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The economics of clean energy resource development and grid interconnection in Africa

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ABSTRACT

This paper analyzes the optimal options for supplying electricity to national economies from both domestic and distant energy resources using high voltage lines to transmit the substantial renewable energy resources of Africa. To meet the growing demand, Africa will need to provide 5.2 GW of new generation per year through 2025. This figure represents an increase of 65% from the 2010 level and will assist in connecting more than 11 million new customers per year through the development of a transmission network. The total discounted system cost is approximately 8% of the continent's GDP. Approximately two-thirds of the discounted system cost is associated with new generation, and the remaining one-third is associated with the development of the transmission network. From 2010 to 2025, trade expansion reduces the total system cost by 21% relative to the business as usual (BAU).

1. Introduction

The African continent has experienced a decline in both private and public expenditures in the power sector during the last decade. To address the short-term growth in demand, most countries have chosen to install small but expensive emergency thermal power generation units which are affected by fuel price fluctuations on the world market. Although this strategy may lead to an increase in electrification rates and assist in meeting the Millennium Development Goals (MDGs), it does not resolve the underlying lack of financing, profitability, and cost-effectiveness. The lack of investment in generation, transmission, and distribution is the greatest challenge encountered by electric utilities in this region. Therefore, there is a need for new policies and institutions that can foster new investments in generation and cross-country transmission capacities to produce the energy that is necessary for development.

Even though its energy consumption in general and electricity consumption in particular remains low[1] (approximately 8% of global electricity consumption), Africa possesses immense energy potential [1,2]. The geographic and technical potential for renewable electricity generation are much greater than the current total consumption in Africa. While hydro and geothermal resources are already highly cost-competitive, grid-connected PV and wind power could generate electricity at production costs that are competitive with those of current fossil fuel plants in the long term.[2] Every country in Africa has surplus energy resources; but financing difficulties have prevented the vast majority of countries from being able to exploit their energy potential.

The provision of low-cost electricity will be critical to the industrial development of the continent. Empirical evidence shows that historical electrification has followed an s-shaped curve and thus suggests that a massive investment is necessary to increase household connections (Fig. 1). Therefore, electrification would not differ for the remaining countries in Africa with low grid coverage. The limited amount of available financial resources should be allocated to technological options that will have the greatest effect on both access rates and prices. The uncertainties surrounding increasing and fluctuating crude oil prices lead us to argue that identifying 30–50 of the greatest large-scale utility solar, geothermal, wind, and hydro generation schemes offers a viable and competitive option for investment.

Rather than engaging in a country-by-country planning of generation and transmission, a continent-wide model is developed

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[1] In 2000, only 22.6% of the population in sub-Saharan Africa had access to electricity, compared with 40.8% in Asia, 86.6% in Latin America and 91.1% in the Middle East.

[2] The continent has one of the highest average annual solar radiations; 95% of the daily global sunshine above 6.5 kWh/m^2 falls on Africa during the winter.

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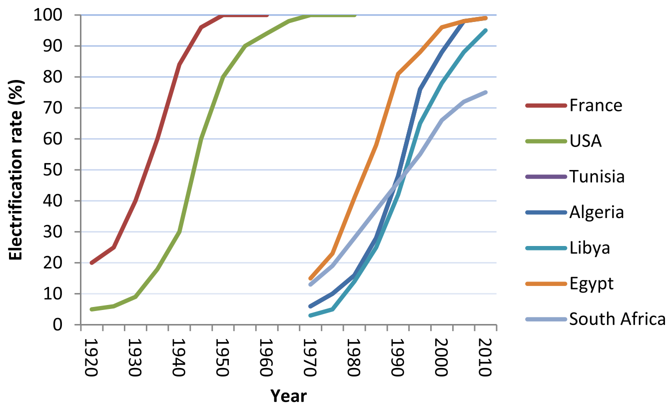

Fig. 1. Historical electrification rates in selected countries.

by considering the dynamic interactions among new projects in different locations. It analyzes electricity integration costs across the continent through 2025. Building on early studies of least-cost electricity access expansion in Kenya, Senegal, and various Millennium Village sites [3–5], the main purpose of this study is to provide necessary and valuable estimates of the least-cost grid expansion strategy for the energy-constrained countries of Africa to determine the extent of possible cost reductions resulting from sourcing less costly electricity sources across neighboring countries.

Numerous studies have analyzed the benefits of regional energy trade in Africa, but few studies have examined cost advantages on a continental scale. For example, Hammons [6] showed that the centralized operation of electric power systems can greatly improve economic efficiencies through economies of scale in hydro exploitation. Bowen et al. [7] found that the centralized and competitive dispatching of the SAPP (Southern African Power Pool) could save US$ 100 million annually. A more recent study by Graeba et al. [8] demonstrated that the benefit from trade expansion in Southern Africa could save US$ 110 million per year (5% of the total system cost) over a period of 20 years. Gnansounou et al. [9] found that a strategy of integrated electricity market in West Africa could reduce total system costs by 38%, which is similar to the 27% reduction that was found in a study that was conducted by Sparrow et al. [10] at Purdue University.

This study differs from its predecessors in the following ways: first, it includes the entire continent of Africa rather than a particular region. Second, it covers renewable expansion alone as well as in combination with fossil fuels attempting to show that clean energy sources have the technical, geographic and economic potential to supply both the short- and long-term energy needs of the continent. Third, it specifically considers the costs that are associated with the intermittency of renewable resources. Fourth, it introduces a more pragmatic approach to modeling demand projection. Fifth, it uses transmission costs, which are a function of both distance and quality of energy sources.

The remainder of this paper is organized as follows. Section 2 develops an electricity demand model that accounts for the specificity of population growth, economic growth, and income elasticity of electricity consumption in African countries. Section 3 explores the economic potential and cost of a renewable electricity supply. In Section 4, transmission costs are evaluated. In Section 5 covers the design of a continent-wide grid expansion based on differences in generation and transmission costs. Finally, discussions and policy implications are provided in Section 6.

2. Demand modeling

Africa produces 7% of the world's total energy, but consumes only 3% of the total at a level of energy intensity that is twice the world average [11]. Within the context of this contradictory situation, the identification of the drivers of aggregate electricity demand is important for forecasting and estimating necessary investments. In the electricity literature [12], several empirical studies have found that the gross domestic product (GDP), actual and relative prices, urbanization, and climate factors are the main drivers of electricity consumption growth. These relationships have been analyzed at the macroeconomic (country-wide, economy-wide, or sectoral) and microeconomic (household and firm) levels. For example, Al-Faris [13] as well as Narayan and Smyth [14] have modeled electricity demand as a function of actual price, the price of a substitute and real income. Nasr et al. [15] modeled electricity demand in Lebanon as a function of GDP proxied by total imports and temperature. Demand studies that have focused on the specific driving effect of GDP alone are reviewed by Jumbe [16] and Chen et al. [17]. In this paper, electricity demand is modeled by considering economic growth, population growth, income elasticity of electricity consumption, and access rate. The foundation of this study is the recognition that demand modeling in Africa suffers from the facts that both supply and demand are typically constrained. The paper uses both an econometric approach to model past income elasticity of electricity consumption and a pragmatic approach to consider projected economic growth, population growth, and electricity access policy goals.

The model begins by projecting demand growth through 2015, 2020 and 2025, as detailed in Appendix A. Then using GIS analysis, the most exploitable sites based on the available potential of hydro, geothermal, solar, and wind energy sources are identified. The 30–50 largest and highest-quality energy resources (hydro, solar, geothermal, and wind) that can resolve the short- and long-term energy supply issue for the continent are selected. Then projected differences in generation costs are computed based on resource quality as characterized by the capacity factor, and follow the computation of transmission costs as a function of the energy source (capacity factor) and the distance to load centers. This calculation is performed using GIS analysis to determine the distance between every potential energy site and demand centers. Finally, the model reveals the most cost-effective way of meeting the projected demand requirement based on various available energy resources and their costs. Other local generation options which are introduced later include thermal sources such as coal, natural gas, diesel and heavy fuel oil. The model links demand points to the least expensive and closest (in terms of transportation) energy resources.

2.1. Income elasticity of electricity consumption

The first exercise examines past trends regarding the relationship between electricity consumption and economic growth for Africa as a whole for the period from 1970 to 2009. For comparison purposes, other large and medium-income countries such as Brazil, China, India, Indonesia and Malaysia whose path of development is likely to be mirrored by Africa are added. Figs. 2a and b present two well-documented and accepted relationships in the energy literature [18]: the positive correlation between growth in per capita electricity consumption and growth in per capita income, and the negative correlation between income elasticity of electricity consumption and per capita income levels. Economic growth is expected to be positively correlated with growth in electricity consumption; however the direction of the causation remains under contention [16].