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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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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

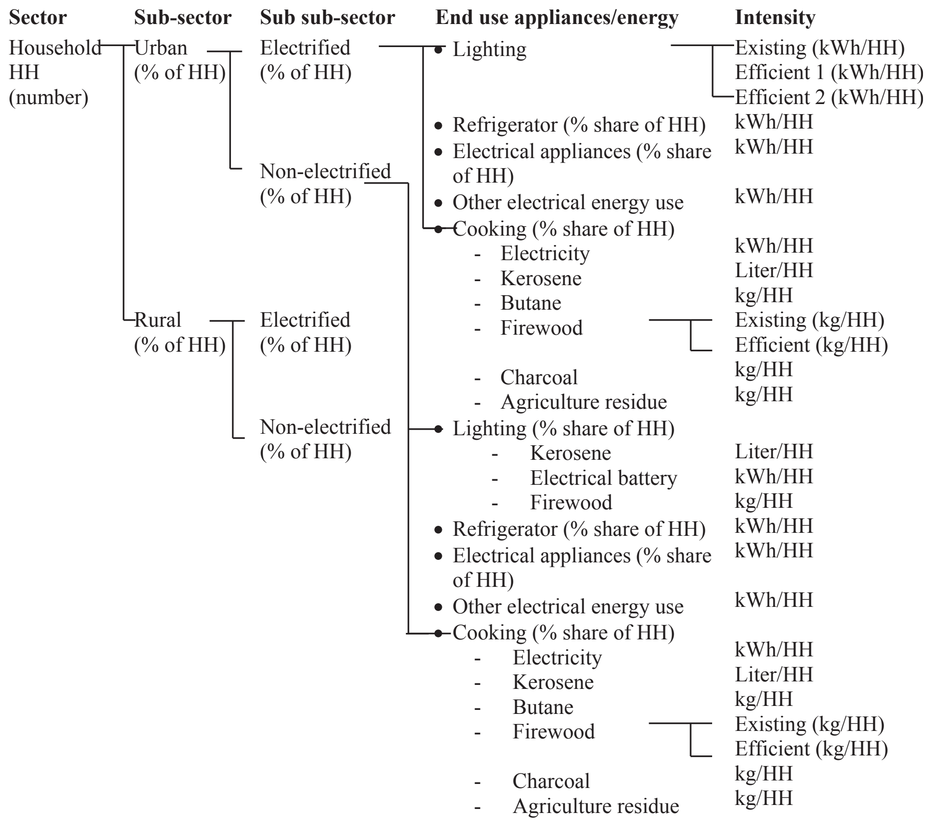


**Fig. 1.** Energy demand tree for demand projection.

Energy (including the energy balance and statistics [2], the biomass energy strategy plan [39], and the sustainable energy for all [37]), the power sector development report of the Ethiopian Electric Power Corporation [43], energy balance report of the International Energy Agency (IEA) [40], the Ethiopian Economic Association Report on the Ethiopian Economy [15], statistical survey reports by the Central Statistical Agency (CSA) [41,42,44], Environment for Development (EfD) reports [6,45], and the World Development Indicators [3]. Below we provide the data sources and assumptions for the reference scenario and each of the 3 alternative future scenarios used in the analysis.

### 2.1. The reference scenario

The reference scenario draws on historical trends of population growth, GDP growth, electrification, and consumption of energy by sector. The reference scenario assumes that historical trends will continue into the future, thereby providing a benchmark from which alternative scenarios can be evaluated. Where possible, existing data from government reports and strategy documents are used to project historical trends out to 2030, considering 2012 as the base year. Where data are not available, best guess assumptions are made regarding future trends in consumption of various energy sources and the rate of penetration of end use technologies. Some input data are also calculated, such as the energy intensity of different economic activities. Actual energy consumption data of major sectors for 2006 and 2011 are presented in Table 1.

Historical population data come from the World Bank's World Development Indicators [3] and the Food and Agriculture Organization (FAO) of the United Nations Statistics Division [46]. These data show that the population of the country almost doubled from 48 million in 1990 to 92 million in 2012 (the base year in the model). In 2012, 17% of the population lived in urban areas. By 2030, the population of the country is expected to increase to 134 million of which 21% are projected to reside in urban areas [15].

The average household size in the country is 4.6 members in 2011 which is slightly lower than the average of 5.0 members in 2005 [44]. Urban households have fewer members with an average of 3.7 compared to rural households which have an average of 4.9 members. Given a continued decrease in the rate of population growth and an increase in the rate of urbanization, the average household size in the country is expected to decrease to 4.4 members by 2030.

The share of the population with access to electricity has increased dramatically from 12.9% in 2006 to 22.5% in 2012 [37]. The rate of access to electricity is high in urban areas at 87%, but much lower in rural areas at about 5% in 2012. Based on the National Growth and Transformation Plan, the government aims to double the proportion of the population with electricity access through the development of a national grid and a decentralized rural electrification system. As a result, the rate of rural electrification is expected to grow to 10% by 2020 and to 20% by 2030. The urban electrification rate is assumed to increase to 90% by 2020 and to 95% by 2030.

Electrified households have the option to use appliances such as light bulbs, refrigerators, televisions, radios, chargers and electric stoves. However, most electrified households in Ethiopia do not yet use refrigerators and televisions—42% of urban households use televisions and only 14% have a refrigerator in 2011 [44]. The use rate of refrigerators and televisions was even lower in 2004 at about 6% and 23%, respectively [42]. In rural electrified areas these appliances are almost never found—only about 0.7% have a television set and 0.1% of rural households own a refrigerator in 2011 [41]. The use rate of televisions was even lower in 2004 at about

**Table 1**
Historical trend of sector-wise final energy consumption (PJ).

| | 2006 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | Petroleum | LPG | Electricity | Biomass | Petroleum | LPG | Electricity | Biomass |
| Industry | 7.0 | – | 3.6 | – | 9.0 | – | 5.0 | 0.0 |
| Transport | 49.6 | | 0.0 | – | 70.3 | – | 0.0 | 0.1 |
| Households | 10.3 | 0.2 | 2.9 | 1080.7 | 10.7 | 0.4 | 5.3 | 1214.9 |
| Other | – | – | 2.2 | 7.3 | 0.0 | – | 3.5 | 9.2 |
| Total | 66.9 | 0.2 | 8.6 | 1088.1 | 90.0 | 0.4 | 13.8 | 1224.2 |

0.23% [42]. Based on recent trends of increased use of appliances, it is expected that 60% of urban households and 20% of rural households will own a television set and 30% of urban households and 10% of rural households will own a refrigerator by 2030.

The Ethiopian Growth and Transformation Plan highlights the importance of energy efficiency and energy conservation. It is reported that about 11 million efficient lamps have already been introduced in the country in lighting to replace incandescent bulbs [37]. Based on this, it is estimated that about 25% of electrified households have access to these efficient lamps. The reference scenario assumes that the share of electrified households using compact fluorescent lamps (CFL) and efficient tube lamps are 10% and 15%, respectively. It is expected that the penetration rate of CFL would be 15% in 2020 and 20% in 2030. Similarly, the penetration rate of efficient tube lamps is expected to increase to 20% by 2020 and 30% by 2030.

Lighting energy intensity is estimated based on the Ethiopian Energy Balance Sheets which provide the amount of electricity consumption for lighting and the share of electrified rural and urban households. Urban electrified households consume an average of 231 kW h (kWh) per year and rural households consume an average of 168 kWh. Efficient tube lamps and CFL are 30% and 70% more efficient, respectively, compared to incandescent bulbs. The estimated energy consumption per refrigerator is relatively low (at 162 kWh) and may be due to limited availability of electricity due to load-shedding or electricity cuts. It is assumed that electricity consumption for refrigerators would increase to 500 kWh per household per year by 2030. Electrical appliances use an average of 160 kWh per year in urban households and 110 kWh per year in rural households. Due to high economic growth, energy use by appliances would increase to 200 kWh and 180 kWh per year in urban and rural households, respectively, by 2030. Electricity use for other purposes such as radios, mobile chargers, and torch light chargers is also expected to increase from 33 kWh per household to 50 kWh per household in urban areas by 2030.

Energy used for cooking purposes per household is calculated based on the Energy Balance Sheets developed by the Ministry of Water, Irrigation and Energy, the Report on the Ethiopian Economy, the IEA's Energy Balance for Ethiopia, and the Ethiopian Biomass Energy Strategy Action Plan. The share of households using various energy sources for cooking in urban and rural areas is shown in Table 2. The first four columns of the table present historic use rates based on CSA reports [41,42,44], while the last columns show the assumed future rates for the reference scenario based on historic trends. Average firewood consumption is higher in rural households at 4600 kg per year compared to the urban households, which use an average of 3400 kg/yr. This is because rural households in Ethiopia rely primarily on firewood for cooking (91%), while only a small proportion of rural households use other fuels as their primary source of cooking fuel, such as charcoal (5%) and agricultural residues (4%) [47]. While charcoal use has increased significantly among rural Ethiopian households—rising from 0.048 million tons in 2000 to 4.13 million tons in 2013 [39]—it is still not widely adopted as most rural households cannot afford to purchase charcoal and biomass energy resources are freely available [8].

Given the importance of firewood in rural areas, the reference scenario assumes that firewood use will decline only slightly to 89% in 2020 and 82% in 2030, while charcoal use is expected to increase marginally to 2.5% in 2020 and 5% in 2030 (Table 1). The reference scenario also assumes that electricity will be used for cooking by 1.5% of rural households in 2020 and by 6% of rural households by 2030. Other cooking fuel sources, such as kerosene and butane, are seldom used and are not likely to increase in importance in the future.

Urban households rely on a wider range of cooking fuel sources, such as electricity, kerosene and charcoal, although most (63%) are still dependent on firewood. As with rural households, urban households' use of firewood is expected to decline only slightly to 55% in 2030. Kerosene use in urban areas is also assumed to decrease, while charcoal use is expected to increase from 17.5% in 2012 to 24% by 2030. Similarly, the share of urban households using electricity for cooking is expected to increase to 10% in 2020 and 15% in 2030.

Given that firewood is likely to remain the dominant source of fuel for cooking throughout the country for the foreseeable future, the government recognizes the importance of improved cookstoves (ICS) to reduce demand for firewood and introduced about 4–5 million ICS [37]. ICSs efficiency depends on their quality and fuel use. One of the Ethiopian Sustainable Energy for All Initiatives is to consider doubling the efficiency of ICS to 20% compared to the existing stoves [37]. Typical traditional firewood and improved cookstove efficiency is 15% and 25%, respectively [48]. Various studies show that the energy saving potential of ICS compared to traditional stoves varies from 20% to 67% [48–53]. In this study, ICSs are considered to save 24% more energy than existing stoves based on study performed by Ref. [54] and the World Bank [55]. Among households reliant on firewood as their main source of cooking fuel, the reference scenario assumes that the rates of use of ICS vary across different sets of households as follows: 6% of rural households without electricity access, 10% of electrified rural households, 15% of urban households without electricity, and 20% of electrified urban households. In the reference scenario, it is further assumed that rate of use of ICS among these groups of households will increase by 5% points in 2020 and again in 2030.

Historical data on growth in GDP come from World Bank [4], and MoFED reports [9,10,47]. These data show that GDP has more than doubled from $9.1 billion in 2000 to $25.1 billion in 2012, which amounts to an average growth rate of 14% per year. Agriculture and services account for the largest shares of GDP at 44% and 46%, respectively in 2012. Industry accounts for the other 11% of GDP. The data show that the share of GDP from the agricultural sector is declining since 2000, while the importance of the service sector in the overall economy has increased.

GDP growth is projected to remain high in the near future—the National Growth and Transformation Plan (GTP) estimates 11.2% growth during 2010–2015 [38]. Similarly, this study assumes a high

**Table 2**
Percentage share of fuel use for cooking.

| Fuel/sector | 2004 | | 2012 | | 2020 | | 2030 | |
|---|---|---|---|---|---|---|---|---|
| | Urban | Rural | Urban | Rural | Urban | Rural | Urban | Rural |
| Electricity | 2.4 | 0.1 | 6.1 | 0.0 | 10 | 1.5 | 15 | 6 |
| Kerosene | 13.8 | 0.2 | 4.9 | 0.2 | 4 | 0.5 | 3 | 1 |
| Butane | 2.4 | 0.1 | 1.1 | 0.0 | 1.2 | 0.05 | 1 | 0.5 |
| Firewood | 65.3 | 84.5 | 63.3 | 90.9 | 60 | 89 | 55 | 82 |
| Charcoal | 7.7 | 0.2 | 17.5 | 0.2 | 20 | 2.5 | 24 | 5 |
| Agriculture residue | 8.5 | 15.0 | 7.0 | 8.0 | 4.8 | 6.45 | 2 | 5.5 |

rate of economic growth out to 2030 at a rate of 11.2% during 2010–2015, 11% during 2015–2020, and 10.5% during 2020–2030. The reference scenario also assumes that the historical trend of the declining importance of agriculture as a share of GDP will continue into the future—declining to 38% of GDP in 2030. Furthermore, it is expected that the share GDP from services will decline slightly to 43% in 2030 while the share of industry in total GDP is expected to increase to 19% by 2030.

The reference scenario also includes several assumptions about the energy intensity of the main economic sectors—industry, services, agriculture, and transport—based on historical trends and realistic assumptions about the rate of future technological innovation, which tends to increase energy efficiency. Energy intensity was calculated for various economic sectors for the historical and base years based on energy balances [4,40], and CSA reports [41,42], sector-wise energy consumption value and sector-wise total GDP [56]. These historical data show a declining trend in energy intensity of the various fuel sources used in these sectors, with the exception of per capita energy use in transport. National energy intensity decreased significantly from 1.01 MJ/USD in 2006 to 0.26 MJ/USD in 2010 (an average decrease of 18.5% per year) due to the very large growth of GDP combined with unchanged primary energy supply [37].

In the industrial sector, historical data show a declining energy intensity of electricity, diesel, kerosene and other oil between 2006 and 2012 of between 1.2% and 2.03%. Intensity for electrical energy use was 0.54 kWh/USD in 2006 and 0.51 kWh/USD in 2012. This intensity is expected to decrease to 0.45 kWh/USD in 2020 and 0.41 kWh/USD in 2030. Similarly, the reference scenario assumes that this declining trend is likely to continue into the future for other energy sources given the likely introduction of new, energy-efficient technologies. In the services sector, the energy intensity of biomass, electricity and petroleum decreased annually by 7%, 4% and 7%, respectively, between 2006 and 2012. Further declines in energy intensity are expected out to 2030, particularly for biomass. In the agriculture sector, the energy intensity of biomass, electricity, and petroleum decreased by 6%, 1%, and 3%, respectively, over the same period. Again, these declining trends are likely to continue out to 2030 with even more dramatic improvements in energy efficiency taking place closer to the end of the period. In contrast to the other sectors, energy intensity per capita in the transport sector increased by 7% and 3% for light and heavy petroleum, respectively, during 2006–2012. The reference scenario assumes that energy intensity will continue to increase out to 2020, when the intensity is expected to be saturated, and then plateau between 2020 and 2030. Expected electric light rail services beginning in 2015 are also included in the reference scenario based on electricity demand projected by the Ethiopian Electric Power Corporation [43].

## 2.2. Alternative scenarios

As mentioned above, this study projects future energy demand under three alternative scenarios: a universal improved cookstove (ICS) scenario, an efficient lighting scenario, and a universal electrification scenario. These alternative policy options were chosen because they were identified as key priorities of the government in several strategy documents, including the Updated Rapid Assessment and Gap Analysis Report on Sustainable Energy for All by the Ministry of Water, Irrigation and Electricity [37]; the Growth and Transformation Plans by the Ministry of Finance and Economic Development [10,38]; and Ethiopia's Climate-Resilient Green Economy Strategy [11]. These policy documents highlight the importance of increasing energy efficiency, expanding energy access and mitigating GHG emissions from energy sector in Ethiopia. This study further explores the implications of these alternative policy scenarios to provide some insights for policymakers. Such analysis is useful to guide policy and investment decisions given funding constraints, by showing which options provide the greatest benefits for the country.

### 2.2.1. The improved cookstove (ICS) scenario

This policy scenario explores the energy-saving potential and GHG mitigation opportunities of a more rapid expansion of improved cookstoves compared to the reference scenario. Given that firewood is likely to remain the primary source of cooking fuel into the future, particularly for rural households, increased diffusion of ICS has the potential to dramatically reduce demand for firewood by improving energy efficiency. Table 3 shows the diffusion rates of improved cookstoves in 2020 and 2030 compared to the base year of 2012 under the reference and universal ICS scenarios. The universal ICS scenario assumes increased diffusion of ICS so that 80% of urban electrified households, 70% of urban households without electricity, 50% of rural electrified households, and 40% of rural households without electricity will use ICS by 2020. This scenario further assumes that the adoption of ICS will increase even further out to 2030 to 100%, 90%, 80%, and 70% for each of these household categories, respectively. The ICS scenario also assumes a gradual increase in the efficiency of traditional stoves using agriculture residues which amounts to energy savings of up to 10% by 2030.

### 2.2.2. The efficient lighting scenario

The efficient lighting scenario assumes a faster diffusion rate of efficient tube lamps and CFL compared to the reference scenario.

**Table 3**
Penetration rate of households using improved cookstoves in the reference and universal ICS scenarios.

| Household category | Base year | Reference scenario | | Universal ICS scenario | |
|---|---|---|---|---|---|
| | 2012 | 2020 | 2030 | 2020 | 2030 |
| Urban electrified households | 20 | 25 | 30 | 80 | 100 |
| Urban non-electrified households | 15 | 20 | 25 | 70 | 90 |
| Rural electrified households | 10 | 15 | 20 | 50 | 80 |
| Rural non-electrified households | 6 | 10 | 15 | 40 | 70 |

Given that tube lamps and CFL are 30% and 70% more efficient than incandescent bulbs, respectively, more rapid adoption of these energy efficient lighting sources would provide considerable electricity savings. The efficient lighting scenario assumes that efficient tube lamps will be used by 30% in 2020 and 60% of electrified households in 2030. Use of CFL increases to 20% in 2020 and 40% of electrified households in 2030. In this scenario, use of incandescent bulbs drops to 50% in 2020 and this lighting source is phased out completely in 2030. As in the reference scenario, differences in electricity consumption for lighting per household between urban and rural households are assumed to influence the total energy savings from switching to improved lighting sources in the efficient lighting scenario. Table 4 compares the penetration rates of various lighting sources under the reference and efficient lighting scenarios.

#### 2.2.3. The universal electrification scenario

The third alternative scenario assumes more rapid expansion of access to electricity through the national grid compared to the reference scenario. Specifically, under the universal electrification scenario it is assumed that 95% and 100% of the urban population will have access to electricity in 2020 and 2030, respectively. Even more dramatic expansion of electricity is assumed for rural areas of 50% by 2020 and 100% by 2030. This scenario also assumes a more rapid rate of urbanization than in the reference scenario: 30% by 2030, compared to 21.4%. Other sector parameters remain unchanged from the reference scenario values. In particular, this scenario does not assume an increase in the usage rate of electric stoves among electrified households.

### 2.3. Limitations of the model

LEAP is not a model for a specific energy system—rather, the model works as a tool that can be used to generate frameworks for different energy systems. This study develops the framework for LEAP model projections of Ethiopia's energy demands using a bottom-up approach for the household sector (energy intensity per household) and a top-down approach for all other sectors (intensity per GDP). The technique and mathematical equations for final energy demand analysis applying LEAP model have discussed in many studies and can be found in Refs. [19,23,57]. Data used to develop this framework were compiled from different sources as there is no systematic practice to collect energy data in Ethiopia. The modeling results are, therefore, limited by the availability and quality of data used to develop the framework for the Ethiopian energy system.

Furthermore, this study does not estimate the investment that is required for the alternative policy options to save energy and improve energy access. The LEAP model is simply a demand-driven, physical accounting system that does not have the capacity for economic optimization—it only optimizes electric generation [58]. The model also has no capacity to allow energy costs to affect overall economic growth. LEAP is, therefore, not suitable for detailed financial planning as it is unable to identify to find least-cost policy solutions.

**Table 4**
Percent of electrified households using efficient lighting in the reference and efficient lighting scenarios.

| Light type | Base year | Reference scenario | | Efficient lighting scenario | |
|---|---|---|---|---|---|
| | 2012 | 2020 | 2030 | 2020 | 2030 |
| Existing bulb | 75 | 65 | 50 | 50 | 0 |
| Efficient tube lamp | 15 | 20 | 30 | 30 | 60 |
| CFL | 10 | 15 | 20 | 20 | 40 |

## 3. Simulation results

### 3.1. The reference scenario

As described above, the reference scenario projects historical trends into the future using the best available data on population growth, economic activities, electrification, and energy consumption. This scenario provides a baseline case against which alternative policy options are evaluated. The LEAP model results for the reference scenario show energy demand increasing across all economic sectors out to 2030. Total energy demand is projected to increase from 1358 PJ in 2012 to about 2120 PJ in 2030 (Table 5), which amounts to an annual average growth of 2.1% during the study period. The largest expected increases come from the industrial sector—results show average growth from 2012 to 2030 to be 11.6% annually (from 15.8 PJ in 2012 to 113.1 PJ in 2030). The dramatic increase in industrial sector energy demand is due to structural transformation of the Ethiopian economy from agriculture to industry. Agriculture and transport show the next highest growth rates in energy demand to 2030 at 4.3% and 4.2%, respectively. Energy demand from the services industry also is projected to grow at 2.7% per year to 2030. The model also projects an increase in energy demand of the household sector from 1340 PJ in 2012 to 1796 PJ in 2030. Total household sector energy demand increases by only 1.34 times during the analysis period suggesting that energy demand per household is almost saturated and that slight increases in demand are due to population growth. While energy demanded by the household sector is projected to grow only 1.6% annually to 2030, this sector still consumes the largest share of energy compared to other economic sectors—accounting for 84.7% of total energy demand in 2030. However, this represents a decrease from the base year (2012) in which the residential sector consumed 91.9% of total energy. Fig. 2 shows that most of the decline in the share of residential energy consumption comes from rural areas while the share of energy consumed by urban households remains roughly the same, given that urbanization is expected to increase into the future. Energy consumed by the agriculture and services sectors as a share of total energy consumption also remains relatively flat between 2012 and 2030, while slight increases in the share of energy consumed by transport and industry can be observed in Fig. 2.

Given the large contribution of the residential sector to total energy demand, it is useful to analyze trends in the urban and rural sub-sectors. Table 6 presents energy demand by urban and rural households out to 2030 for different fuel types. The table shows that rural households are expected to continue to consume large amounts of firewood out to 2030 although the annual average growth rate is only 1.4% between 2012 and 2030. While the growth rate in demand for other fuels such as LPG, charcoal, and electricity, are considerably higher, at 17.5%, 16.8%, and 9.1%, respectively, these fuel sources still comprise a small share of total energy demand in 2030 among rural households. Similarly, among urban households, the growth in firewood demand is somewhat lower than growth in demand for other fuels such as electricity and charcoal. However, firewood still comprises the bulk of total energy demanded in 2030. At the same time, demand for other biomass energy resources, such as crop residues and animal dung, is expected to decline by 2.8% annually among urban households during the study period. Demand for electricity and charcoal increase by 7.0% and 5.5% annually, respectively, among urban households out to 2030, while demand for other fuel sources remains limited. Overall in household sector, electricity demand increases from about 1.6 TWh in 2012 to about 6 TWh in 2030 with an average annual growth of 7.6% during the study period. This represents an increase of 3.6 and 4.8 times among urban and rural households, respectively, compared

**Table 5**
Energy demand by sector (PJ).

| Sectors | 2012 | 2015 | 2020 | 2025 | 2030 | 2012–30 Ann. Avg. growth (%) |
|---|---|---|---|---|---|---|
| Household | 1340.0 | 1343.2 | 1422.0 | 1574.3 | 1796.4 | 1.6 |
| Agriculture direct energy | 14.1 | 17.4 | 19.7 | 28.4 | 30.1 | 4.3 |
| Service and other | 15.4 | 18.0 | 18.7 | 26.0 | 24.8 | 2.7 |
| Industry | 15.8 | 31.4 | 45.7 | 80.3 | 113.1 | 11.6 |
| Transport | 73.0 | 92.5 | 127.2 | 141.2 | 155.3 | 4.3 |
| Total | 1458.3 | 1502.6 | 1633.3 | 1850.3 | 2119.8 | 2.1 |

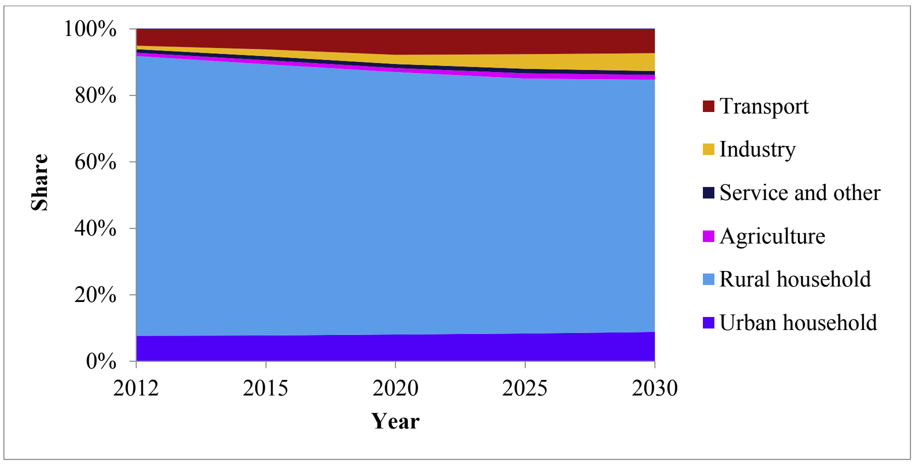


**Fig. 2.** Sector-wise percentage share of energy consumption.

**Table 6**
Energy demand by urban and rural households (PJ).

| Fuels | Urban households | | | | Rural households | | | |
|---|---|---|---|---|---|---|---|---|
| | 2012 | 2020 | 2030 | 2012–30 Ann avg. growth (%) | 2012 | 2020 | 2030 | 2012–30 Ann avg. growth (%) |
| Electricity | 4.2 | 6.7 | 14.3 | 7.0 | 1.5 | 2.6 | 7.2 | 9.1 |
| Kerosene | 0.3 | 0.4 | 0.4 | 1.2 | 5.9 | 6.6 | 8.7 | 2.2 |
| LPG | 0.1 | 0.1 | 0.1 | 3.2 | 0.0 | 0.0 | 0.2 | 17.5 |
| Wood | 99.2 | 113.8 | 155.2 | 2.5 | 1172.6 | 1220.4 | 1514.0 | 1.4 |
| Charcoal | 5.9 | 8.4 | 15.6 | 5.5 | 0.3 | 0.9 | 4.2 | 16.8 |
| Biomass | 2.4 | 2.3 | 1.5 | −2.8 | 47.6 | 59.9 | 75.2 | 2.6 |
| Total | 112.1 | 131.6 | 187.0 | 2.9 | 1227.9 | 1290.4 | 1609.4 | 1.5 |

to the base year consumption values.

Table 7 shows Ethiopia's total energy demand by different fuel sources between 2012 and 2030. Demand for all fuel sources is increasing over this period but is particularly high for some fuel sources. The projections show that demand for oil, electricity, and LPG will grow rapidly between 2012 and 2030 at an annual growth rate of 11.3%, 9.7%, and 8.3%, respectively. Demand for charcoal and gasoline will also grow considerably during this period at an annual rate of 6.7% and 6%, respectively. While the rate of growth in demand for fuelwood is only 1.6% annually to 2030, fuelwood still comprises the largest share of energy demand in 2030 at 79.9% of total energy demand.

Fig. 3 compares the energy demand projections from this study with those of the earlier Ethiopian energy economy report [15]. The report projected energy demand from 2008 to 2030. The report does not provide the observed value of energy consumption for 2011 and 2012, but rather estimates them based on an average annual growth of 4.9%. The present study uses 2012 as the base year and, therefore, is able to integrate more recent historical data on energy demand. Like the Energy Economy report, this study also projects energy demand by sector. However, it also includes a

**Table 7**
Total energy demand by fuel (PJ).

| Fuels | 2012 | 2015 | 2020 | 2025 | 2030 | 2012–30 Ann. Avg. growth (%) |
|---|---|---|---|---|---|---|
| Electricity | 15.1 | 24.2 | 34.1 | 56.4 | 80.0 | 9.7 |
| Gasoline | 23.4 | 33.2 | 50.1 | 58.5 | 66.6 | 6.0 |
| Kerosene | 6.2 | 6.4 | 7.0 | 7.9 | 9.1 | 2.2 |
| Diesel | 59.8 | 75.3 | 98.7 | 119.5 | 137.5 | 4.7 |
| LPG | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 8.3 |
| Oil[a] | 3.8 | 7.5 | 10.8 | 18.7 | 25.8 | 11.3 |
| Wood | 1284.0 | 1284.3 | 1350.8 | 1493.9 | 1693.2 | 1.6 |
| Charcoal | 6.2 | 7.1 | 9.2 | 13.5 | 19.7 | 6.7 |
| Biomass | 59.8 | 64.6 | 72.5 | 81.7 | 87.5 | 2.1 |
| Total | 1458.3 | 1502.6 | 1633.3 | 1850.3 | 2119.8 | 2.1 |

[a] Oil refers here "other petroleum" than light and heavy petroleum used in industry sector only based on energy balance sheets.

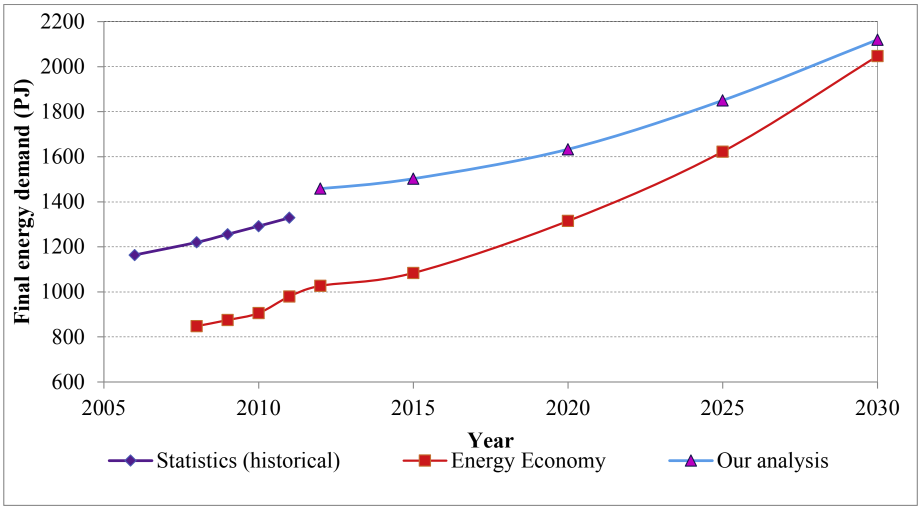


**Fig. 3.** Energy demand comparisons.

comprehensive analysis of household sector (which is, by far, the largest consumer of energy in Ethiopia) including all existing end use technologies and their energy consumption per household. As a result, actual energy demanded was much higher in the present study than the Energy Economy report projected in 2008 and 2011. The projections in this study follow these recent trends and predict higher energy demand out to 2030. However, as shown in the figure, energy demand in the two studies start to converge by 2030, with the projections in this study only slightly higher than those of the Energy Economy report (2120 PJ compared to 2047 PJ). This convergence can be attributed to the fact that this study incorporated energy efficiency improvement opportunities in the future years in the reference scenario based on the existing practices and that reduces energy demand in later years.

Senshaw's (2014) study of Ethiopian energy scenarios [14] using the LEAP model projected much higher demand out to 2050. The study applied a top-down approach considering average GDP growth of 7% between 2006 and 2050, GDP growth by sectors, and limited energy efficiency improvement opportunities in the residential sector in the reference scenario for energy demand and supply projections that led to the higher projected energy demand. Specifically, the study found that energy demand increases from 1313 PJ in 2010 to 1606 PJ in 2015, 2934 PJ in 2030 and 6552 PJ in 2050. The present study applies bottom-up and top-down approaches and energy intensity method for energy demand projection that are more accurate and reliable. The energy demand projected in the present study falls within the range of these two previous studies.

The Ethiopian Power System Expansion Master Plan Study [16] shows that domestic electricity demand would be 11.2 TWh by 2030 and 17.6 TWh by 2037. The report also mentions that the Ethiopian Electric Power Corporation projects that domestic demands will be 10 TWh in 2030 and 16.4 TWh in 2037. Our study shows that total household demand would be 11.06 TWh in 2030. This result is comparable to the previous projections of domestic electricity demand.

Previous projections of the country's total electricity demands, however, are dramatically different. Acres International (a North American-based power and energy consulting farm) projected Ethiopia electricity demand (using regression analysis) to be 6.02 TWh in 2033 and Parsons Brinckerhoff Consultant's forecasts energy demand to be 77.4 TWh by 2033, a significant difference between the two forecasts. Our study shows that total electricity demand would be 27.3 TWh by 2030 under the universal electrification scenario. This result is a more realistic target for policy makers to meet the future demand through various energy supply options.

The rise in energy demand is naturally accompanied by an increase in GHG emissions. The model estimates $CO_2$ emissions to increase from 6.7 million metric tons (mmt) in 2012 to 17.2 mmt in 2030. These figures also show the similar past growth trend of $CO_2$ emissions from 5.8 mmt in 2000 to 6.4 mmt in 2010. Table 8 shows fuel-wise GHG emissions during the analysis period. Total GHG emissions are expected to rise by 1.8 times with respect to the base year value of 16.9 mmt. GHG emissions from diesel are projected to rise 4.7% annually between 2012 and 2030 reaching 10.1 mmt of $CO_2$ equivalent by 2030 (from 4.4 mmt $CO_2$ equivalent in 2012). Table 8 shows that the largest share of GHG emissions come from burning wood and diesel, as these fuels are mainly used for cooking and lighting in the residential sector. The largest growth in GHG emissions over the period between 2012 and 2030 come from oil, LPG, charcoal and gasoline, however, these fuel sources are responsible for only a small share of total emissions in 2030.

### 3.2. *Efficient lighting scenario*

Results for the efficient lighting scenario show large savings in energy out to 2030 compared to the reference scenario (Fig. 4). Expansion of efficient lighting would result on slower growth of electricity demand—an average of 3.4% per year between 2012 and 2030 compared to 7.6% under the reference scenario. This results in a savings of electricity in the household sector of 289 GWh, 1265 GWh and 3061 GWh in 2020, 2025 and 2030, respectively. The

**Table 8**
GHG emissions by fuel type (million metric tons (mmt) $CO_2$ equivalent).

| Fuels | 2012 | 2015 | 2020 | 2025 | 2030 | 2012-30 Ann. Avg. growth (%) |
|---|---|---|---|---|---|---|
| Gasoline | 1.6 | 2.3 | 3.5 | 4.1 | 4.7 | 6.0 |
| Kerosene | 0.5 | 0.5 | 0.5 | 0.6 | 0.7 | 2.2 |
| Diesel | 4.4 | 5.5 | 7.3 | 8.8 | 10.1 | 4.7 |
| LPG | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.3 |
| Oil | 0.3 | 0.6 | 0.8 | 1.4 | 1.9 | 11.3 |
| Wood | 9.7 | 9.7 | 10.2 | 11.3 | 12.8 | 1.6 |
| Charcoal | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 6.7 |
| Biomass | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 2.1 |
| Total | 16.9 | 19.1 | 22.8 | 26.7 | 30.8 | 3.4 |

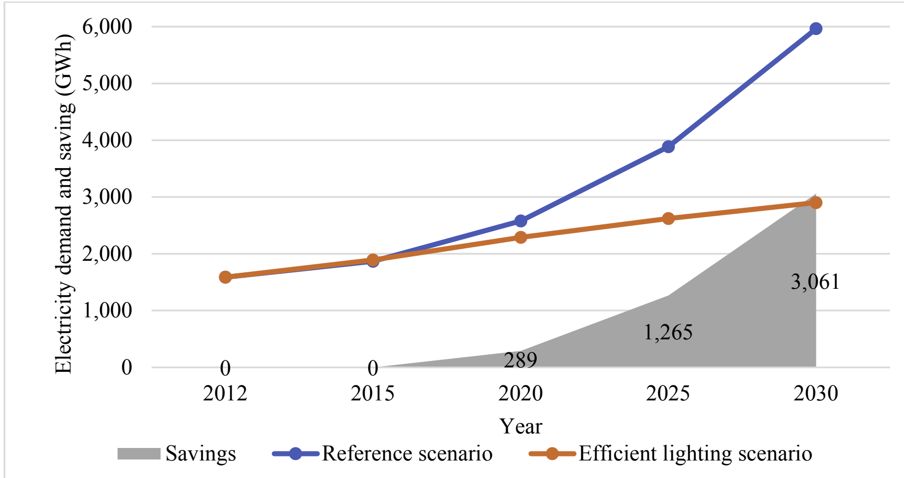


**Fig. 4.** Average residential sector electricity demand in GWh under the efficient lighting and reference scenarios.

results from this scenario suggest that promoting efficient light bulbs in the residential sector would minimize the need for electricity supply.

### 3.3. *Improved cookstove scenario*

Under the ICS, the residential sector would save 241 PJ of energy in 2030 compared to the reference scenario, which amounts to total savings of 13.4% (Fig. 5). Most of these savings come from a reduction of demand for firewood (233.2 PJ) and a very small portion comes from savings in demand for biomass (7.7 PJ). Given the heavy use of biomass energy resources in Ethiopia out to 2030 these savings have positive implications for the level of GHG emissions. Specifically, a greater dissemination of ICS would reduce greenhouse gas emissions by 0.8 mmt of $CO_2$ equivalent in 2020 and 1.8 mmt of $CO_2$ equivalent in 2030. This represents a reduction in GHG emissions of 3.5% and 5.8% in 2020 and 2030, respectively, compared to the reference scenario. Such reductions would contribute to Ethiopia's goal of promoting a low carbon society.

### 3.4. *Universal electrification scenario*

Under the universal electrification scenario, demand for electricity would increase considerably in the household sector due to an increase in the rate of electrification (Fig. 6). Total electricity demand is projected to increase from 4192 GWh in 2012 to 27,321 GWh in 2030 in the universal electrification scenario (Table 9). By 2030 demand for electricity would be 5094 GWh higher under the universal electrification scenario compared to the reference scenario. The average annual growth in electricity demand by the household sector is expected to be 11.38% during the study period under this scenario. In particular, demand by urban households is expected to grow from 1170 GWh in 2012 to 5839 GWh in 2030, with an average annual growth rate of 9.3%, while demand by rural households would increase dramatically from 418 GWh in 2012 to 5218 GWh in 2030, with an annual growth rate of 15.1%. This growth rate is very high due to the huge number of rural households that would gain access to electricity by 2030 under this scenario. These results show that meeting the Ethiopian government's target to provide universal electricity access by 2030 would require a significant investment additional power plants to meet the growth of projected demand compared to the baseline scenario.

The implications for GHG emissions in this scenario would be negligible given that electricity would be mostly generated from renewable sources (hydropower). Overall electricity demand share

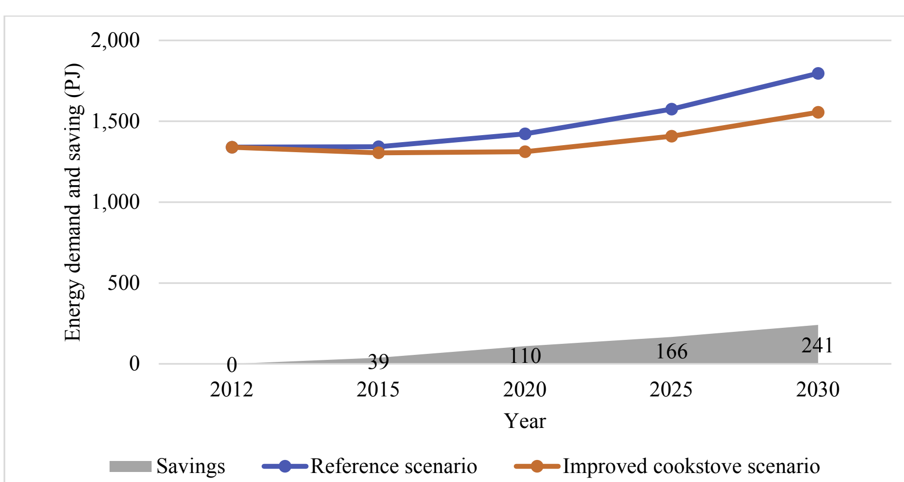


**Fig. 5.** Energy demand (PJ) in the household sector under the improved cookstove scenario compared to the reference scenario.

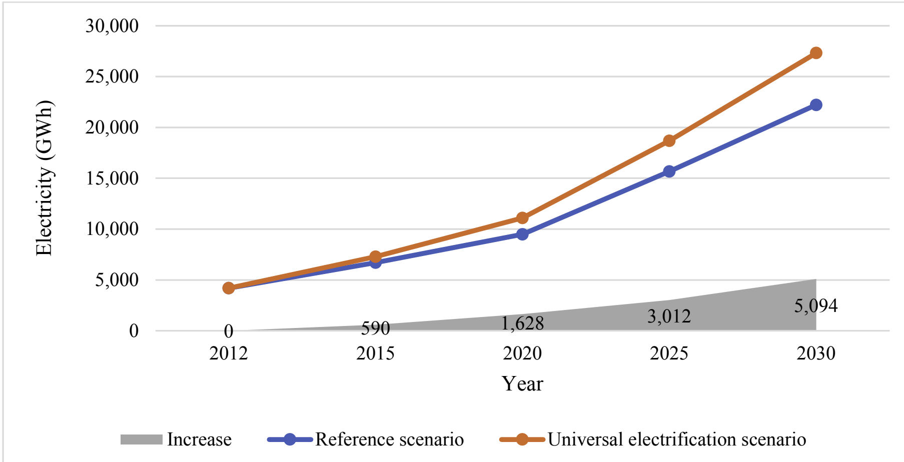


**Fig. 6.** Electricity demand under the universal electrification scenario compared to the reference scenario (GWh).

**Table 9**
Sector-wise electricity demand (GWh) under the universal electrification scenario.

| Electricity | 2012 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Urban | 1170 | 1503 | 2347 | 3682 | 5839 |
| Rural | 418 | 895 | 1860 | 3215 | 5218 |
| Agriculture | 38 | 53 | 77 | 133 | 180 |
| Service | 1029 | 1355 | 1648 | 2580 | 3017 |
| Industry | 1536 | 3089 | 4580 | 8263 | 11,998 |
| Transport | 0 | 405 | 596 | 817 | 1069 |
| Total (GWh) | 4191 | 7300 | 11,108 | 18,690 | 27,321 |

by sector is presented in Fig. 7. The residential and industrial sectors account for the largest shares of electricity demand at 37.9% and 36.6%, respectively, in 2012. Due to expected industrial development, which would increase the sector's share of GDP, electricity demand share also increases significantly in 2030 to 43.9%. The residential sector's share of electricity demand also increases slightly to 40.5% by 2030. Growth rates of electricity demand are high in the transport, agriculture, and services sectors. However, these sectors represent a smaller share of total electricity demand out to 2030 compared to the household and industrial sectors.

## 4. Potential to achieve Ethiopia's sustainable energy development goals

The Ethiopian government has emphasized the importance of sustainable energy development in different policy documents such as GTP [10], green economy strategy [11], sustainable energy for all [37] and biomass energy strategy [39]. Model simulation results provide important insights regarding the potential for Ethiopia to achieve its sustainable development goals (Table 10). The indicators of sustainable energy development identified by the World Energy Council (WEC) fall into 3 categories: environmental sustainability, energy security and energy equity [59]. Historical and projected values for some of these sustainable development indicators for the reference and alternative scenarios are presented in Table 9. The environmental sustainability indicators include $CO_2$ emissions per capita and $CO_2$ intensity per GDP. As this study did not deal with energy supply, energy security indicators are not provided as these indicators refer to import/export dependency and diversification of energy use to meet the demand. Energy equity indicators can be derived by using electricity use per capita as energy development requires a transition to modern fuel sources, a decrease in energy poverty, and an increase in energy affordability [60].

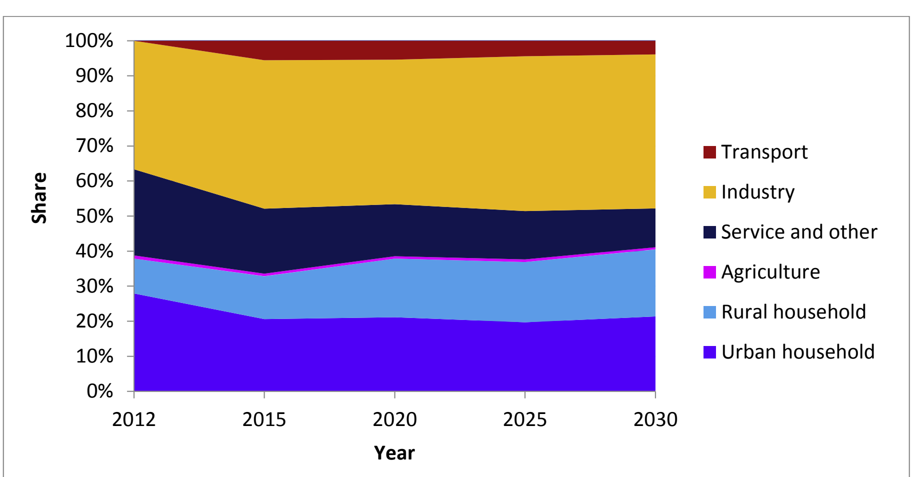


**Fig. 7.** Percentage share of electricity demand by sector under the universal electrification scenario.

**Table 10**
Summary of statistical [3] and projected Ethiopian energy development indicators.

| Indicators | Scenario | 2000 | 2008 | 2012 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ intensity (kg of $CO_2$/kg of oil equivalent) | Reference | 0.23 | 0.202 | 0.193 | 0.245 | 0.307 | 0.333 | 0.340 |
| | ICS | | | 0.193 | 0.198 | 0.200 | 0.193 | 0.183 |
| $CO_2$ emissions (kt) | Reference | 5830 | 6369 | 6717 | 8805 | 11,973 | 14,723 | 17,219 |
| | ICS | | | 6717 | 7115 | 7804 | 8514 | 9244 |
| $CO_2$ per capita (ton/capita) | Reference | 0.088 | 0.077 | 0.071 | 0.089 | 0.109 | 0.121 | 0.129 |
| CO2 per GDP (kg/USD) | Reference | 0.64 | 0.312 | 0.268 | 0.235 | 0.206 | 0.136 | 0.109 |
| Electricity consumption (GWh) | Reference | 1507 | 3399 | 4191 | 6710 | 9480 | 15,678 | 22,227 |
| | Universal electrification | | | 4191 | 7300 | 11,108 | 18,690 | 27,321 |
| Electricity per capita (kWh/Cap) | Reference | 22.83 | 41.13 | 45.69 | 67.98 | 85.94 | 128.50 | 166.37 |
| | Universal electrification | | | 45.69 | 73.96 | 100.71 | 153.20 | 204.50 |

Per capita $CO_2$ emissions in Ethiopia are relatively low as the country produces electricity mostly from hydropower. Per capita electricity consumption is projected to increase from about 46 kWh in 2012 to about 166 kWh in 2030 in the reference scenario and increases even more under the universal electrification scenario to 204 kWh. Across all sub-Saharan African countries, electricity consumption per capita increased from 511 kWh in 1995 to 529 kWh in 2010. This study shows that Ethiopian electricity sector development follows the past trend of Kenya—per capita electricity consumption in Kenya increased from 127 kWh in 1995 to 155 kWh in 2010. The comparison with Kenya is reasonable considering Ethiopia's economic structure and lower per capita energy reference value compared to the other developing countries in the region.

## 5. Conclusions

This paper provides best-guess forecasts of energy demand in Ethiopia to 2030 (the reference scenario) based on a comprehensive modeling approach which considers the current energy situation of the country and ongoing economic dynamics. This study also considers important policy priorities of the Ethiopian government and projects energy demand under three alternative scenarios based on these priorities: an efficient lighting scenario, an improved cookstove scenario, and a universal electrification scenario. The alternative scenario results show the impacts of these policies compared with the reference scenario. Energy sector development indicators are also estimated in order to provide a comparison with other developing countries.

The results show that the expansion of efficient lighting and improved cookstoves has the potential to significantly reduce demand for energy compared to the reference scenario. The improved cookstove scenario also has significant potential to reduce GHG emissions—results show this scenario helps to reduce about 5.8% of GHG emissions in 2030 compared to the reference scenario. On the other hand, more rapid expansion of electricity would increase demand for energy considerably, which would require additional investment in energy infrastructure to increase energy supply. The universal electrification scenario increases per capita electricity consumption to 204 kWh in 2030 compared to 166 kWh under the reference scenario. Although this value is low compared to other sub-Saharan African countries, where average per capita electricity consumption was 529 kWh in 2010, it still represents a large increase for the country. Electricity demand growth is projected to grow by 9.7% and 11% annually during 2012–2030 in reference and universal electrification scenario, respectively. This growth signals to policy makers that an investment in additional power generation capacities will be required to meet future energy demand to meet the government vision to provide “Light to All”.

The study results suggest that efforts to promote and strengthen the energy efficiency improvement program will help the country meet future energy demand while contributing to sustainable energy development.

The results also show that the growth in demand for energy will have implications for the level of GHG emissions. GHG emissions are expected to almost double between 2012 and 2030 under the reference scenario. Only the expansion of improved cookstoves has the potential to slightly reduce the level of greenhouse gas emissions by reducing consumption of firewood and other biomass fuel sources. In the absence of alternative technologies for cooking (such as the expansion of electric stoves), there is unlikely to be considerable savings in GHG emissions given that a considerable share of emissions come from burning firewood for cooking.

The results of the simulation modeling show that previous projections of energy demand out to 2030 and 2050 either under- or over-estimate the likely growth in demand for energy given recent economic trends. This may impede the development of a coherent overall energy policy as well as the healthy development of the electricity sector, in particular. Realistic energy demand forecasts that take into account possible technological changes and energy conservation measures, such as socio-economic dynamics, are, therefore, essential for the development of the energy sector and the design of energy policies.

This modeling approach provides significant insights on policy decisions in Ethiopia regarding energy supply options. The selection of least-cost technologies to supply energy is crucial for Ethiopia to meet the projected energy demand (specifically electricity) if the country is to achieve universal electricity access.

## Acknowledgement

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