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Review

An indicative analysis of investment opportunities in the African electricity supply sector — Using TEMBA (The Electricity Model Base for Africa)

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ABSTRACT

Africa is a resource-rich continent but lacks the required power infrastructure. Efforts such as the United Nations Sustainable Energy for All and U.S. President Obama's Power Africa initiatives aim to facilitate much needed investment. However, no systematic national and regional investment outlook is available to analysts. This paper examines indicative scenarios of power plant investments based on potential for electricity trade. OSeMOSYS, a cost-optimization tool for long-term energy planning, is used to develop least cost system configurations. The electricity supply systems of forty-seven countries are modelled individually and linked via trade links to form TEMBA (The Electricity Model Base for Africa). A scenario comparison up to 2040 shows that an enhanced grid network can alter Africa's generation mix and reduce electricity generation cost. The insights have important investment, trade and policy implications, as specific projects can be identified as of major significance, and thus receive political support and funding.

Contents

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Introduction

Access to modern energy services is extremely low in a number of African countries, particularly in Sub-Saharan Africa. National electrification rates vary greatly from country to country; for instance, this figure is at 85% in South Africa, while it only reaches 3% and 4% in Central African Republic and Chad respectively. Even within countries, there is great disparity between urban and rural communities; electrification rate in Cameroon ranges from 88% for urban and 17% for rural communities. At the same time, demand of electricity on the whole continent is projected to grow from 385 TWh in 2012 to about 1250 TWh in 2030 and 1870 TWh in 2040. This corresponds to an average annual growth rate of 4.6% in Sub-Saharan Africa, while it reaches 7.6% and 7.1% in East and West Africa respectively (IEA, 2014).

The electricity supply sector in Africa faces two major challenges; (a) to improve access rates and (b) to cope with the rapidly increasing demand for electricity. Extensive investments in generation, transmission, and distribution are needed to address these two challenges. There are a large number of publications that examine the issue of the underdeveloped African power sector. Some provide an overview of the current status of the system and recognize the problem (Eberhard et al., 2008), others argue for action and call for the necessary investments (Eberhard et al., 2011; Foster and Briceño-Garmendia, 2010), while others focus on the required measures and investigate scenarios that will enable universal access to modern energy services (Bazilian et al., 2012; Brew-Hammond, 2010). Relevant to this latter point, a comprehensive review of African energy policies pertaining to sustainable energy development has been conducted to examine whether existing policy making is heading in the right direction (Mandelli et al., 2014). Long-term explorative scenarios have been used by the World Energy Council to conclude that besides introduction of appropriate energy policies, an environment that can attract internal and external capital and innovation is important (Panos et al., 2015). The International Renewable Energy Agency argues that renewable energy integration can reduce the continent's generation cost (IRENA, 2012), while smart-grids are also suggested as way of leapfrogging traditional power system design and accelerating the achievement of electrification targets (Welsch et al., 2013).

The United Nation's Sustainable Energy for All and U.S. President Obama's Power Africa Initiatives offer important impetus. The former has the goals of increasing energy access, improving energy efficiency and doubling Renewable Energy Technology (RET) investment (SE4All, 2015). The latter has similar goals. It focuses explicitly on Africa. It aims to electrify some 60 million homes and support the investment of 30 GW of clean power generation (Power Africa | U.S. Agency for International Development, 2015). As of yet, however, there is no coherent 'by country' and 'by region' set of investment scenarios, nor an open long-term energy planning toolkit that may be used to investigate detailed scenarios.

The purpose of this paper is to examine the potential for and relationship between electricity investments and power trade between countries in Africa, making use of a higher geographical resolution than what has been developed previously (Taliotis et al., 2014a). An open source long-term cost-optimization tool is used to estimate the most economic generation technology mix on a national scale. Two key scenarios, in which the transmission system is either limited to existing and committed projects or expanded, allow the identification of countries with the greatest export potential, as well as those with the largest expected demand for cost-competitive electricity. Beyond the substantial fossil fuel reserves present in specific regions of the continent, there is considerable renewable energy potential (IRENA, 2014), which largely remains unexploited due, in part, to the lack of required infrastructure. This paper identifies areas where extensions would be required in the grid network, so as to unlock part of this potential, thus leading to a cost-optimal growth of the African electricity supply system. Despite the potential for electricity exports from North Africa to Europe (Trieb et al., 2012), the paper's scope does not consider this aspect and only focuses on intra-continental electricity exchanges.

Methodology section of the paper briefly presents the methodology and the adopted model structure. The main results from the selected scenarios are presented in Results and discussion section, where there is also a discussion on the main energy-planning insights offered by the analysis. The paper concludes with a summary of the key outcomes in Conclusions and suggests future steps and model enhancements to build on existing research efforts.

Methodology

The work presented in this paper builds on previous efforts in terms of research scope and model structure (Taliotis et al., 2014a). The following sub-sections describe the methodology followed to develop and apply TEMBA, a model of the African electricity system. The methodology includes details on the model structure, the modelling tool used, and the key assumptions. Further, the model from source code to data is open source to ensure repeatability and access.

OSeMOSYS

The model discussed in this paper, TEMBA, is developed using the Open Source energy MOdelling SYstem (OSeMOSYS) (Howells et al., 2011). OSeMOSYS is a dynamic, bottom-up, multi-year energy system model applying linear optimization techniques. It determines the optimal investment strategy and production mix of technologies and fuels required to satisfy an exogenously defined energy demand. While this is a simplification in the model in that it does not consider demand side management or energy efficiency measures, the aim of the model is to show the cost-optimum supply profile for a specified volume of electricity. Alternative demand scenarios can then be investigated so as to address this issue; this is a planned task for future enhancements of the present study. Technical, economic and environmental implications associated with the identified least-cost energy systems can be easily extracted from the model results. Like other optimisation models, OSeMOSYS assumes a perfect market with perfect competition and foresight. OSeMOSYS has been used to investigate climate resilience of proposed power infrastructure on the African continent (Cervigni et al., 2015), and thus its functionality has been tested in large models in the past.

Model structure

Similar to the model used by Taliotis et al. (2014a), the model structure developed in this paper consists of demand projections and a database of power supply technologies that are characterised by economic, technical and environmental parameters, and information regarding the existing capital stock and its remaining life span. Energy resource prices and quantities are defined by the model user. Furthermore, the model is restricted by so-called "constraints" used to reflect, amongst others, operational requirements, governmental policies, or socio-economic realities. All parameters entered in the modelling framework are time dependent and can be adjusted over the study horizon to represent a variety of potential futures.

Once the country level values have been derived, other past and projected national statistics – including population share between urban and rural populations, electrification rates, share of industrial activity in total GDP, market penetration of certain key technologies and their corresponding energy intensities on a household basis – can be used to split the country level value into the three components under review in this study:

- Heavy industry (e.g. mining), which connects to generation at a high voltage level and generally requires less transmission and no distribution infrastructure;
- Urban residential, commercial, and small industries, which are connected to generation via a more extensive transmission and distribution system with associated higher losses;