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Ethiopian energy status and demand scenarios: Prospects to improve energy efficiency and mitigate GHG emissions

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ABSTRACT

The energy sector of Ethiopia continues to largely rely on traditional biomass energy due to limited access to modern energy sources to meet growing demand. Long-term energy demand forecasting is essential to guide the country's plans to expand the energy supply system. This study provides a general overview of Ethiopia's current energy demand and forecasts sector-wise energy demand out to 2030 for alternative policy scenarios using the Long-range Energy Alternative Planning (LEAP) model. The reference scenario assumes a continuation of recent energy consumption trends and takes account of current energy and economic dynamics. Three alternative scenarios on improved cookstoves, efficient lighting, and universal electrification scenario were identified as key priorities of the government of Ethiopia and modeled. Results from the model can assist energy planners in ensuring that the country's capacity for supply meets projected growth in demand for energy. They also shed light on the tradeoffs implicit in alternative policy priorities and investments in terms of economic development and environmental sustainability. Most importantly, the results suggest that alternative investments can conserve energy, improve environmental sustainability, enhance energy equity and improve the country's development indicators.

1. Introduction

Having access to modern energy sources is essential for economic development and livelihood improvement [1]. Access to modern energy supports both income generation activities and the national development agenda through improving education, reducing indoor air pollution, and ensuring environment sustainability. The Ethiopian energy sector 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 economic growth in recent years, sustaining this growth into the future will require dramatic expansion of energy supply.

Power generation for the electric grid in Ethiopia currently depends almost entirely on hydropower. At the same time, in 2012, only about 23% of the total population was connected to the national grid [3]. There are stark differences in the rate of electricity access in urban and rural areas—in urban areas 87% of the population has access to electricity [2], while in rural areas electricity access remains extremely low at about 5% [3]. Eighty-three percent of the population resides in rural areas, largely relying on traditional biomass energy sources for cooking and heating. Electricity is mostly used by urban households and small industry [4]. Per capita electricity consumption was 23 kWh in 2000 [3] and increased to about 41 kWh by 2008 and 70 kWh by 2014 [2]. This level is far below the average level of per capita energy consumption across all African countries (500 kWh per capita) [5].

The primary source of energy in Ethiopia is biomass, which accounts for 91% of energy consumed [4]. Petroleum supplies about 7% of total primary energy and electricity accounts for only 2% of total energy use. Biomass consumption accounts for over 98% of total supply in the residential sector. The World Development Indicators [3] and many other studies [6–8] show that the national energy balance is dominated by a heavy reliance on firewood, crop residues, and dung. Due to the dependence on biomass for cooking, CO_2 emissions in Ethiopia have 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 tons of CO_2 in 2005, 0.075 tons in 2010, and 0.19 tons in 2014

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[3].

Ethiopia is endowed with various renewable energy resources. The estimated potential for hydropower is 45 GW, wind is 10 GW, geothermal is 5 GW, and solar irradiation ranges from 4.5 kWh/m^2/day to 7.5 kWh/m^2/day [9]. In light of this, the Government of Ethiopia's strategic priorities in the energy sector are: universal electrification access, energy efficiency improvement, decentralized off-grid power generation through the development of renewable energy technologies, and exporting electricity to neighboring countries. In particular, the government is developing large-scale hydroelectric projects with the aim of increasing the supply of renewable energy sources from the present generation capacity of 2000 MW to 8000–10,000 MW by the end of 2014–15 [10]. The Grand Ethiopian Renaissance Dam (GERD) is under construction and expected to be completed soon. The GERD hydropower plant would add 6000 MW to meet the government targets of over 8000 MW capacity. The Ethiopian green economy report by the Ethiopian Economic Policy Research Institute (EPRI) highlighted key strategies to mitigate greenhouse gas (GHG) emissions and save energy including promotion of efficient light bulbs to achieve 100% penetration, dissemination of fuelwood efficient cooking stoves to 16 million households and afforestation and reforestation of 2 million hectares and 1 million hectares, respectively, by 2030 [11].

Previous studies on energy related issues in Ethiopia have examined sustainable energy access [5], power sector development [2], residential electricity demand [6], rural energy use [7], food versus fuel [8], potential for renewable energy resources [12], biogas technology and its contributions [9], residential electricity modelling [13], and long term energy strategies [14].

Previous studies have also projected energy demand using different methods. The Ethiopian energy economy report projected energy demand from 2008 to 2030 by the Ethiopian Economic Policy Research Institute [15]. The report projects demand using energy demand coefficient and macro-economic variables. Senshaw (2014) assesses long-term energy scenarios for Ethiopian sustainable strategies where energy demand also projected [14]. Ethiopian Power System Expansion Master Plan (prepared by Parsons Brinckerhoff Consulting) uses a combination of a regression analysis and end user models to forecast Ethiopia's electricity demand in 2014 [16]. However, to the authors' knowledge, there is no literature providing a comprehensive analysis of Ethiopian energy demand projections under alternative policy scenarios.

Projections of future energy demand and composition have implications for policy decisions, such as investments in large infrastructure projects. The experience of many developing countries shows that demand for energy is likely to increase rapidly with economic growth. The Ethiopian Government aspires to achieve economic development at an annual rate of more than 10%, which requires growth in the development of electric power supply of more than 14% per year [11]. While GDP growth may be the driving factor, future energy demand also depends on a number of other factors such as population growth, the degree of urbanization, technological change, characteristics of end use technologies, and the cost of different fuel sources. Limited capability and resources to improve energy efficiency are also the main factors contributing to the increase in Ethiopia's energy demand [13]. Incorporating these factors into energy demand forecasts is crucial for a capital-constrained developing country, like Ethiopia, where reliable energy supply capability is limited.

Ethiopia launched the “Light to All” National Electrification Program in November 2017 with the goal of providing electricity access to all by 2025 [17]. To provide an accurate assessment of what this will involve, this paper projects Ethiopian energy demand to 2030, incorporating anticipated socio-economic and technological changes over time using the Long-range Energy Alternatives Planning LEAP model [18]. Alternative policy scenarios are developed in line with government goals for universal electrification, energy efficiency improvement and mitigation of GHG emissions in the energy sector. Results presented in this study are compared with previous studies results and discusses the strength of this applied method and techniques.

The results from this model can directly assist energy planners in linking the country's capacity for supply with projected growth in demand for energy and electricity. The results also shed light on the tradeoffs implicit in alternative policy priorities and investments in terms of economic development and environmental sustainability. The model results also provide insights on environmental implications (specifically, GHG emissions) of changes in energy demand over time, which can help policymakers balance economic development and sustainability goals.

The following sections describe the methods used to project future energy demand as well as the data used in the model for the reference scenario and for 3 alternative energy future scenarios: the improved cookstove (ICS) scenario, the efficient lighting scenario and the universal electrification scenario. Section 3 presents the model results under the reference and alternative scenarios; and discuss the policy implications of these results.

2. Methodology

The Long-range Energy Alternatives Planning (LEAP) model is widely used to analyze energy policies, forecast energy demand and assess GHG mitigation options. It is a powerful tool that considers the complete life cycle of an energy source from its extraction to production and consumption. The LEAP model is flexible and easy to use and performs energy analyses of complex energy systems. Each energy system can be modeled independently since the initial data requirements of the LEAP model are limited [19]. The LEAP model has been used for many different studies such as for energy systems planning [20–25], sector-level analyses [26–29] GHG mitigation analyses [30–33], and energy efficiency [34].

The LEAP modeling method is based on building an energy use and supply database and extending it to simulate various energy demand and supply scenarios. The model simulates and assesses the scenarios in terms of physical, economic, and environmental impacts. It consists of four modules: a demand module, a transformation module, a resource module, and a Technology and Environmental Database (TED). The TED is used to estimate GHG emissions in this study. The TED contains emission factors for hundreds of energy-consuming and energy-producing technologies, including the default emission factors suggested by the IPCC (Intergovernmental Panel on Climate Change) for use in climate change mitigation analyses. The demand module uses a bottom-up accounting framework and an end-use driven approach to forecast energy demand [35].

The data for energy demand projections are assembled hierarchically in four tiers: sector level (residential, commercial, etc.), sub-sector (urban/rural households), further end-use options (lighting, cooking, etc.), and finally end-uses based on device (electricity, kerosene, etc.) or fuel use by device [36]. Fig. 1 presents the structure of the Ethiopian sector-wise energy demand tree that was applied in this study to project Ethiopian energy demand. Finally, sustainable development indicators such as: CO_2 intensity, CO_2 emission, electricity consumption and per capita electricity use under different scenarios are estimated and compared with neighboring developing countries.

The model draws on data from a number of sources including the Growth and Transformation Plan (GTP) of the Ministry of Finance and Economic Development, (MoFED, GDP projections) [9,10], several reports from the Ministry of Water, Irrigation and