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Africa energy future: Alternative scenarios and their implications for sustainable development strategies

Nadia S. Ouedraogo

UN - Economic Commission for Africa (UNECA), Avenue Menelik II, P.O. Box 3001, Addis Ababa, Ethiopia

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ABSTRACT

The long-term forecasting of energy supply and demand is of prime importance in Africa due to the steady increase in energy requirements, the non-availability of sufficient resources, the high dependence on fossil-fuels to meet these requirements, and the global concerns over the energy-induced environmental issues. This paper is concerned with modelling possible future paths for Africa's energy future and the related emissions. Future energy demand is forecasted based on socio-economic variables such as gross domestic product, income per capita, population, and urbanisation.

The Long-range Energy Alternative Planning System (LEAP) modelling framework is employed to analyse and project energy demand and the related emissions under alternative strategies for the period of 2010–2040. Results of scenarios including business-as-usual (BAU) policies, moderate energy access and accelerate energy access policies, renewable energies promotion and energy efficiency policies and their environmental implications are provided.

The study provides some policy insights and identifies synergies and trade-offs relating to the potential for energy policies to promote universal energy access, enable a transition to renewable energy, and mitigate climate change for ~~a~~ sustainable development.

1. Introduction

Since 2000, Africa has been experiencing economic growth and energy consumption has risen by 45% (AIE, 2014). However, the regional energy systems are under-developed and unable to meet the populations' demand. Indeed, despite the fact that energy resources are more than sufficient to meet domestic needs, access to modern energy services remains limited. Over 620 million people, almost two-thirds of Africans, do not have access to electricity and nearly 730 million rely on traditional solid biomass for cooking. Those that do have access rely on a very expensive, low-quality supply (AIE, 2014).

Meeting the growing energy demand of their population and ensuring universal access to modern energy services with respect to the environment are, thus, the principal goals of African countries.

To that end, energy management strategies that will ensure that any energy supply-demand related policies and investment decisions will consider all feasible demand- and supply-side options, and are consistent with global goals of sustainability are vital (Bazilian et al., 2012). Energy demand modelling that will predict the future of energy consumption patterns and trends is a crucial component of energy management. It allows for strategy formulation and energy policy recommendations for efficient management, in addition to the effective utilisation of energy resources, improvements in energy efficiency and energy reliability, and emissions reductions (Charles River Associates for the World Bank, 2005).

Energy models have been widely developed following the first oil crisis in the 1970s. The early energy supply models were focused on only one facet of the problem, meaning either on energy supply security, costs, or environmental impacts of energy consumption and production. Moreover, the energy supply models were considering only one energy sector or one energy system or form. Furthermore, the energy demand models were developed based on econometric methods and theories, and demand is projected thanks to macroeconomic indicators, such as GDP and population growth projections. More recently, a great number of energy models and modelling frameworks and tools has been developed, which consider all energy consumption sectors and energy systems, but also environmental related issues.

In general, energy models can be classified based on an analytical approach (i.e., top-down and bottom-up), purpose of the analysis (i.e., forecasting, exploring or scenarios analysis, and backcasting), the underlying methodology (i.e., econometrics, macro-economics, economic equilibrium, optimisation, simulation, spreadsheet, backcasting, and multi-criteria methodologies), the mathematical approach (i.e., linear programming, mixed integer programming, and dynamic pro-

E-mail addresses: Nouedraogo@uneca.org, Ouedraogo.s.nadia@gmail.com.

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gramming), the data requirements (i.e., qualitative and quantitative, desegregate and aggregate), the time horizon (i.e., short, medium, and long term), and the geographical coverage (i.e., local, national, regional, and global) (Van beeck, 2003; Nakata, 2011).

Regarding the modelling framework or tools existing for long-term energy forecasting, they can be divided into seven major categories, including simulation (e.g., RAMSES, BALMOREL, LEAP, WASP, etc.), scenario (e.g., MARKAL/TIMES, MESSAGE, LEAP, etc.), equilibrium (e.g., MARKAL, PRIMES, etc.), top-down (ENPEP-BALANCE, LEAP, etc.), bottom-up (HOMER, RAMSES, MARKAL/TIMES, MESSAGE, etc.), operation optimisation (BALMOREL, MESSAGE, RAMSES, etc.), and investment optimisation tools (MESSAGE, MARKAL/TIMES, RETScreen, etc).

These models are increasingly being used to provide insights into how energy systems can evolve in the future. They have, thus, become very widespread and it is, in practise, more and more difficult to classify any particular model into a specific category or categorise any modelling framework or tool as performing a specific task.

These different modelling methodologies have been extensively used to analyse energy demand, policy, and planning concerns in industrialised countries. The most recent literature on primary energy access forecasting in developed countries includes, among others, Adams and Shachmurove (2008), Baker and Rylatt, 2008, Dimitropoulos et al. (2005), Ediger and Tathdil, 2002, Edigera and Akarb (2007), Ekonomou (2010), Hunt et al. (2000), Hunt and Ninomiya (2003), Hunt et al. (2003a, 2003b), Hashim et al. (2005), Koltsaklis et al. (2013), Mackay and Probert, 2001, O′Neill and Desai, 2005, Papagiannis et al. (2008).[1]

Some of these approaches have been applied for investigating similar policy and planning concerns in developing economies. However, developing countries possess some common characteristics that make the modelling and forecast of their energy systems challenging (Urban et al., 2007, Bhattacharyya and Timilsina, 2009). The high reliance on traditional energies and the existence of large informal sectors pose challenges to the modelling exercise in developing countries. Indeed, data on prices and supply for traditional energy demand, as well as those on informal sectors, are not always available. Inefficient energy sectors, characterised by poor performance of power sector and by supply shortages, energy poverty, and inequity in energy access, and a rapid increase in demand for electricity are additional challenges to energy forecasting in developing countries. In addition, the energy sectors of these countries are facing economic and social barriers to capital flow and technology diffusion, in conjunction to frequent energy policy changes (Pandey, 2002; Urban et al., 2007; Bhattacharyya and Timilsina, 2009). These factors differentiate the energy systems of developing countries from those of the developed countries and make the modelling and forecast exercise in the developing world challenging.

Traditionally, most developing countries have been using end-use approaches for energy demand modelling. Top-down approaches have been used for assessing economy-wide responses to policies and other driving variables through the end-use behaviour and historical macroeconomic variables, such as income or income per capita, population, etc. Bottom–up optimisation energy models have been used for determining the least-cost technology-mix and for assessing cost and emission implications of different technology-mix scenarios (Pandey, 2002). Nevertheless, such models are limited in their policy prescriptions, because they sometime fail to incorporate the main characteristics of developing countries' energy systems and economies.

In the specific case of Africa, the lack of data has led to very sparse literature on energy demand modelling. Most of the existing studies on Africa are focused on electricity demand for which data are available. These forecasting exercises, both in terms of power generation capacity, capacity expansion, and demand, include Gnansounou et al. (2007), Rosnes and Vennemo (2012), Bazilian et al. (2012), Pachauri et al. (2012), Taliotis et al. (2014a, 2014b), Panos et al. (2015, 2016), Taliotis et al. (2016), Ouedraogo (2017). In addition, the African subregions have carried out regional forecasting for electricity demand (Nexant, 2004; The African Development Bank, 2008; Nexant, 2009; SNC Lavalin and Parsons Bricherhoff, 2011; PIDA, 2010; IRENA, 2015).

Only a few studies on total energy demand modelling within the context of Africa exist. These studies include Howells et al. (2005) that employed a bottom-up framework TIMES model, an extension of the MARKAL energy modelling system, to project rural energy consumption in South Africa through 2018. They found, for the reference scenario, a total energy consumption that will have increased from 7 Tera joules in 2003 to 7.8 Tera joules in 2018.

Riahi et al. (2011) developed global energy scenarios within the MESSAGE model to assess universal energy access in the most energy poor regions, including Africa. They found that final energy demand per capita will stand at around 10 gigajoules (Gj) in 2030.

Chakravarty and Tavoni, (2013) used the IEA World Energy Outlook projections method to assess the quantity of individual energy consumption by 2030. They found for Africa, an aggregate final household energy consumption of 9.5 exajoules (EJ) in a business as usual (BAU) case in 2030. However, they concluded that an additional 9.7 EJ would be necessary to eradicate energy poverty in Africa.

Nevertheless, while this is challenging for developing country modellers, developing sound forecasting methods that will better reflect energy demand in African countries' context and delivering more reliable input to policy formulation are important for policy makers. An appropriate allocation of the available resources, thanks to proper energy management and energy planning policies, is crucial for economic development and environmental security in Africa. The provision of reliable, clean, and affordable energy to those who currently do not have access to such energy is vital for the development of Africa, which accounts for 13% of the world's population, but only 4% of the world's total energy consumption.

The purpose of the present study is to bridge the gap existing in the literature of energy demand forecasting, at least partially, by forecasting the total energy demand for African countries for a long-term period and to simulate alternative energy futures, along with environmental emissions, under a range of user-defined assumptions.

The remainder of this paper is organised as follows: Section 2 briefly reviews the related literature and discusses various approaches for energy planning and demand projections. In Section 3, a concise overview of energy sector systems in Africa is presented. Section 4 presents the modelling scenarios and related data. Section 5 presents and discusses in detail the results of the modelling work. Finally, Section 6 concludes.

2. Overview of energy sector in Africa

2.1. Energy access in Africa: a reflection of the economic situation

As for 2014, primary energy demand in Africa was 752 million tonnes of oil equivalent (Mtoe), of which North Africa accounted for 20%. In sub-Saharan Africa (SSA), energy demand has increased by 50% since 2000, reaching 590 Mtoe in 2014 (AIE, 2014). However, SSA countries still account for only 4% of the world's energy demand. With only a quarter of the population, South Africa (141 Mtoe) and Nigeria (133 Mtoe) are the region's largest energy consumers, accounting together for more than 40% of the total demand (AIE, 2014). The average energy consumption per capita in Africa is only one-third of the global average and just 50% of the level of Southeast Asia, the second most energy-poor region in the world (AIE, 2014). The averages mask large differences in per-capita consumption across SSA and

[1] For more discussion on energy demand modelling, please refer to Jebaraj and Iniyan, (2006), Urban et al. (2007) and Bhattacharyya and Timilsina (2010).