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Modeling sustainable long-term electricity supply-demand in Africa

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HIGHLIGHTS

- This study is one of the first detailed and complete representation of the African power system.
- It models, within LEAP, possible future paths for the regional power systems.
- All the end-users and supply side activities and actors are considered.
- Three scenarios are examined: the baseline, the renewable energy, and the energy efficiency.
- The energy efficiency scenario has allowed to draw a sustainable pathway for electrification.

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ABSTRACT

This paper develops a scenario-based model to identify and provide an array of electricity demand in Africa, and to derive them from the African power system of development. A system-based approach is performed by applying the scenario methodology developed by Schwartz in the context of the energy-economic modeling platform 'Long-range Energy Alternative Planning'. Four scenarios are investigated. The Business as Usual scenario (BAU) replicates the regional and national Master Plans. The renewable-promotion scenario increases the share of renewable energy in the electricity mix. The demand and supply side efficiency scenarios investigate the impact of energy efficiency measures on the power system. The results show an increase in electricity demand by 4% by 2040, supply shortages and high emissions of Greenhouse Gases. Contrary to expectations, the renewable energy scenario did not emerge as the best solution to a sustainable electrification of the region. The energy efficiency scenarios have allowed us to draw a sustainable pathway for electrification.

1. Introduction

Despite Africa's large energy endowment and the progress achieved in the establishment of Regional Power Pools over the last two decades, the power network in Africa is still underdeveloped with inadequate generation systems, leaving millions of people in Africa without electricity.

Nearly two-thirds of Africans (more than 620 million people) do not have access to electricity (WEO, 2014). And the per capita electricity consumption is very low in the majority of sub-Saharan Africa (SSA) countries, reaching on average only 17 kW-hours (kW h) per year (225 kW h if South Africa is excluded). Moreover, those that do have access are facing high prices for an unreliable supply with frequent power outages. Scheduled blackouts, as well as random power outages, are a daily occurrence in the region. The economic losses due to the power interruptions are estimated to vary annually from 1% to 5% of the GDPs of the countries [1,2]. This energy poverty (i.e., a lack of access to modern energy services or access to unreliable energy sources) is believed to hinder economic growth in African economies [3,4].

This situation is expected to get worse as population, urbanisation, and income are projected to rise, driving up electricity demand that is predicted to increase significantly in the coming years. This will put a future strain on the currently insufficient generating capacity and poor regional and national power infrastructure.

Therefore, there is an urgent need to raise and improve the capacity of the power sector in Africa. Power systems planning, which consists of ensuring that energy-related policy and investment decisions consider all possible power supply and demand side options, is critical. That will help improve power generation, anticipate and respond to the increase in energy demand for sustainable development in Africa.

A prerequisite to power systems planning is an electricity demand forecast, which is the prediction of demand for power in the future. Forecasting is an important component of power

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system management. Precise forecasting helps the electric power companies make unit commitment decisions, reduce the spinning reserve capacity, and properly schedule device maintenance plans [5]. It also reduces the generation cost and increases the reliability of the power system.

Rigorous demand forecasting is crucial in developing countries with low rates of electrification in order to support effective development of the power systems. Sound predictions of demands and demand trends in a highly uncertain environment is more than ever needed to convince outside investors (e.g., private sector, bi- and multilateral investors, project shareholders, etc.) [6]. Long-term planning is necessary to support optimal allocations of the investments in developing countries.

Nevertheless, there are currently several obstacles to producing such studies for developing countries, including SSA countries. Besides data paucity and quality, particularly regarding renewable resources data, and a shortage of expertise [1,2,7], the analysis methods and the tools used are not always appropriated to the respective regions, including their policies, and investment questions.

Indeed, energy forecasting models in developing countries are derived from those of industrialised countries. Consequently, it is assumed that the energy systems of developing regions will behave like those of developed regions and that they will follow the historic development trajectories of developed countries [8]. However, the developing countries have their own characteristics which differ from those of developed countries and extrapolate the energy modeling technique of these later to low-income countries may result in biased models and inadequate modeling of the energy systems of developing countries [9].

Overall, the existing modeling frameworks give a partial view of the energy systems in Africa and the related issues they are facing and result in fragmented results and figures, making their understating as complementary pieces of information by policy-makers difficult [7].

For better planning objectives, there is, thus, a need for developing new or improved existing energy models which will adequately address the characteristics of African countries' energy systems and economies.

This study develops a scenario-based model to quantitatively analyse the current status of power generation and predict the composition of the future generation profile, and the associated global warming potential. The energy-economic Modeling platform 'Long-range Energy Alternative Planning', which emerged as the most suitable energy Modeling framework for developing countries, is applied to analyse the regional power systems expansion and explore different potential scenarios to achieve universal access to electricity, as well as their associated greenhouse gas emissions. These scenarios include the deployment of renewable energies and demand and supply side energy-efficiency policies. Contrary to the existing literature, a detailed representation of the African power system is proposed. All the end-users and supply side activities and actors are considered.

To the best of our knowledge, this study is one of the first detailed and complete models of the African regional electricity systems.

The remainder of the paper is as follows: Section 2 presents the literature review on the long term electricity forecasting. The power sector of Africa is described in Section 3. The empirical methodology and the source of data are described in Section 4. The results are discussed in Section 5 and, Section 6 concludes the discussion.

2. Literature review

The need for accurate and efficient power system planning, as well as for handling the increasing complexity and number of parameters that influence the trends of electricity demand [10] has led to the evolution and development of forecasting methods over the last few decades. Today, a diverse array of energy models employing a variety of different techniques, which have been used to analyse a wide range of issues, exists[1].

Table 1 displays the main long term global energy models existing today. Tables A1 and A2 in the Appendix display a description and a classification of energy systems models as well as their options, purpose and structure[2].Table A3

Primarily built and used in the developed countries, some of these models, however, have been applied to assess the energy systems in developing countries, including SSA countries. Nevertheless, energy systems of the developing world present different characteristics from those of the industrialised world that, many forecasting models biased towards the latter, fail to adequately address [9]. These characteristics include the informal economy, supply shortages, poor performance of the power sector, structural economic change, low electrification rate, high share of traditional biomass, and rural households.

By analysing the number of main characteristics of developing countries addressed per model Urban et al. [9] showed that, among the above cited-methods, LEAP, MESSAGE, and WEM are those which address a large number of developing countries' characteristics.[3]

Among these three models, LEAP has been selected as the preferred framework to elaborate upon scenarios regarding the development of the African power system for different reasons.

First for all, while the World Energy Model (WEM) of the International Energy Agency (IEA) is a simulation model covering energy demand, energy transformation, and energy supply, including the majority of the end-use sectors and energy-related CO_2 emissions, the model is a "black box" that is not available for public use.

Secondly, MESSAGE is an optimisation model used to optimise energy investment decisions by finding the best solutions; that means that investment and operating cost data are of prime importance in this model. However, such data availability, within the context of African countries, is sparse. Moreover, optimisation models assume the existence of optimal consumer behavior and perfect markets; market imperfections and obstacles as in Africa's context are not considered, resulting in improbably low projections of energy demand [12–14].

In contrast to optimisation models, such as MESSAGE, that provide an image of what would be an optimal trajectory, the Long Range Energy Alternative Planning System (LEAP) model is an integrated assessment tool that can be used to represent plausible future trajectories. It allows for the track of energy resource extraction, production and consumption, in all sectors of an economy as well as for the simulation and assessment of the impacts of alternative energy policies on energy systems. It can also be used to track energy sector and non-energy sector GHG and local pollutants emissions [15]. Therefore, LEAP can be used to compare alternative electricity generation systems over the medium to long-term in order to enable economic and environmental impact analysis [16].

[1] It should be noted that, if model, tool and Modeling framework are used interchangeably throughout the literature, these are, in a strict sense, different. An energy model is a simplified representation of a specific energy system, and a tool or Modeling framework model refers to the computer programme used to create the different models [11].

[2] For complete reviews of the energy system models, tools and Modeling frameworks refer to Urban et al. [9] and Bhattacharyya and Timilsina (2010).

[3] The RETScreen has also been identified by [9], as one of the models, addressing a large number of developing countries characteristics. However, Retscreen is a local, technology-specific tool, used to assess and optimise the technical feasibility and financial viability of potential clean energy projects (Retscreen, http://www.nrcan.gc.ca).