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Electricity supply and demand scenarios for the Southern African power pool

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ABSTRACT

The study presents long-term electricity supply and demand scenarios for the twelve countries in the Southern African Power Pool, based on detailed bottom-up demand analysis for all countries and a set of internally consistent development scenarios. Total regional electricity demand and supply increase by eight to fourteen times from 2010 to 2070, with major shifts in both the sectoral composition of demand and the geography of demand, with South Africa becoming a much smaller share. On the supply side, the fuel mix shifts from coal and toward hydro in the medium term, but towards other renewables, such as solar, in the longer term, particularly in the scenarios with the fastest decline in capital costs for renewables. This leads to declining unit carbon dioxide emissions in the more aggressive scenarios, even though total power sector emissions still increase. The unit cost of generation for the entire region is stable across all scenarios. The potential transformation of the supply sector would require a fundamental shift in resource use, grid management and infrastructure development in the region, as well as greater regional integration. This also implies significant institutional capacity development in the SAPP Coordination Centre or similar structures for cooperative management of resources.

1. Introduction

The southern African region has experienced sustained economic growth and increasing prosperity over the past decade, driven largely by increasing demand for natural resource-based commodities and facilitated by increased peace and stability. As the Southern African Development Community (SADC) region industrialises on its path to improved human development, the demand for power is increasing dramatically. As a result, the electricity sector is a key component of the infrastructure that drives both regional integration and economic growth, with energy security being increasingly important to continued development across southern Africa (AU, 2012; Eberhard et al., 2011). At the same time, the chronic power shortages in the region in recent years has hampered short-term economic development. The Southern African Power Pool (SAPP), established in 1995, provides a forum for regional solutions to electricity generation and supply through coordinated planning and operation of the regional power system, which consists of generators and international inter-connectors.

Since the early days of SAPP, numerous studies have examined the outlook for power sector expansion in the region, as well as the potential benefits from increased trade and cooperation on regional projects (Alfstad, 2005; Bowen et al., 1999; Economic Consulting

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Associates, 2009; Nexant, 2007; Rowlands, 1998). More recently, two studies have looked in more detail at the role of renewable energy in the development of the SAPP system – the SADC Renewable Energy Strategy and Action Plan (RESAP) (CEEEZ, 2012) and a study by the Energy Research Centre and the International Renewable Energy Agency (IRENA) (Miketa and Merven, 2013). In addition, the SAPP Coordination Centre compiles the demand and supply forecasts from the national utility members and publishes this ten-to-fifteen-year outlook each year, although without any further analysis (e.g. SAPP, 2014, 2013). While these studies often provide detailed supply optimisation analysis, none of them include detailed bottom-up demand analysis. In fact, many of the studies either rely on utility estimates (which are rarely based on bottom-up analysis) or simply use a constant annual growth rate over the study period. In addition, the time frame for most studies was limited to 20 years, or even 10 years for the SAPP reports (CEEEZ, 2012; Economic Consulting Associates, 2009; Miketa and Merven, 2013; Nexant, 2007; SAPP, 2014). Even the recent IRENA study, which extended the timeframe to 2050, simply used an extrapolation of earlier national growth rates for this longer period. One additional study that did include bottom-up demand analysis out to 2030 (Merven et al., 2010), did not include any supply analysis. A 20-year timeframe for analysis has two important limitations: first, the declining costs of renewable power alternatives may take several decades to tip the balance away from fossil fuel dependence in supply planning, as well as to address the limited opportunities for storing non-dispatchable power. Second, many of the SAPP national power systems are dominated by hydropower, which could be vulnerable to long-term changes in climate – and therefore water availability – but this impact may only be visible over 30–50 years (Spalding-Fecher et al., 2014; Stanzel and Kling, 2014). A final important issue with earlier studies is that the underlying drivers of electricity demand, such as population growth, economic growth and the shifts in the structure of the economy, are not always internally consistent or do not have a coherent development framework. This makes it difficult to compare the results, because the underlying visions of the future may be quite different from study to study, and this is not made explicit in those estimates.

The objective of this study is to analyse and provide projections of electricity supply and demand for SAPP over a long time period (2010–2070), based on a set of internally consistent development scenarios, and using bottom-up demand analysis. In addition, the analysis combines a simulation of the stated expansion plans of the regional electricity utilities (e.g. out to 2025) with an optimisation analysis of what power options should be used to meet demand over the longer term, taking into consideration changing capital and fuel costs. Section 2 introduces the energy modelling framework and overall methodology. Section 3 then presents data and assumptions used for modelling demand, supply, trade, generation costs, and greenhouse gas emissions, as well as the calibration of the modelling framework. The demand and supply results are then presented in Section 4, along with discussion, followed by conclusions in Section 5.

2. Methodology

As Bazilian et al. (2012) and Koppelaar et al. (2016) explain, there are numerous long-term energy forecasting and simulation modelling tools that each have their own strengths and weakness. The tool selected for this analysis is the Long-range Energy Alternatives Planning (LEAP) modelling system, developed by Stockholm Environment Institute (SEI) (Heaps, 2012), and increasingly used as part of integrated water-energy-climate modelling analyses (see, e.g., Howells et al., 2013; Sattler et al., 2012; Yates and Miller, 2013).

The overall structure of LEAP is presented in Fig. 1 showing the main flows of information through LEAP for this analysis. LEAP is not a model of a particular energy system; rather it a flexible software framework within which models of different energy systems can be

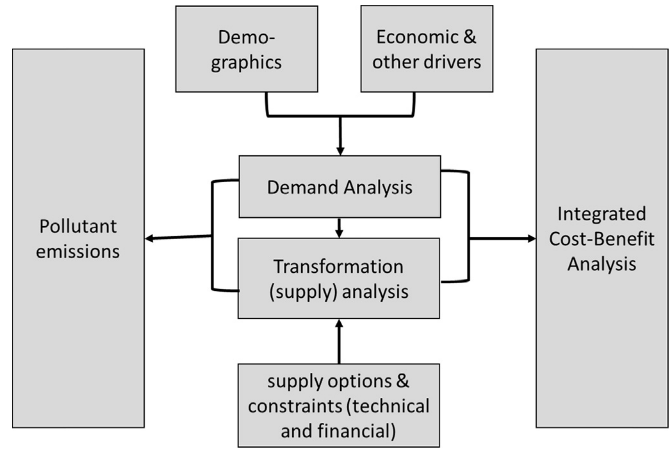

Fig. 1. Structure of LEAP model as applied in this study.

constructed. Its most important features for this study are its support for multi-regional (in this case multi-country) analyses, alternative scenario projections, and the ability to combine bottom-up energy service-based demand forecasts with least-cost optimisation modelling of electric generation.

LEAP models are demand-driven and typically combine bottom-up energy service-based energy demand forecasts with simulation or optimisation-based models of energy production and conversion (which in LEAP is referred to as "Transformation"). LEAP's demand models are based around a straightforward accounting approach that calculates energy consumption as the product of some type of activity level and an annual average energy intensity specified as units of energy consumption per unit of activity. Activity levels are typically broken down into their various components within a hierarchical tree structure displayed within LEAP and used to organize the main sources of data. For example, in the household sector energy intensities may be specified per household by fuel for each major end-use (cooking, lighting, appliances, etc.), while the total number of households in each country may be broken down into urban versus rural households and then into electrified and unelectrified households. The user is free to specify how each of these values may evolve in the future based, for example, on expected rates of population growth, urbanisation, electrification and technology penetration. In the industry, services and agriculture sectors, energy consumption can be disaggregated by major subsectors, and energy intensities may be specified per unit of value added in each subsector. LEAP models are typically used for integrated energy planning that considers all fuels and the potential for substitution among fuels and technologies. However, for this study, the demand modelling is limited to consider only demands for electricity. The major macroeconomic and demographic assumptions used in the study are described in details in Sections 3.1 and 3.2.

In terms of the Transformation analysis, the model developed for this study combines a relatively simple set of accounting projections for transmission, distribution and own use energy losses, with a multi-regional least-cost optimisation model for electric generation. LEAP's optimisation calculations are based on the Open Source Energy Modelling System (OSeMOSYS) (Howells et al., 2011) and the GNU Linear Programming Kit (GLPK), a software toolkit intended for solving large scale linear programming problems by means of the revised simplex method and the CPLEX Solver. This system can be used to calculate least-cost pathways for capacity expansion and plant dispatch in any particular scenario. The assumptions behind the supply analysis are presented in Section 3.3.

LEAP can also be used to calculate the emissions of greenhouse gases and other local air pollutants in any scenario through the specification of emissions factors, typically entered as emissions per unit of energy combusted. LEAP's optimisation calculations can use an