, distance to existing grid, size of loads, and local availability of resources (both fuel and human resources) (Reddy and Srinivas, 2009). If they prove to be the most feasible, solar home systems have the potential to contribute to poverty reduction and support the achievement of some of the Millennium Development Goals (MDGs). However, this contribution can only be accomplished if the systems work reliably for a reasonable period of time (Tillmans and Schweizer-Ries, 2011).

In order to extend electricity to rural and other peri-urban communities that currently lack access to electricity, energy agencies spend substantial time to undertake studies to obtain reasonably accurate estimates of electrification cost for these communities (Mahapatra and Dasappa, 2012; Pinheiro et al., 2011). Therefore, there is the need for planners to develop tools to make rapid assessment of cost-effectiveness of grid expansion and other stand-alone technology options (solar photovoltaic, diesel mini-grid) for electrifying communities. Energy system tools and models are useful, as they depict complicated systems and perform comprehensive calculations and system analyses (Hiremath et al., 2007). The identification of transition pathways between the current situation and future targets can be aided by models and tools able to account, in an integrated manner, for energy demand, energy supply and the transformation chain (Haydt et al., 2011; Tsoutsos et al., 2009). Economically, a more sound way to meet the demand is to apply least cost planning principles (Ramana and Kumar, 2009).

A model adopted in this study, called the Network Planner, is a decision support tool for exploring costs of different electrification technology options in un-electrified communities. The web-accessible model is written in Python, and developed by a team from Modi Research Group, at the Earth Institute in Columbia University, based in New York, USA. The model combines data on electricity demands and costs with population and other socio-economic data to compute detailed demand estimates for all communities in a dataset. Then, the model computes cost projections of three electrification options and proposes the most cost-effective option for electrifying communities within a specified time horizon. This helps planners both to understand costs and time frames for electrification overall, as well as to prioritise areas where grid expansion is a cost-optimized option and where other stand-alone options are preferred. The aim of this paper therefore, is to apply this model to recommend electrification technology options for 2600 un-electrified communities in Ghana and determine the estimated cost of electrification and other inputs (such as length of medium and low voltage lines), for these communities at different penetration rates.

The model incorporates Geographical Information System (GIS) tools to perform spatial processing and analyses. Starting with geospatial and population data, along with several growth and cost parameters, the model algorithmically generates a comprehensive, cost-optimized electricity plan, including a map of the projected grid extension, communities to be served by off-grid technologies, and all related costs. Because the model can generate results at any geographical scale based on the availability of data used in the modelling process, it provides policy makers a tool for planning electrification at the national, regional or local level. The model results can be visualised on a map to show the communities with their recommended electrification technology, along with existing and proposed grid network linking the communities.

Electricity planners today face dynamic and uncertain future technology costs and performance, and therefore it make sense to include alternative scenarios for evaluating technology costs and strategies (Awerbuch, 2005). According to Haynes and Krmenec (1989), a system that is either over- or under-designed will have an effect on the investment cost of electrification. In light of this, sensitivity analysis is considered to play a vital role when it comes to electricity planning. And because the model is scenario-based it allows users to perform sensitivity analysis, helping planners to understand the effects on electrification cost of changing certain factors such as electricity demand, prices and governmental policies.

Model concept and methodology

Data requirement

The data used for modelling the un-electrified communities are grouped into five (5) categories:

(i) Geospatial data — the spatial location of the un-electrified communities and the existing grid network which are needed by the model to compute distances, and therefore costs, to connect communities with MV line;
(ii) Socio-economic data — data on interest rate, economic growth rate and elasticity of electricity demand per year which are needed in estimating the discounted cost and projecting cost in a specified time horizon;
(iii) Demographic data — initial population, population growth rate, and mean household sizes which are needed to project population and household count to the base year, and to project electricity demand at the end of the time horizon;
(iv) Electricity demand — including four facility demand types: household, productive (such as grinding mills, water pumps, welding shops), commercial (shops, market places, industries) and institutional (health, education, public lighting); and
(v) Cost data — both initial and recurring costs (such as fuel, operation and maintenance) of grid electrification and the two stand-alone technologies (diesel mini-grid and solar PV). It is noteworthy that beside these above-mentioned options, any other stand-alone technology option such as wind technology can be used. This model used the two above-mentioned stand-alone electrification options because of the availability of cost and technical data, wide geographic applicability, and the acceptability to communities.[3]

Modelling projected population and its demand data

In this model, residential electricity demand of a location is dependent on a settlement's total population, and increases over time with economic and population growth. Settlements with larger total populations (towns and cities) tend to have higher electricity demand per household than small villages. In the initial step, the user loads data into the model, including the geospatial data (latitude and longitude coordinates) of the communities and the base year population of each. The model projects each settlement's population forward to the final year of the planning time horizon by applying different population growth rates to rural and urban areas based on the user-defined urban threshold (a value of population size below which a community is deemed rural and above which is deemed urban). The model applies the population growth rate every successive year till the planning year, and includes provisions allowing for a community to begin with a rural growth rate and end up with an urban growth rate as its population passes the urban–rural threshold.

With population as the basis, the model uses mean household size and electricity demand per household to compute residential demand, with additional factors accounting for economic growth and the elasticity of electricity demand. The model computes both peak demand (in kW) data and the total electricity demand (in kWh) for each settlement at the end of the specified time horizon.

The model employs two kinds of user-defined curves to model the variation across settlements of different sizes in both the number of

[3] A more detailed description of this process, with examples, can be found on the website http://networkplanner.modilabs.org/docs/.