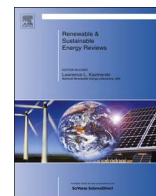




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Ethiopian power sector development: Renewable based universal electricity access and export strategies

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ABSTRACT

This paper presents an assessment of alternative, long-term energy supply strategies for the Ethiopian power sector, during 2015–2045, using the MARKAL energy system model. This study also identifies alternative, sustainable energy supply options to meet Ethiopia's rising demand for energy, while also achieving the policy goals of universal electrification, zero greenhouse gas emissions, increased electricity exports, and improved energy security. In all scenarios, the results show a large potential for renewable energy technologies, such as hydropower, solar PV and wind. These technologies have implications for neighboring countries in the region and will also affect the agriculture sector in Ethiopia. Hydropower, for example, is a renewable energy source that can contribute to rural electrification, while also providing water to support irrigation expansion. An alternative policy scenario prioritizing renewable energy technologies reduces dependence on fossil fuel completely at minimal cost, while providing long-term environmental benefits. Expansion of electricity access to the entire population entails large investments in power generation capacity as well as substantial increases in the total system cost of energy production. Such a scenario would also increase the country's reliance on fossil fuels and geothermal energy sources. Most alternative policy options show higher investment costs will be required to achieve policy goals in the near term (with the exception of the export scenario). However, the analysis shows long-term benefits from investing in energy supply including sustainable energy system development, expansion of access to modern sources of energy, and the development of a low carbon society.

1. Introduction

Energy consumption is an important indicator for any society given that energy is a critical input for socio-economic development [1]. The energy sector of Ethiopia faces the dual challenges of limited access to modern energy and heavy reliance on traditional biomass energy sources to meet growing demand. While Ethiopia has seen dramatic growth of Gross Domestic Product (GDP) in recent years. The annual GDP growth rate varied between 8.6% and 12.7% during 2003–2012 and growth averaged 11% [2]. Sustaining this growth into the future will require dramatic expansion of energy supply.

Power generation in Ethiopia currently depends almost entirely on hydropower. Total power generation capacity was 2167 MW in 2012 and hydropower, diesel, wind and geothermal shares were 90.0%, 6.0%, 3.7% and 0.3%, respectively [3]. By 2012, only about 23% of the total population was connected to the national grid [4]. The rate of electricity access is high in urban areas (87%), but remains extremely low in rural areas at about 5% in 2012. Primary energy consumption in Ethiopia is predominately derived from biomass, which accounts for

91% of energy consumed [5]. Petroleum supplies about 7% of total primary energy and electricity accounts for only 2% of total energy demand. Electricity is mostly used by urban households and small industry. The household sector accounts for about 93% of energy consumption, followed by the transport sector (5%), and industry (1%) [5,6]. Per capita electricity consumption was 23 kWh in 2000 and increased to 41 kWh in 2008 [7]. This level is far below the average level of per capita energy consumption across all African countries (500 kWh/capita/year) [8]. Biomass consumption accounts for over 98% of total supply in the residential sector and about 76% in the industrial sector [8]. Due to reliance on biomass energy sources for cooking, CO₂ emissions in Ethiopia increased from 5.1 million tons in 2005 to 6.5 million tons in 2010. On a per capita basis, this amounts to 0.06 t of CO₂ in 2005 and 0.075 t in 2010 [7].

According to the National Growth and Transformation Plan, the government aims to double the proportion of the population with electricity access and is developing large-scale hydroelectric projects with the aim of increasing the supply of renewable energy sources from the existing generation capacity of 1950 MW to 8000–10000 MW by

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the end of 2014–15 [9,10]. The Ethiopian Electric Power Corporation (EEPCo) also plans to integrate alternative power plants, such as solar, wind, geothermal, fuel-oil and gas-based plants, to meet the expected increase in domestic electricity demand due to rapid economic development and also to export electricity to neighboring countries. Ongoing and planned power generation capacity is expected to reach 22,500 MW by 2025 [11].

Ethiopia is endowed with various renewable energy resources. The estimated potential for hydropower is 45 GW, the potential for wind is 10 GW, the potential for geothermal is 5 GW and the potential for solar irradiation ranges from 4.5 kWh/m²/day to 7.5 kWh/m²/day [5,12]. The reserve of fossil fuels is also significant. For example, the natural gas reserve is about 4 trillion cubic feet and the reserve of coal is over 300 million tons [12]. Therefore, it is possible for Ethiopia to meet the projected increase in energy demand while expanding electricity access to all and improving energy security.

Rapid economic growth in Ethiopia is leading to large sectorial and livelihood transformations throughout the country, including rapid urbanization and increased industrialization. To meet growing demand, sustain growth, achieve policy targets [4,9,13] investment in the sector needs to rapidly increase. The main barriers to widespread electricity access are financing, planning, governance and institutional capacity [14]. The Government of Ethiopia has plans for universal electricity access, clean energy generation from renewable energy resources, and electricity export to neighboring countries [9,15]. Optimization models can be used to analyze the technical and economic feasibility of diversifying the energy supply-mix over the long term, providing valuable insights for energy policy design and investment. Energy policy and investment decisions should consider all expected energy supply and demand-side options that are consistent with national development goals. Long-term comprehensive energy systems planning is required to improve modern energy access, increase energy security, and mitigate greenhouse gas (GHG) emissions. Energy planning using comprehensive modeling tools enables national governments to anticipate and respond to the rapid changes that are occurring in the energy sector, including taking advantage of new innovative technologies. This type of assessment is currently lacking in Ethiopia.

Representative energy supply modeling tools for national and regional scale analysis include: MARKAL/TIMES, MESSAGE, POLES and WASP [16]. The market allocation (MARKAL) model used in this study, is the most widely used energy system optimization model [17]. The MARKAL model has been used for many national, regional and global studies. National studies of developing countries have focused on the potential for renewable energy technologies [18,19], low carbon development strategies [20–23], long-term energy policy development [24–26], scenario analysis for power sector development [27,28], the impacts of wind and solar photovoltaics on the future energy supply mix [29,30], GHG mitigation potential [31], and the impact of improved cookstoves [32].

This study develops a MARKAL model based assessment for first-time in Ethiopia to identify least-cost solutions for alternative technology selection over the next 30 years (2015–2045) to meet the projected electricity demand. The main objective of this study is to identify alternative energy development pathways applying this MARKAL framework that meet Ethiopia's rising electricity demand while improving energy security, promoting access to modern energy, and mitigating GHG emissions. The intention of this study is not to predict future development of the energy sector, but to provide insights into the implications of different technology options that can be pursued by the Ethiopian Government in a sustainable way over the long term. The MARKAL model allows for a wide range of hypothetical assessments to be carried out, taking into account different strategies, energy sources and the availability of alternative technologies as well as climatic constraints [26].

Drawing on policy goals outlined in the Ethiopian Growth and

Transformation Plan (GTP), the climate-resilient green economy strategy, the UNDP strategy for sustainable energy for all (SE4All), and the strategies of the Ethiopia Electric Power Corporation (EEPCo) for further development of the power sector [4,10,13,15], the following policy scenarios were developed for the MARKAL model:

1. Reference scenario: This scenario assumes a continuation of current energy and economic dynamics without imposing any policy constraints. It provides a reference for comparing alternative technology investments, the power generation capacity of these technologies, energy consumption levels, and alternative policy options.
2. Universal electrification (UE30) scenario: This scenario is based on a goal stated in the government's Growth and Transformation Plan to provide electricity access to all households by 2030.
3. Accelerated renewable energy development scenario (ARED): This scenario evaluates the effects of renewable energy development for power generation. It assumes that the target to meet 100% of the country's electricity demand from renewable energy resources by 2025 is achieved based on the Ministry of Finance and Economic Development (MOFED)'s 2014 GTP implementation plans. This scenario would reduce carbon emissions to zero by 2025 in the power sector and place the country on a path towards sustainable socio-economic development.
4. Electricity export beginning in 2020 (EE20) scenario: This scenario assesses the impact of exporting electricity to neighboring countries. Based on the Ethiopian electricity development plan, this scenario considers an upper bound of electricity exports of 20% of total national demand from 2020 onwards to determine its impacts on power sector development.
5. Accelerated renewable, universal electricity and export (ARUE) scenario: This scenario assumes that specific policy interventions are carried out to ensure that the following targets are met: 100% renewable energy-based electricity from 2025, electricity exports are permitted up to a maximum limit of 20% of national demand starting in 2020, and universal electrification by 2030.

2. MARKAL model

The MARKAL model is a linear programming model developed in 1974 by a consortium of members of the International Energy Agency to serve as an energy system planning and optimization tool. MARKAL enables analysis of long-term energy supply alternatives and can be used for cities, provinces, countries or regions. About 70 countries and approximately 250 institutes have applied this model [33]. MARKAL determines the energy and technology mix needed to meet the energy demand of a particular energy system, given specific limitations regarding available technologies and energy sources. It then determines an optimal energy supply mix (in economic terms) based on technological and economic parameters, such as the minimum cost for the technologies selected [34].

MARKAL consists of a set of constraints and one objective function, which is usually chosen to minimize the long-term discounted system cost of the energy system. The constraints and objective function are expressed by decision variables and parameters, where decision variables are unknown quantities, which MARKAL determines, and parameters are known quantities that are specified by the modeler. The configuration of the supplied reference energy system (RES) is dynamically adjusted by MARKAL in such a way that all model equations are satisfied and long-term system cost is minimized. In this process, MARKAL captures a partial equilibrium of the RES at all intermediate stages, such as flow conservation, demand satisfaction, capacity transfer and utilization, resource capacity and emissions constraints. These aspects are discussed in earlier studies [16,23].

MARKAL is a demand-driven model, in which energy demand is driven by existing and forthcoming technologies and available energy resources. The schematic structure of the MARKAL model for Ethiopia

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