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Powering the growth of Sub-Saharan Africa: The Jazz and Symphony scenarios of World Energy Council

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ABSTRACT

The energy sector of Sub-Saharan Africa today faces major challenges with total installed electricity generation capacity less than 100 GW and 590 million people lacking access to electricity. We analyse two long-term explorative scenarios, developed together with the World Energy Council, to assess the policy and technology mixes required to achieve long-term energy equity, energy security and environmental sustainability in the region. We find that more than $55 billion in investments is required in power infrastructure annually until 2050. Access to electricity increases from 31% of the population in 2010 to more than 80% in 2050, but the region remains well behind than the rest of the world. The analysis suggests that a one-size-fits-all solution does not exist: the policy makers need not only to address the design and implementation of suitable energy policies, but also to create an investment climate to mobilise domestic and foreign capital and innovation.

Introduction

The lack of access to a reliable electricity supply stifles income-generating activities and hampers the provision of basic services such as health and education. Especially in Sub-Saharan Africa (SSA), limited electricity access is one of the biggest barriers to development and prosperity, with nearly 590 million people out of a total population of 860 million lacking access to electricity[4] in 2010 (IEA, 2013a); this is almost twice the total population of the USA. Viewed another way, the entire installed electricity generation capacity in Sub-Saharan Africa is 91 GW — no more than that of the UK— and one quarter of this capacity is unavailable because of age and poor maintenance. As a result, at least 30 countries in the region experience chronic power shortages. A key concern is thus how to power SSA's economic and social development along three key dimensions of energy sustainability: energy security, energy equity and environmental sustainability. The World Energy Council (WEC) refers to these three dimensions as the energy trilemma (WEC, 2013).

Together with WEC, we have developed two energy scenarios to 2050 assessing the energy trilemma at global and regional scales (Frei et al., 2013). The scenarios were built through a number of workshops with key energy stakeholders around the world and they incorporate a coherent set of economic, social and political key drivers, which were quantified and implemented with a detailed energy system model. The two scenarios are exploratory,[5] in that no specific targets were set along the axes of the energy trilemma. The first scenario ("Jazz") is market-facilitated with a focus on achieving economic growth through competitive and low-cost energy. The second scenario ("Symphony") considers stronger policy regulations with priority given to sustainability and energy security. Both scenarios include climate change policies and recent technological advances.

Under the two sets of scenario assumptions, we have quantified long-term cost-effective configurations of SSA's energy system. To forecast the population with access to electricity we have also developed a

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[4] Based on IEA definition, electricity access is first electricity supply connection to the household and then an increasing level of electricity consumption over time to reach the regional average (IEA, 2011b).

[5] Exploratory scenarios (also known as descriptive scenarios) are those that begin in the present and explore trends into the future. By contrast, normative (or prescriptive or anticipatory) scenarios start with a prescribed vision of the future (optimistic, pessimistic or neutral) and then work backwards in time to visualise how this future could emerge (Alcamo, 2001).

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reduced-form econometric model[6] that takes into account key socio-economic factors affecting the electricity access. This model constitutes also a contribution to the current research on electrification in developing countries.

As summarised in Nanka-Bruce (2010) the majority of the research on electrification in developing countries considers: i) the evaluation of electrification project/programmes (Davidson and Mwakasonda, 2004; GNESD, 2004; Goldemberg et al., 2004; Karekezi and Kimani, 2004; Nouni et al., 2008; Zhong Ying et al., 2006), ii) the progress of electrification projects (GNESD, 2004), iii) the assessment of relations between electrification, poverty reduction and economic development (Winkler et al., 2011; Oseni, 2012; Kooijman-van Dijk and Clancy, 2010; Shiu and Lam, 2004; Yang, 2003; GNESD, 2004) and iv) energy demand modelling describing the relationship between electricity consumption and socio-economic factors (Bhattacharyya and Timilsina, 2009; Kanagawa and Nakata, 2008). To the best of our knowledge there are three studies to date, which have analysed factors influencing electricity access using an econometric approach. One is by Kemmler (2007) and examines the factors influencing household electrification in India, showing that it depends on household characteristics, the electricity tariff and the quality of electricity supply. The second one is by Nanka-Bruce (2010), which analysed the impact of socio-economic factors on rural electrification development. The results indicate that the Human Development Index, the distribution of wealth, the level of institutional development and the urbanisation rate of the population play significant role in the rural population electrification rate. In the third study (Onyeji et al., 2012) the determinants of electricity access in SSA are analysed. The study suggests that the share of poor in population, gross domestic saving rates, corruption, urbanisation and government effectiveness are explaining over 90% of the variation of electricity access levels across emerging countries. However, none of the above studies attempts projections of the electricity access in the longer term and we contribute to the existing literature by developing a tool that is suitable for such projections.

In this paper we provide detailed numerical results for SSA from the two World Energy Council's global scenarios, which have not been published in WEC's special report (Frei et al., 2013). We discuss the energy supply options for the region and their implications in terms of energy access, investment needs, environmental sustainability and energy security. The results help to identify the future energy challenges in Sub-Saharan Africa.

We also provide the scientific background of the study by describing the two models used in it. Additional details about the structure of the econometric model for estimating the electricity access are given in the Appendix for the interested reader. It is worthy to note that the methodology followed in constructing the econometric model is generic enough to be applied also to other developing regions and countries. The interface that links the econometric model to a large scale energy system model is also generic, which allows the use of the model with a wide range of global or regional energy system models.

Thus, the paper contributes both to the literature about the future energy challenges in Sub-Saharan Africa and to the available methodologies and tools for estimating the population with electricity access in developing regions.

The modelling framework

As mentioned in the introduction two models were used in this study (Fig. 1). The first model is the Global Multiregional MARKAL (GMM) model (Densing et al., 2012; Gül et al., 2009; Krzyzanowski et al., 2008; Rafaj and Kypreos, 2007; Rafaj et al., 2006, 2005; Barreto, 2001), belonging to the family of MARKAL models (Loulou et al., 2004). The GMM model was used in assessing the development of the whole energy system. The second model is a reduced-form econometric model that estimates the population with access to electricity given the economic and demographic assumptions from the scenarios and the output from GMM on the electricity consumption per capita and the level of electrification of demand.

As shown in Fig. 1 the two models are sharing common assumptions regarding the GDP and population projections. The link between the two models is established on the average electricity consumption per capita in the residential sector and the percentage of electrification of the residential demand. When assessing exploratory scenarios the GMM model provides the electricity consumption and the electrification rate of demand to the econometric model and the latter forecasts the population with access to electricity. When assessing normative scenarios, in which specific population electrification rates should be met, the link between the two models is reversed: the average electricity consumption per capita and the electrification rate of demand required to attain the imposed target are calculated from the econometric model and then the updated electricity demands are given to the GMM model as inputs. In this setting, the GMM model finds the cost-optimal configuration of the energy system (technology mix, investments) need to achieve the imposed electrification targets. The two scenarios examined in the present study are exploratory in their nature. Thus, the GMM model is driving the econometric model, by providing to the latter the average electricity consumption per capita and the electrification rate of the residential demand.

In the next sub-sections the two models are described in more details, with emphasis on the design of the new econometric model developed specifically for this study.

The GMM model

The GMM model is a perfect-foresight, bottom-up, technology rich model. It computes an intertemporal partial equilibrium across all energy markets under policy and technical constraints by minimising the total energy system cost (Fig. 2). Equilibrium is established at every stage of the energy system: that is, for primary energy and secondary energy commodities and energy services. The time horizon of the model covers the period 2010 to 2100, with a step length of 10 years. In each period a simplified seasonal and day/night disaggregation is incorporated to account for supply and demand variations.

The spatial resolution of GMM consists of 15 world regions, with Sub-Saharan Africa represented as a single region (Fig. 3). The energy system in each region is represented in detail, from resource extraction to final consumption, using the concept of the "Reference Energy System" (Fig. 4). GMM includes more than 400 technologies from resource extraction to final energy consumption, with the capability of modelling endogenous technology dynamics based on the concept of learning-by-experience (Loulou et al., 2004). The fossil resources in each region are categorised by different extraction costs and by probability of existence: ranging from easily extractable, proven reserves, through more cost-intensive reserves or speculative resources, to unconventional resources (Turton et al., 2013; BGR, 2012; GEA, 2012). Trade of energy carriers across regions is subject to transportation costs.

The energy demand sectors represented in GMM are industry, residential/commercial, transport and non-energy uses. The industry and residential/commercial sector energy demands are disaggregated to thermal and specific uses. Transport includes subsectors for private passenger transport, aviation and other surface transport. The energy demand technology options operate at the level of energy uses. The useful energy demands are derived from the scenario assumptions based on a coherent storyline. The GMM model supplies the useful

[6] An econometric model is in a reduced-form when it has been rearranged algebraically so that each endogenous variable is on the left side of one equation, and only predetermined variables (exogenous variables and lagged endogenous variables) are on the right side.