Ethiopian Universal Electrification Development Strategies

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Introduction

Having access to modern energy sources is essential for economic development and livelihood improvement. Access to modern energy supports both income generation activities and the national development agenda through improving education, reducing indoor air pollution, and enhancing 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. 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, while in rural areas electricity access remains extremely low at about 5%. 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. Per capita electricity consumption was 23 kWh in 2000 and increased to 41 kWh by 2008 and 70 kWh by 2014; a level far below the African average of 500 kWh per capita.

According to the National Growth and Transformation Plan (GTP), the government aims for universal electrification and is developing large-scale hydroelectric projects to support this goal; furthermore, the Ethiopian Electric Power Corporation (EEPCo) 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 and also to export electricity to neighboring countries. Ongoing and planned power generation capacity is expected to reach 22,500 MW by 2025.

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/m^2/day to 7.5 kWh/m^2/day (Mondal et al., 2017). 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. Thus, there are many alternative energy sources to meet Ethiopia's electricity access goals.

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. 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 innovative technologies. This type of assessment is currently lacking in Ethiopia.

This study develops the first-ever TIMES model-based assessment for Ethiopia to identify least-cost solutions for alternative technology selection over the next 36 years (2014-2050) to meet the projected electricity demand. It identifies alternative energy development pathways applying the TIMES modelling framework to meet Ethiopia's rising electricity demand while improving energy security, promoting access to modern energy, and mitigating greenhouse gas (GHG) emissions.

Government of Ethiopia Strategies toward Universal Electrification

The Government of Ethiopia has plans for universal electricity access, clean energy generation from renewable energy resources, and electricity exports to neighboring countries (EEPC, 2014a; MoFED, 2010).

Drawing on policy goals outlined in the Ethiopian GTP, the climate-resilient green economy strategy, the UNDP strategy for sustainable energy for all (SEforAll), and the strategies of the Ethiopia Electric Power Corporation (EEPCo) for further development of the power sector (EEPC, 2014a; FDRE, 2011; MoFED, 2014; MoWIE, 2013), the following policy scenarios were developed and incorporated into the TIMES model:

1. **Reference scenario (REF):** This scenario assumes a continuation of current energy and economic dynamics without imposing policy constraints. It provides a reference for comparing alternative technology investments, their power generation capacity, energy consumption levels, and alternative policy options.
2. **Universal Electrification (UE30) scenario**: This scenario is based on a goal stated in the government's GTP to provide electricity access to all households by 2030.

3. **Reference + Targeted Renewable Energy Production (REF+TREP) scenario**: In this "what if" scenario a certain share of renewable-based power generation (except for hydro) is targeted to meet electricity demand. This scenario assumes accelerated development of solar, wind, geothermal and biomass-based power generation from 20 percent of the country's total electricity demand by 2025 to 40 percent by 2040 with Reference scenario electricity demand.
4. **Universal Electrification + Targeted Renewable Energy Production (UNI+TREP) scenario:** This scenario uses the renewable energy production targets of scenario 3 combined with UE30 (scenario 2) electricity demand.

TIMES model development

The development of a reference energy system (RES) in TIMES is a key contribution. The RES includes all the activities (and associated energy demands), conversion technologies, current fuel mix, and primary energy resources in each energy system. This reference system allocates primary energy resources based on technologies selected by capacity and year, considering the performance of various technologies and their ability to meet the year-wise specific energy demand. A bottom-up approach is used to estimate Ethiopian energy demand using the Long-range Energy Alternatives Planning (LEAP) model (Mondal et al., 2018). In the Reference scenario, the expected annual growth rate of electricity demand is 9.7%. Under the universal electrification scenario, annual growth increases to 11.4%.

The TIMES model requires input data on the availability of all primary energy resources for power generation as well as their cost. The key energy sources considered are: hydro, geothermal, wind, solar, natural gas, coal, diesel oil and furnace oil. Assumptions regarding the costs associated with the exploration of natural gas, coal and fuel oil are incorporated into the model starting in 2020. Data on the potential of renewable energy resources for power generation are derived from recent reports and papers.

The model incorporates a representative set of conversion technologies, including 11 different conversion technology types: pulverized coal (coal), oil-based steam turbine simple cycle, gas-based steam and combined cycle, large hydropower, solar photovoltaics (PV), concentrated solar power (CSP), wind, biomass and geothermal based on the Ethiopia Power System Expansion Master Plan of 2014 (EEPC, 2014b) as well as updated information on existing power plants provided by the Ministry of Water, Irrigation and Electricity. Transmission and distribution (T&D) losses were also incorporated in the modelling. For each technology type, values are given for efficiency, capital cost, and operation and maintenance (O&M) costs, as well as GHG emissions per unit of energy production, year of introduction, and residual (existing) capacity.

The analysis covers a 36-year period (2014-2050) and considers three types of GHG emissions: carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Due to the lack of Ethiopian emission factors, Intergovernmental Panel on Climate Change emission coefficients were used. Only centralized-grid electricity was considered as the main aim of the study is to determine how much electricity must be generated to feed to the national grid to meet domestic demand. The investment cost of expected technologies is based on regional and international studies, given that Ethiopia imports all of these technologies from abroad.

Results

The optimization model results for the Reference scenario suggest that capacity for power generation grows from 4.23 GW in 2014 to 47.8 GW by 2050 to meet projected electricity demand. Under the Universal Electrification Scenario, capacity would grow faster, to 69.3 GW in 2050. The structure of generation technologies changes significantly with the introduction of natural gas, coal, and solar PV-based technologies in all alternative scenarios. Geothermal contributes only under the policy constraints imposed under the UE30 and the renewable target production scenarios. Figure 1 presents fuel-wise generation capacity by year for all alternative scenarios.

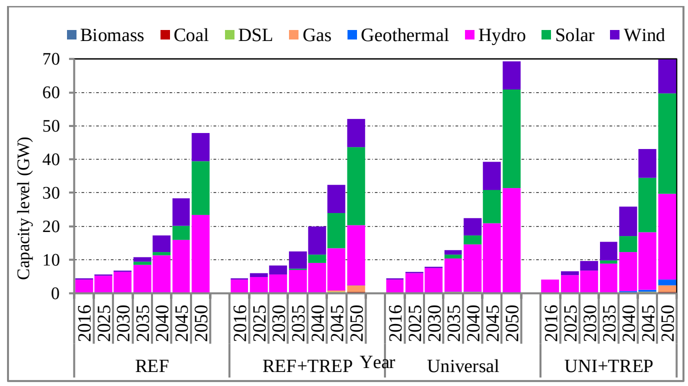

Figure 1: Technology capacity (GW) selection by year in all generated scenarios

The power generation capacity from large hydropower is projected to increase from the current 4 GW to 31 GW in 2050 in the UE30 scenario which reaches the maximum hydropower installation capacity among the alternative pathways studied.

Model results show that there is a significant opportunity to invest in solar PV and wind power plants. Specifically, the cost of producing electricity through solar and wind is expected to decrease dramatically over time given technological advances, which makes these technologies economically viable in the future. Solar PV installation capacity increases from 16 GW in 2050 in the Reference scenario to 23 GW, 29 GW and 30 GW in 2050 in the REF+TREP, UE30 and UNI+TREP scenarios, respectively. Least-cost solutions include coal and gas-based power generation only at the end of the analysis period.

Electricity production grows from 8 TWh in 2014 to 226 and 317 TWh, respectively, in the Reference and UE30 scenarios. The contribution from hydropower in 2050 increases from 154 TWh in the Reference to 208 TWh in the UE30 scenario. Due to the targeted production of other renewables to diversify the energy supply-mix, hydropower production decreases to 117 and 170 TWh in 2050 in the

REF+TREP and UNI+TREP scenarios, respectively. Least-cost, fuel-wise electricity production shares in 2050 under the UNI+TREP scenario are: Coal 1%, gas 5.1%, geothermal 3.7%, hydro 53.9%, solar 24.8% and wind 11.5%. The targeted renewable production scenarios significantly contribute to reduce the dependency on hydro based generation to meet future electricity demands.

To summarize the extensive results generated for each of the scenarios, the primary energy supply-mix in 2050 is selected as a principal metric to compare the contribution of the various energy resources (Figure 2). This metric gives a good indication of the types of primary energy choices that meet policy targets at least cost. In Figure 2, the colored bars represent the breakdown of energy resources used in PJ for the reference year 2014 and for 2050 as well as results for alternative policy scenarios for 2050.

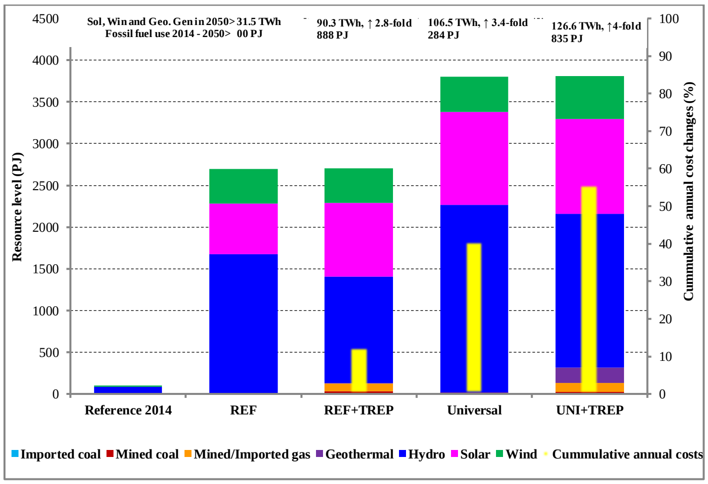

Figure 2: Primary energy mix in 2014 and 2050 for all scenarios, and cumulative annual cost change (%, yellow middle bar) compared to the Reference scenario.

Diesel and fuel oil are not shown as they are not selected for electricity production in 2050 in any of the scenarios. The center yellow bar in the REF+TREP, UE30 and UNI+TREP scenarios presents the percentage change in cumulative (2014–2050) annual investment costs compared to the Reference scenario. The cumulative cost includes the cost of energy conversion technologies, fuel, O&M, and other costs. To compare the total costs of different scenarios, the total annual activity costs of the Reference scenario are used as the base cost from which percentage changes in total costs are calculated for the other scenarios. The numbers in the first row above each scenario bar present electricity generation from renewables (except hydro) in 2050 as well as a comparison with the Reference scenario. The second row shows fossil fuel requirements during the study period (in PJ) across scenarios.

The primary energy requirement in 2014 was 97 PJ. Based on varying electricity demands (REF and UE30), the expected total primary energy (fossil fuel and renewables) requirement is about 2698 PJ, 2705 PJ, 3800 PJ, and 3812 PJ in the REF, REF+TREP, UE30 and UNI+TREP scenarios, respectively, in 2050. Solar PV, wind and geothermal based power generation increases from 31.5 TWh in the Reference Scenario to 90.3 TWh, 106.5 TWh and 126.6 TWh in the REF+TREP, UE30 and UNI+TREP scenarios, respectively.

Total (cumulative) annualized costs increase by 12.5%, 40.6% and 55.9% compared to Reference scenario costs. However, long-run costs are not significantly higher. Figure 3 presents annual lumpsum process costs for all scenarios.

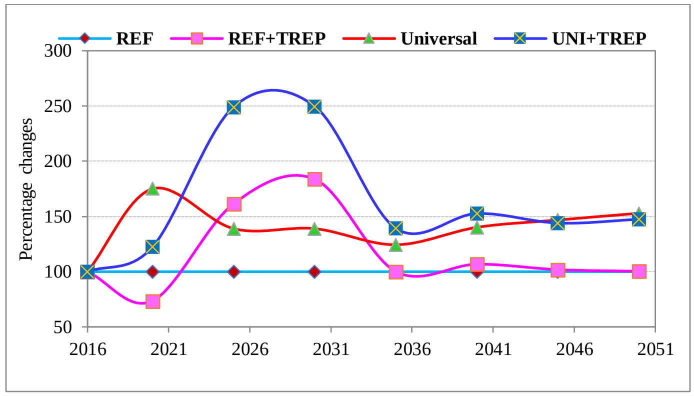

Figure 3: Annual lumpsum investment costs by scenario

The lumpsum investment cost slightly increases (0.36%) in 2050 in the REF+TREP scenario compared to the Reference scenario. On the other hand, costs in the UNI+TREP scenario are 3.56% lower than under the UE30 scenario. Therefore, targeted renewable-based power generation is a suitable policy and investment option for supporting sustainable energy systems development in the long run in Ethiopia.

Conclusions and recommendations

The results presented here have important policy implications. Alternative energy development pathways can meet different policy priorities or policy goals, such as providing electricity for all (universal electrification), decreasing fossil fuel use, and promoting reliable and affordable energy sector development through the optimal use of renewable energy sources. Each of these policy choices affects total systems cost of power generation to meet demand and has differing environmental impacts. All of these factors must be considered carefully when determining the course of Ethiopia's power sector development for the future.

Notably, the results show that across all the developed alternative policy options, the current supply of energy sources to generate electricity will need to diversify from hydropower to a mix of hydro, solar, and wind. The potential of natural gas and coal based power plants to electricity generation is limited to scenarios where renewable energy resources cannot meet the projected demand in the later period of this analysis. In general, the model results suggest that initial investments in renewable energy-based power generation capacity can be paid back over the long term. Expansion of electricity access to the entire population entails large investments in power generation capacity and substantial increases in total system costs (40.6% increase compared to the Reference option) of electricity production. Geothermal energy supply becomes an economically viable option when the policy goals include both universal electrification and targeted renewable energy expansion.

While most of the alternative scenarios involve an increase in total energy systems costs, lumpsum investments in the Reference and Targeted Renewable Energy Production scenarios are almost equal in the later period of analysis. Lumpsum investment requirements are also similar in the Universal Electrification and UE30 with Targeted Renewable Energy Production scenarios. Therefore, prioritization of renewable energy sources and technologies does not have large additional cost implications, particularly over the long run as investment costs for these technologies are expected to decline rapidly.

The results support the feasibility of investing in alternative technologies for power generation in Ethiopia to meet projected electricity demand. In particular, solar PV and wind power have significant potential to supply Ethiopian power as investment costs of these technologies are slated to decline dramatically in the future.

This results brief provides an overall picture of the renewable energy potential for power generation in Ethiopia and demonstrates to which extent renewable energy technologies can be integrated into the Ethiopian power sector. The results suggest that it would be attractive for the country to move forward on diversified, targeted renewable energy production, including solar PV and wind energy, to achieve universal electrification goals while also improving energy security.

The Ethiopian government must weigh tradeoffs on energy transitions and carefully consider long-term energy policy for green growth transformation. Achieving these important policy goals will not only require a vision, but also strong policy support and the recognition that the higher near-term investment cost will be paid back in the long-run with significant diversification of the primary energy supply-mix to improve energy access for all in Ethiopia.

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