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**Working Paper**

## Energy futures modelling for African countries: LEAP model application

WIDER Working Paper, No. 2017/56

**Provided in Cooperation with:**

United Nations University (UNU), World Institute for Development Economics Research (WIDER)

*Suggested Citation:* Ouedraogo, Nadia S. (2017) : Energy futures modelling for African countries: LEAP model application, WIDER Working Paper, No. 2017/56, ISBN 978-92-9256-280-9, The United Nations University World Institute for Development Economics Research (UNU-WIDER), Helsinki, <https://doi.org/10.35188/UNU-WIDER/2017/280-9>

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WIDER Working Paper 2017/56

## **Energy futures modelling for African countries**

LEAP model application

Nadia S. Ouedraogo\*

March 2017

**Abstract:** This study develops a scenario-based model to assess the current and future trends in energy demand in Africa and associated greenhouse gas emissions. Future energy demand is forecast on the basis of socio-economic variables such as gross domestic product, income per capita, population, and urbanization. The Long-range Energy Alternative Planning model is applied to analyse and project energy demand and the related emissions under alternative strategies for the period 2010–2040. Two main policy implications can be derived from the results of this study. First, it is essential for Africa to promote energy conservation policies that will improve energy efficiency and address issues related to energy shortages, energy poverty, and energy security. Second, policies that favour cleaner energies over other sources are required as early as possible to displace fossil fuel usage and to support sustainable economic development.

**Keywords:** energy forecasting, energy efficiency, renewables, sustainable energy for all, carbon emission intensity, climate change

**JEL classification:** Q47, Q41, Q42, Q43, Q48, Q50

**Acknowledgements:** This research project started while the author was a Research Fellow at UNU-WIDER. She acknowledges support from UNU-WIDER's project 'Africa's energy futures'. The views expressed here are those of the author and do not necessarily represent or reflect those of UNECA.

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This study has been prepared within the UNU-WIDER project on 'Africa's energy futures'.

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ISSN 1798-7237 ISBN 978-92-9256-280-9

Typescript prepared by Joseph Laredo.

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The Institute is funded through income from an endowment fund with additional contributions to its work programme from Denmark, Finland, Sweden, and the United Kingdom.

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The views expressed in this paper are those of the author(s), and do not necessarily reflect the views of the Institute or the United Nations University, nor the programme/project donors.

## 1 Introduction

Since 2000, Africa has been experiencing economic growth, and energy consumption has risen by 45 per cent (IEA, 2014). However, the regional energy systems are under-developed and unable to meet the demand of the populations. Indeed, despite energy resources more than sufficient to meet domestic needs, access to modern energy services remains limited. Nearly two-thirds of Africans (more than 620 million people) do not have access to electricity and nearly 730 million rely on traditional solid biomass for cooking. Those that do have access rely on very expensive, low-quality supply (IEA 2014). Meeting the growing energy demand of their population and ensuring universal access to modern energy services with respect to the environment is thus the principal goal of African countries.

To that end, it is vital for African countries to develop energy demand management strategies that will ensure that any energy supply/demand-related policies and investment decisions take into account all feasible demand- and supply-side options, and are consistent with global sustainability goals (Bazilian et al. 2012). Energy demand modelling that will predict energy consumption patterns and trends is a crucial component of energy management. It enables the formulation of strategies and recommendations for energy policies that will lead to efficient management and effective utilization of energy resources, improvements in energy efficiency and energy reliability, and emissions reductions (Charles River Associates 2005).

Energy demand models can be categorized in terms of what is modelled (energy system, energy demand, or energy supply) and the modelling methodology applied (engineering-economy, econometric, optimization, simulation, partial or general equilibrium, and end-use accounting) (Edenhofer et al. 2010). A basic distinction is often made between a top-down approach, based on an econometric approach and requiring a small amount of data, and a bottom-up approach, which is suitable for detailed analysis of energy policies but is data-intensive (Urban et al. 2007; van Beeck 1999). Though this common distinction is widespread, the top-down and bottom-up approaches are not mutually exclusive. A ‘hybrid’ approach that combines the features of both also exists. Hybrid methodologies help to detect missing information and dynamics that cannot be detected by either a top-down or a bottom-up approach alone (Hourcade et al. 2006).

These different modelling methodologies have been extensively used to analyse energy demand and policy and planning concerns in developed countries, and some have been applied to investigating similar policy and planning concerns in developing economies.

Traditionally, most developing countries have adopted end-use approaches to energy demand modelling. Top-down approaches have been used to assess economy-wide responses to policies and other driving variables through end-use behaviour and historical macroeconomic variables such as income or income per capita.

Bottom-up optimization approaches have been applied to addressing operational planning issues at an individual utility level. They are also used for analysing medium- to long-term capacity expansion, and for determining least-cost technology mixes (Pandey 2002).

In the specific case of Africa, the lack of data has led to a very sparse literature on energy demand modelling. The high reliance on traditional energies and the existence of large informal sectors bring challenges to the modelling exercise in Africa. Indeed, data on traditional energy prices and supply and on informal sectors are not always available. The energy sectors of developing countries are facing additional challenges that include inefficiency, characterized by poor performance of the

power sector and by supply shortages; energy poverty and inequity in energy access; and a high and rapid increase in demand for electricity. Moreover, African energy sectors are facing economic and social barriers to capital flow and technology diffusion, as well as frequent energy policy changes (Pandey 2002; Urban et al. 2007; Bhattacharyya et al. 2009). These factors differentiate the energy systems of developing countries from those of developed countries and make modelling and forecasting in the developing world challenging.

Therefore, most of the studies on Africa are focused on electricity demand, for which data can be easily found. These forecasting exercises—in terms of power generation capacity, capacity expansion, and demand—include Gnansounou et al. (2007), Rosnes and Vennemo (2012), Bazilian et al. (2012), Pachauri et al. (2012), Taliotis et al. (2014, 2016), Panos et al. (2015, 2016), and Ouedraogo (2017). In addition, the African sub-regions have carried out regional forecasting for electricity demand (Nexant 2004, 2009; African Development Bank 2008; SNC Lavalin and Parsons Brinckerhoff 2011; PIDA 2011; IRENA 2015).

Only a few studies on total energy demand modelling in the context of Africa exist. These studies include Howells et al. (2005), which employed a bottom-up framework TIMES model—an extension of the MARKAL energy modelling system—to project rural energy consumption in South Africa until 2018. They found, for the reference scenario, that total energy consumption increases from 7 terajoules in 2003 to 7.8 terajoules in 2018.

Riahi et al. (2011) developed global energy scenarios within the MESSAGE model to assess universal energy access in the most energy-poor regions, including Africa. They found that final energy demand per capita will stand at around 10 GJ in 2030.

Chakravarty et al. (2013) used the IEA's World Energy Outlook (IEA 2014) projections method to assess individual energy consumption by 2030. They found, for Africa, an aggregate final household energy consumption of 9.5 exajoule (EJ) in a business-as-usual (BAU) case in 2030. However, they concluded that an additional 9.7 EJ would be necessary to eradicate energy poverty in Africa.

Nevertheless, while this is challenging for developing country modellers, developing sound forecasting methods that will better reflect energy demand in the African context and deliver more reliable input to policy formulation is important for policy makers. An appropriate allocation of the available resources, thanks to proper energy management and energy planning policies, is crucial for economic development and environmental security in Africa. The provision of reliable, clean, and affordable energy to those who currently do not have access to such energy is vital for the development of a continent that accounts for 13 per cent of the world's population, but only 4 per cent of total world energy consumption.

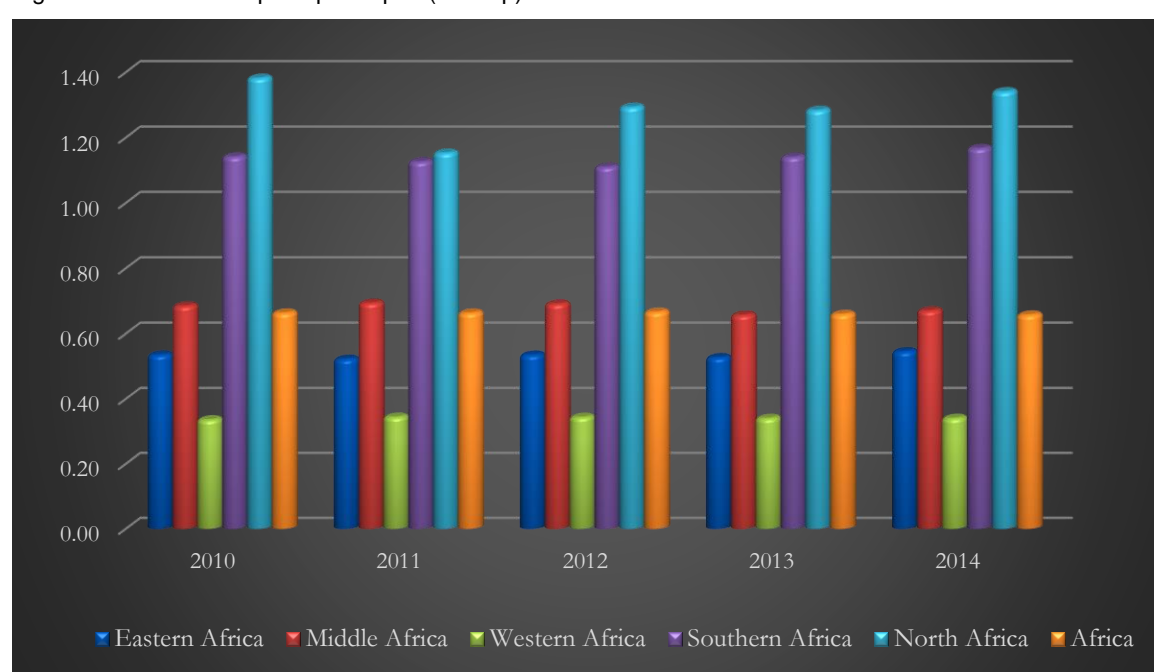
The purpose of the present study is to contribute to the existing literature on energy demand modelling in Africa by forecasting the total energy demand for African countries. Scenario-based modelling, using the Long-range Energy Alternatives Planning (LEAP) system (Heaps 2012), is applied to analyse and forecast energy demand and simulate alternative energy futures and their associated environmental effects for 52 African countries until the year 2040. Detailed end-use analysis of five sectors (residential, industry, agriculture, services, and transport) is combined with analysis of energy resources, power generation, and transmission and distribution. This system-based approach is well suited to energy demand modelling in the African context. It allows concerns and characteristics specific to African economies to be incorporated in the forecasting models so that they have good simulation capability and therefore generate a high degree of confidence in their results and long-term policy recommendations.

## 2 Overview of the energy sector in Africa

### 2.1 Energy access in Africa: a reflection of the economic situation

In 2014, primary energy demand in Africa was 752 million tonnes of oil equivalent (Mtoe), of which North Africa accounted for 20 per cent. In Sub-Saharan Africa (SSA), energy demand has increased by half since 2000, reaching 590 Mtoe in 2014. However, SSA countries still account for only 4 per cent of world energy demand. South Africa (141 Mtoe) and Nigeria (133 Mtoe) are the region's largest energy consumers, accounting together for more than 40 per cent of the total demand despite having only a quarter of the population. The average energy consumption per capita in Africa is only one-third of the global average and just 50 per cent of the level of Southeast Asia, the second most energy-poor region in the world (WEO 2014). The averages mask large differences in per capita consumption across SSA and between rural and urban areas (Figure 1).

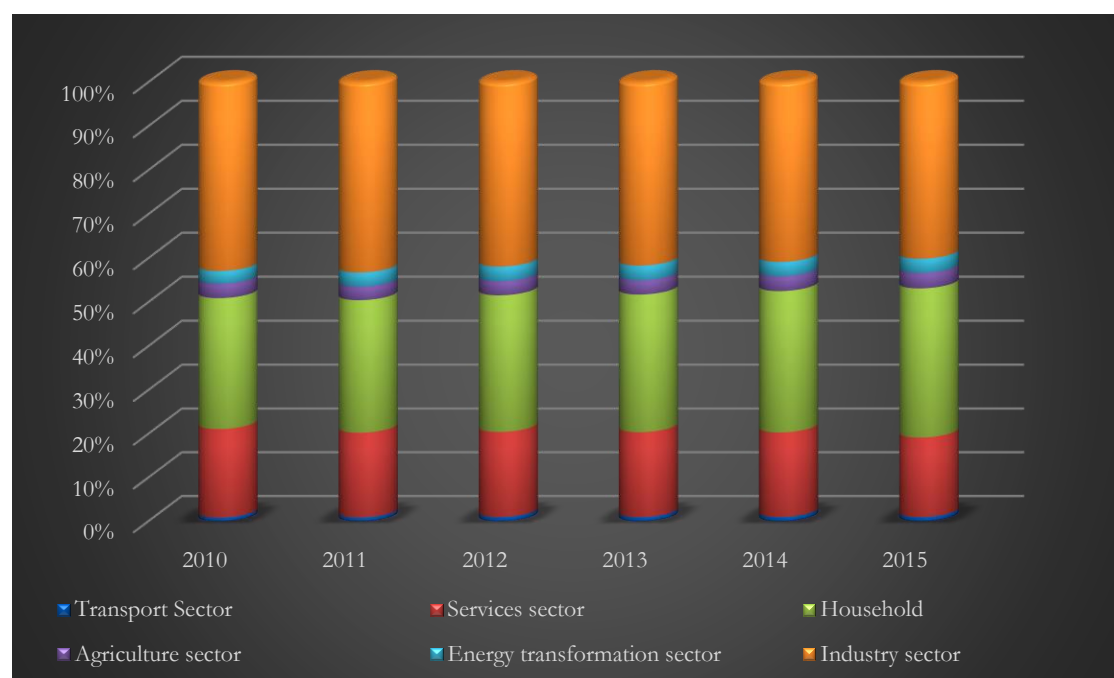
Figure 1: Total consumption per capita (toe/cap)



Source: Author based on Enerdata, 2015.

Electricity access in Africa is very low. For instance, electricity's share of final energy consumption is 7 per cent in SSA (4 per cent if South Africa is excluded), compared with 18 per cent globally. Industry (led by mining and refining activities), particularly because of its importance in South Africa, Nigeria, Ghana, and Mozambique, accounts for 50 per cent of electricity consumption (Figure 2).

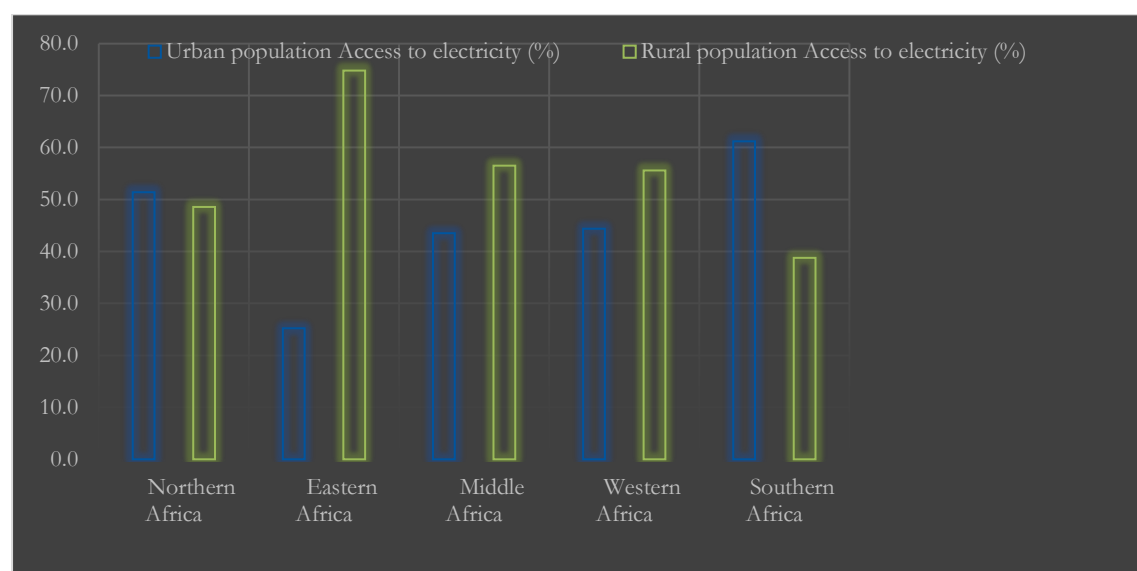
Figure 2: Consumption structure by sectors in Africa



Source: Author based on Enerdata, 2015.

The residential sector represents only 27 per cent of total electricity consumption. While 99 per cent of the total population of North Africa has access to electricity, in SSA more than 620 million people, almost half the population, have no access to electricity—and this number is increasing on account of rapid population growth. Per capita electricity consumption in Africa is thus the lowest of any region in the world (e.g. 75 per cent below that of developing Asia), and is significantly lower still in rural areas. Nearly 80 per cent of those lacking access to electricity across SSA live in rural areas (IEA 2014) (Figure 3).

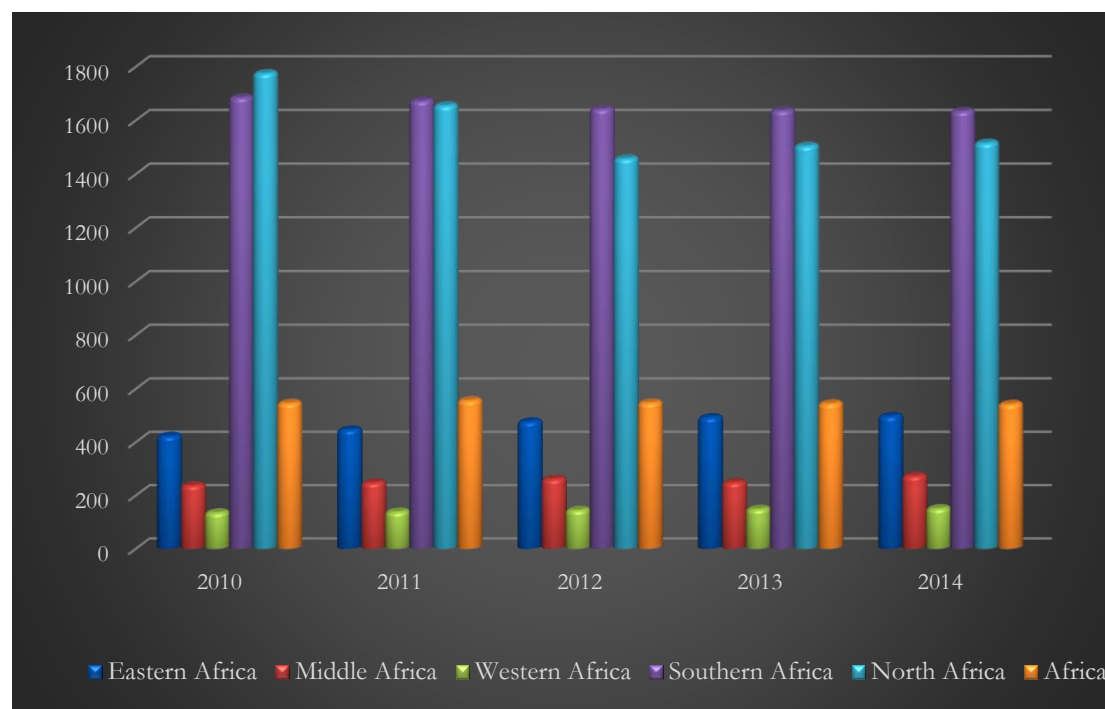
Figure 3: Urban/rural population access to electricity (%)



Source: Author based on Enerdata, 2015.

There are also disparities in consumption levels across and within the sub-regions.<sup>1</sup> Driven principally by very high levels in South Africa, average per capita consumption in Southern Africa is the highest of all the sub-regions. In 2014, average annual electricity consumption was about 250 kWh per capita in Middle Africa, 450 in East Africa, 490 in West Africa, and 1,600 kWh in Southern Africa (Figure 4).

Figure 4: Per capita electricity consumption (kWh/cap)



Source: Author based on Enerdata, 2015.

Energy poverty in Africa can also be measured by access to clean cooking facilities (i.e. fuels and stoves that do not cause air pollution). Almost 730 million people in SSA rely on traditional solid biomass (mainly wood and agricultural waste) for cooking. Nearly three-quarters of these people live in rural areas and they often spend many hours each day collecting wood (IEA 2014). In some countries, the share of biomass is as high as 90 per cent of the cooking mix.

## 2.2 Energy resources and supply in Africa

Regarding energy resources and supply in Africa, even if resources are spread unevenly across the continent and are at differing stages of development, the region is well endowed with energy resources. As a whole, Africa has enough resources—fossil fuel as well as renewable resources—to meet regional energy needs. However, despite significant potential and efforts in recent years to develop it, renewable resources remain almost entirely untapped. Modern renewable energies (hydro, solar, wind, geothermal, and non-traditional solid biomass) still account for less than 2 per cent of the SSA energy mix.

In particular, hydropower potential is significant but remains untapped. For instance, only 2 per cent of the hydro potential in the DRC, 5 per cent in Ethiopia, and 12 per cent in Congo has so

<sup>1</sup> Based on United Nations Country Grouping (see Table B1 for the regional classification adopted in this study).



far been developed (IEA 2014). Table 1 gives an overview of energy capacity and resources in Africa.

Table 1: Energy capacity and resources in Africa, 2015

	Africa	North Africa
Capacity		
Crude oil refining capacity (bbl/d)	3,739,500	1,991,100
Liquefaction capacity (LNG) (Mt/yr)	72	41
Installed hydroelectricity capacity (MW)	31,005	4,907
Installed thermal electricity capacity (MW)	139,163	66,595
Installed electricity capacity from solar (MW)	2,132	405
Installed geothermal electricity capacity (MW)	614	0
Resources		
Crude oil, NGL resources (mbl)	342,643	120,519
Natural gas resources (mcm)	83,275,000	45,170,000
Proved amount of coal in place (Mt)	122,572	91
Gross theoretical hydroelectric resources (Gwh)	3,855,300	150,000

Source: Author, based on Enerdata, 2015.

## 2.3 Economy

The economy of Africa grew at an average rate of 5 per cent from 2000 to 2014. Even if growth has been weaker in the last two years, due to the global economy downturns and the drop in commodities prices, this trend is expected to continue. In 2015, growth in real GDP in Africa was estimated at 3.6 per cent. Growth is highest in East Africa, followed by West Africa and Middle Africa, and is lowest in Southern Africa. In 2015, growth in Central, North, and West Africa was above 3 per cent, while average growth rates of 4.2 per cent and 2.2 per cent were observed in East Africa and Southern Africa, respectively (AfDB/OECD/UNDP 2016).

Yet, income per capita in the region remains significantly below that of the other regions of the world. Due to the rapid growth of population already mentioned, GDP per capita has increased more slowly, at only around 4.5 per cent (IEA 2014).

Overall, the growth of African economies is still stimulated by the agriculture sectors. The manufacturing sectors of some countries have registered improvements but remain constrained by lack of capital. The construction sector, driven by both public infrastructure programmes and private investment, is supporting growth in many countries. Services such as transport, trade, public and financial services, real estate, and new information and communication technologies are also contributing to growth in Africa (AfDB/OECD/UNDP 2016). This increase in productivity and growth will lead to an increase in energy needs and will put further strain on available resources.

## 2.4 Demography trend

The ongoing population changes in SSA have major implications for the development of the energy sector. The population is growing rapidly: it numbered nearly 950 million in 2015 and is

expected to reach 1 billion before the end of this decade. Growth will be particularly rapid in West and East Africa (IEA 2014).

Population growth is uneven between urban and rural areas, but SSA is expected to continue to see significant growth in both its urban and rural populations (UN 2015). This growth trend exacerbates many existing challenges, including expanding access to modern energy services (IEA 2014). Extensive and specific efforts, including effective solutions for rural as well as urban and peri-urban communities, are thus necessary to address African energy issues.

### **3 Modelling approach**

Traditionally, top-down and bottom-up methodologies are used to forecast energy demand in most developing countries. However, these methodologies produce less realistic projections than hybrid models. Top-down models rely on cost-drivers, which do not play an important role in developing countries and cannot adequately capture traditional energy consumption or the informal sector. Bottom-up models fail to adequately capture some issues such as subsidies and energy shortages.

A combination of the economic equilibrium character of the top-down model and the optimization or accounting frameworks of the bottom-up model appears to be the most appropriate model for energy demand forecasting in developing countries. Such a hybrid model is able to model both the policy priorities of equity and sustainability that are specific to and critical for developing countries, and current and anticipated changes in energy industries (Pandey 2002).

Although the Long-range Energy Alternative Planning (LEAP) system cannot be categorized as a hybrid model, it allows a combination of bottom-up and top-down approaches and therefore an assessment of total system impacts (Song et al. 2007). It is an energy-planning system developed by the Stockholm Environment Institute, Boston (SEI-B). The system incorporates the Technology and Environmental Database (TED), which has been developed jointly by SEI-B and the United Nations Environment Programme (UNEP) (SEI 2008).

TED provides information describing the technical characteristics, costs, and environmental impacts of different energy technologies. It therefore allows pollution resulting from each stage of the fuel chain to be tracked. Policies and measurements for GHG emissions reduction on both the demand and supply sides can also be modelled (SEI 1995).

By integrating bottom-up and top-down features, the LEAP framework allows the analysis of non-price policies and structural changes in detail. Both demand- and supply-side energy flow is analysed from the initial point of primary and secondary energy production, through transformation, losses in transmission, and distribution to end-user consumption (SEI 1995).

Furthermore, end-use models such as LEAP can include rural energy demand, which is difficult to capture through econometric models (Bhattacharyya and Timilsina 2010). Moreover, LEAP relies on simple accounting principles, and its initial data requirements are relatively low (Heaps 2012). Given the paucity of data already mentioned, this characteristic makes LEAP well suited to examining the energy system in Africa.

Therefore, LEAP is chosen for this analysis as the best tool to assess current energy patterns and simulate alternative energy futures, along with GHG emissions, under a range of user-defined hypotheses for 52 African countries for the period 2010–2040.

### 3.1 Algorithm of LEAP

Energy consumption and carbon emissions in the LEAP model are calculated as below.

*Energy demand*

Total final energy demand is calculated as follows:

$$ED_n = \sum_i \sum_j AL_{n,j,i} \times EI_{n,j,i} \quad (1)$$

where  $ED$  is the total energy demand of a given sector,  $AL$  is the activity level,  $EI$  is the energy intensity,  $i$  is the sector,  $n$  is the type of fuel, and  $j$  is the device.

Net energy consumption for transformation is calculated as follows:

$$EDT_s = \sum_s \sum_m \sum_t ETP_{t,m} \times \left[ \frac{1}{f_{t,m,s}} - 1 \right] \quad (2)$$

where  $EDT$  is the net energy consumed for transformation,  $ETP$  is the product of the transformation process,  $f$  is energy transformation efficiency,  $m$  is the equipment,  $s$  is the type of primary energy, and  $t$  is the type of secondary energy.

*Carbon emissions*

The carbon emissions from final energy consumption are:

$$CE = \sum_i \sum_j \sum_n AL_{n,j,i} \times EI_{n,j,i} \times EF_{n,j,i} \quad (3)$$

where  $CE$  is the carbon emissions,  $EF_{n,j,i}$  is the carbon emissions factor from fuel type  $n$  for equipment  $j$  from sector  $i$ , and  $AL$  and  $EI$  are as specified above.

The emissions from energy transformation are calculated as follows:

$$CET = \sum_s \sum_m \sum_t ETP_{t,m} \times \frac{1}{f_{t,m,s}} \times EF_{t,m,s} \quad (4)$$

where  $CET$  is the carbon emissions,  $EF_{t,m,s}$  is the emission factor from one unit of primary fuel type  $s$  used to produce the secondary fuel type  $t$  through the equipment  $m$ , and  $ETP$  and  $f_{t,m,s}$  are as specified above.

### 3.2 Model and data

The LEAP-Africa model used in this paper takes into account the final energy demand and transformation sectors as well as main primary and secondary energies consumed in all SSA and North African countries. The analysis covers the period 2010 to 2040. The main components of the model are population size, economic growth, structural change, improvement of energy efficiency, and renewable fuels switching. Five end-use sectors are included in the model: residential, agriculture, services, industry, and transport. The residential sector is divided into urban and rural households. The energy conversion system includes the power generation, transmission, and distribution sectors. Each level comprises the process of conversion and the output.

## *Scenario design*

Five types of economic development, energy access policy, and climate mitigation scenarios are investigated in this study: the business-as-usual (BAU) scenario and four scenarios based on universal access to modern energy services in line with the Sustainable Energy for All (SE4All) initiative.

SE4All is a multi-stakeholder partnership involving both the public and private sectors that seeks to provide universal access to modern energy services;<sup>2</sup> double the share of renewable energy in the global energy mix; and double the rate of improvement in energy efficiency worldwide by 2030 (UN 2011). So far, 44 African countries have adopted SE4All, which was implemented on the continent in 2012 by the New Partnership for Africa's Development (NEPAD), the technical body of the African Union. Investment in doubling renewable energy in the global energy mix and improving energy efficiency in African countries will help to develop the local resources necessary to increase access to electricity and sustainable energy on the continent.

As the most widespread, coherent, and effective energy policy across Africa, SE4All is believed to be a good starting point for modelling future African energy pathways and assessing the conditions of universal energy access. In addition, a recent energy policy of the African Development Bank that aims to accelerate SE4All is modelled.

### **A: Baseline scenario**

The reference scenario is the expected energy demand under BAU. Its main purpose is to enable the quantification of all existing policies. Any future government target or policy is excluded.<sup>3</sup>

The reference scenario is associated with an economic development that will follow past trends: the continuation of the development of technology and science, a smooth increase in urbanization and industrialization, population growth, income progress, and the consequent gradual improvement of the transport sector.

In line with universal access to electricity and the development of modern energy policies, the following scenarios are modelled:

### **B: Energy access improvement**

#### *B1: Moderate Energy Access scenario*

The Moderate Energy Access (MEA) scenario assumes an annual growth rate of 0.7 per cent in electrified population and 1.7 per cent in access to non-solid fuels—i.e. a continuation of the growth rates in electrification and modern energy access over the last couple of years (IEA/World Bank 2015). According to this global tracking framework report, the same rate of growth in electrification and modern energy access will be observed in the coming years, but universal access cannot be achieved by 2030 in most African countries.

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<sup>2</sup> Universal access to modern energy refers to electricity for lighting and clean fuels and/or technology for cooking (UN 2011).

<sup>3</sup> The SE4All targets are not modelled in this scenario.

### *B2: Accelerated Energy Access scenario*

The Accelerated Energy Access (AEA) scenario assumes a high improvement in energy access. This scenario models the African Development Bank's Energy New Deal for Africa.<sup>4</sup> This New Deal aims to achieve 100 per cent urban electrification and 95 per cent rural electrification in Africa by 2025. The target number of connected households is 292 million (compared with 87 million in 2015). It also aims to increase access to clean cooking facilities for 130 million households.

### **C: Sustainable energy**

Two further scenarios targeting the same objectives as the MEA scenario but coupled with climate change mitigation objectives are modelled.

#### *C1: Energy Efficiency scenario*

The Energy Efficiency (ENEF) scenario models the doubling of the rate of improvement in energy efficiency in the countries under investigation. The SE4All objective for this scenario is an annual 2.6 per cent drop in energy intensity from 2010 to 2030.

#### *C2: Renewable Energies scenario*

The second SE4All objective, which is the doubling of the share of modern renewable energies (hydro, solar, and wind energy) in the energy mix, is modelled in the Renewable Energies (RENEW) scenario.

All five scenarios modelled use the same economic and demographic growth forecasts from recent studies (UN 2015; UNCTAD 2015; World Bank 2016) to determine the need for energy services. In doing so, they all assume relatively smooth growth in the African economies. Regarding economic growth, urbanization, industrialization, and services and transport sector development, it is assumed that they will follow the same pattern as in the past decade.

Populations, as well as the urbanization growth rates, follow the medium variant projection of the 2015 Revision of the World Population Prospects (UN DESA 2015).

### *Data*

Data sources are as follows:

- Economic variables (real income per capita, income growth): ERS International Macroeconomic Data Set (2014)
- Sectoral value added variables (industry, agriculture, transport, services): UN Statistics Division (available at: <http://data.un.org/Default.aspx>)
- Demographic data (total population, population growth rate, urbanization): World Population Prospects: 2015 Revision of the United Nations (UN DESA 2015)
- Number of households and size of household: based on UN DESA (2014)
- Energy data: Enerdata (2015); World Bank (2016)

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<sup>4</sup> Launched at the World Economic Forum in Davos in January 2016, the African Development Bank energy policy is billed as a 'New Deal' on energy for Africa, in reference to former US president Roosevelt's plan to rebuild the US economy after the Great Depression of the 1930s. By 2025, the plan envisages 160 GW of new grid-connected generation capacity and 75 million new off-grid power connections, a 20-fold increase over today's number.

- Projections on industry, transport, service, and agriculture: UNCTAD (2015).

## 4 Results and discussion

### 4.1 Energy consumption

#### *Demand-side results*

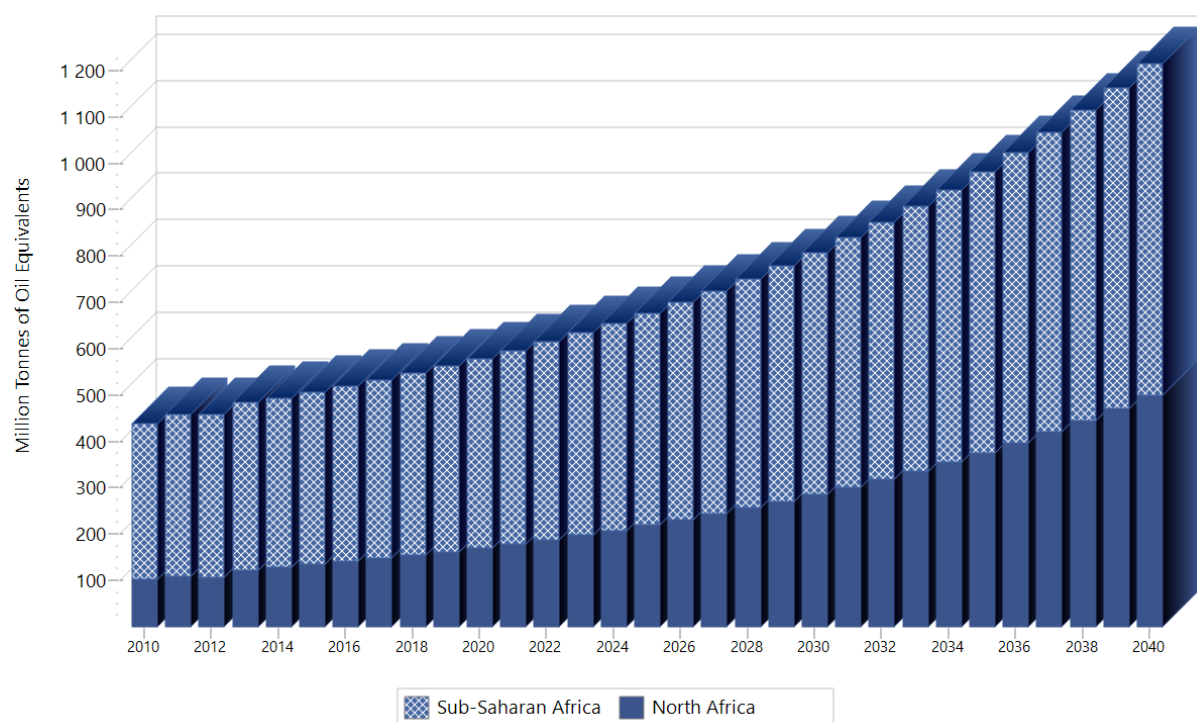
Based on the various parameters of socioeconomic development in Africa listed in Section 3, total energy demand forecast by the LEAP-Africa model for the different scenarios, from 2010 to 2040, is shown in Table 2 and Figure 5. Overall, energy demand under each scenario is predicted to increase steadily until 2040, but with different growth rates.

Table 2: Energy demand final units (Mtoe)

	Scenarios	2010	2015	2020	2025	2030	2035	2040
All fuels, Sub-Saharan Africa	Reference	336.26	370.58	408.57	458.01	522.42	606.38	715.88
	MEA improvement	336.26	373.08	413.35	465.28	532.39	619.28	731.99
	AEA improvement	336.26	405.29	528.72	663.61	728.02	811.97	921.48
	Energy efficiency	336.26	356.43	380.51	407.89	439.12	474.81	515.70
	Renewables energy	336.26	373.08	413.35	465.28	532.39	619.28	731.99
All fuels, North Africa	Reference	103.03	134.43	170.38	219.20	285.55	375.80	498.66
	MEA improvement	103.03	135.75	173.26	223.77	291.97	384.23	509.26
	AEA improvement	103.03	137.80	182.13	239.33	305.68	395.93	518.79
	Energy efficiency	103.03	116.80	134.13	155.46	181.65	213.71	252.91
	Renewables energy	103.03	135.75	173.26	223.77	291.97	384.23	509.26
All fuels, Africa	Reference	439.29	505.01	578.95	677.21	807.97	982.18	1,214.54
	MEA improvement	439.29	508.83	586.61	689.05	824.36	1,003.51	1,241.25
	AEA improvement	439.29	543.09	710.85	902.94	1,033.70	1,207.90	1,440.27
	Energy efficiency	439.29	473.23	514.64	563.35	620.77	688.52	768.61
	Renewables energy	439.29	508.83	586.61	689.05	824.36	1,003.51	1,241.25

Source: LEAP simulation results, 2016.

Figure 5: Energy demand final units, BAU scenario, all fuels



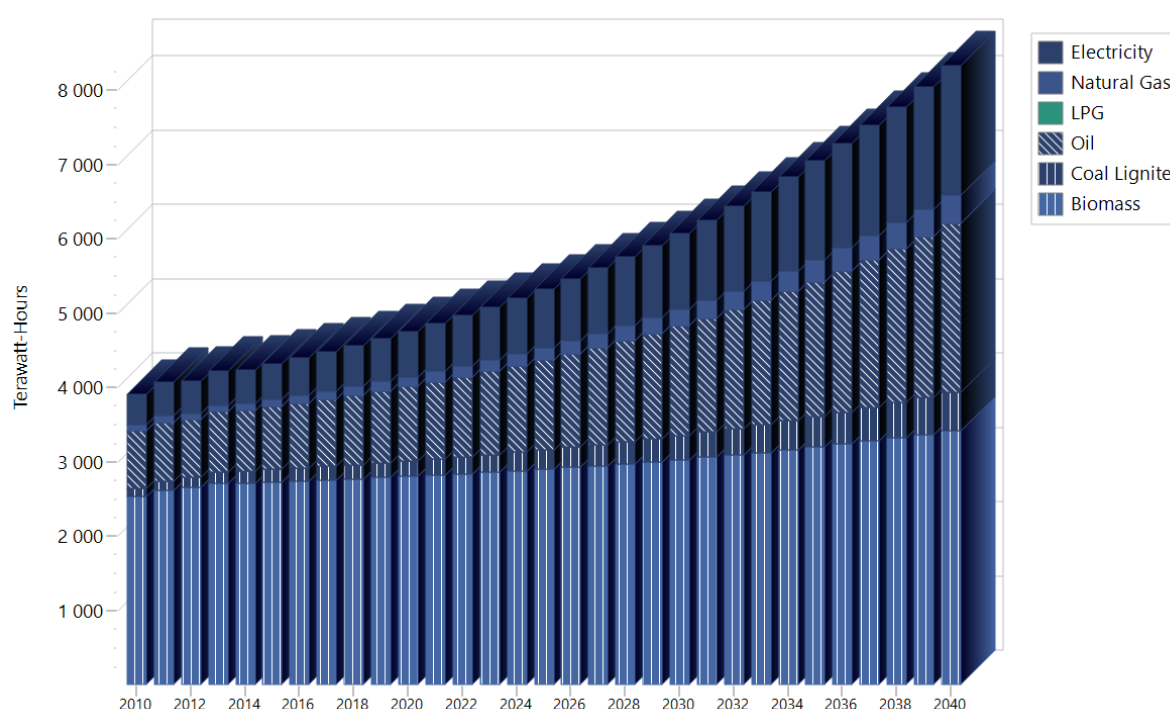
Source: LEAP simulation results, 2016.

In the BAU case, the total forecast energy demand in 2040 is 1,214 Btoe.<sup>5,6</sup> In SSA, the BAU scenario will reach 716 Mtoe in 2040 in total with an average annual growth rate of 2.8 per cent. Under the BAU, in North Africa, energy consumption will reach 499 Mtoe with an average annual growth rate of 5 per cent (Figure 6).

<sup>5</sup> In 2014, the WEO forecast an energy demand of 1 Btoe for Africa in 2040 (IEA 2014).

<sup>6</sup> Excluding electricity generation activities.

Figure 6: Energy demand final units BAU scenario, all fuels, SSA



Source: LEAP simulation results, 2016.

With an annual growth rate of 0.7 per cent in electrified population and 1.7 per cent in access to non-solid fuels, the total energy consumption under the MEA scenario is not much higher than the BAU scenario. The difference is from 2.5 Mtoe in 2015 to 10 Mtoe in 2030 and 16 Mtoe in 2040.

These results were expected, as SE4All policies have been in the process of being implemented across the continent since 2012. However, by simulating the goals of the SE4All policy separately, we were able to show that universal access to energy will not be met by 2030. As already stated, the annual growth rates of 0.7 per cent for electricity and 1.7 per cent for modern fuels are not enough to meet the SE4All target by 2030.

Indeed, under the MEA scenario, the proportion of the urban population that has access to electricity in SSA will increase by only 20 per cent by 2030 and 31 per cent by 2040. For the rural population, these shares are 12.6 per cent and 19.4 per cent, respectively.

Under the AEA scenario, energy consumption will reach 1,440 Btoe in 2040 with an average annual growth rate of 5 per cent for North Africa and for SSA until 2025, and then an average annual growth rate of 2 per cent. These growth rates are the highest amongst the five scenarios.

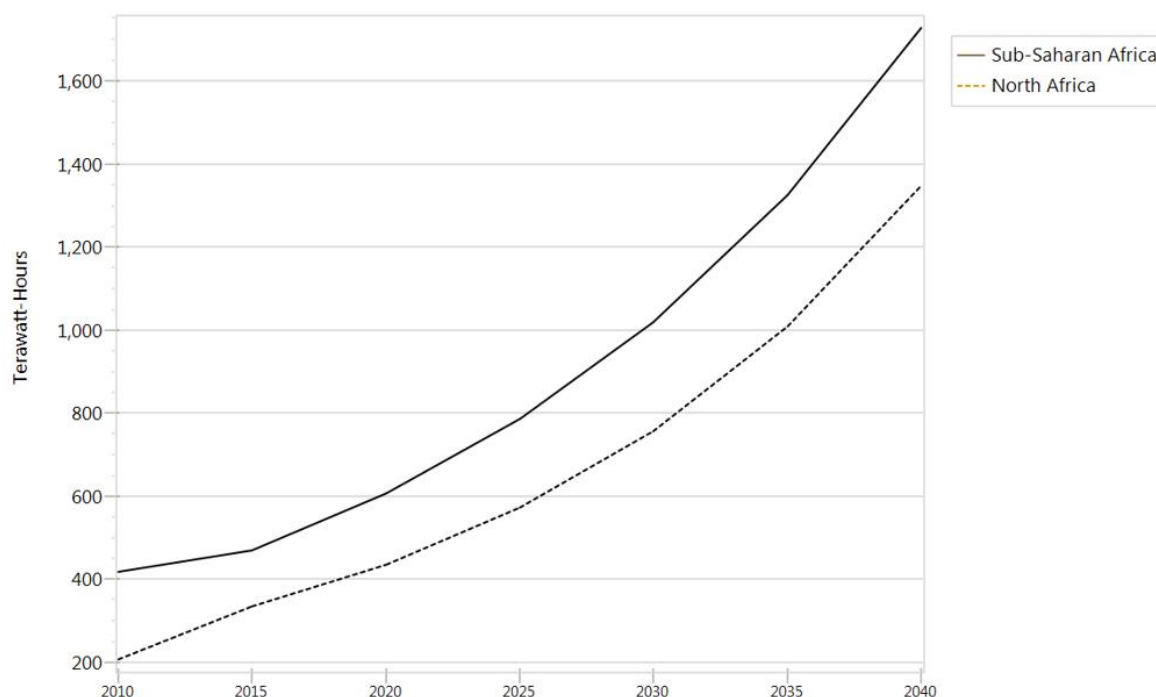
The increase in energy demand under the ENEF scenario over the projection period will be the slowest, at an average annual rate of 1.3 per cent for SSA and 3 per cent for North Africa. Total energy consumption under this scenario will reach 768.61 Mtoe in 2040. The same energy needs will be met with a smaller amount of energy. This fact is explained by the huge potential of African countries, especially Sub-Saharan countries, for improving energy efficiency, which will reduce their consumption (see Section 5).

In term of fuels consumed, by 2040, under BAU, biomass will still account for a large part of the total energy consumed in Africa, followed by oil, which will represent 27 per cent of total



consumption. Electricity in the BAU case will account for only 20 per cent of total energy consumption in Africa. It will reach 1,726 Terawatt-hours (Twh) in 2040 (Figure 7).<sup>7</sup>

Figure 7: Electricity demand, BAU scenario



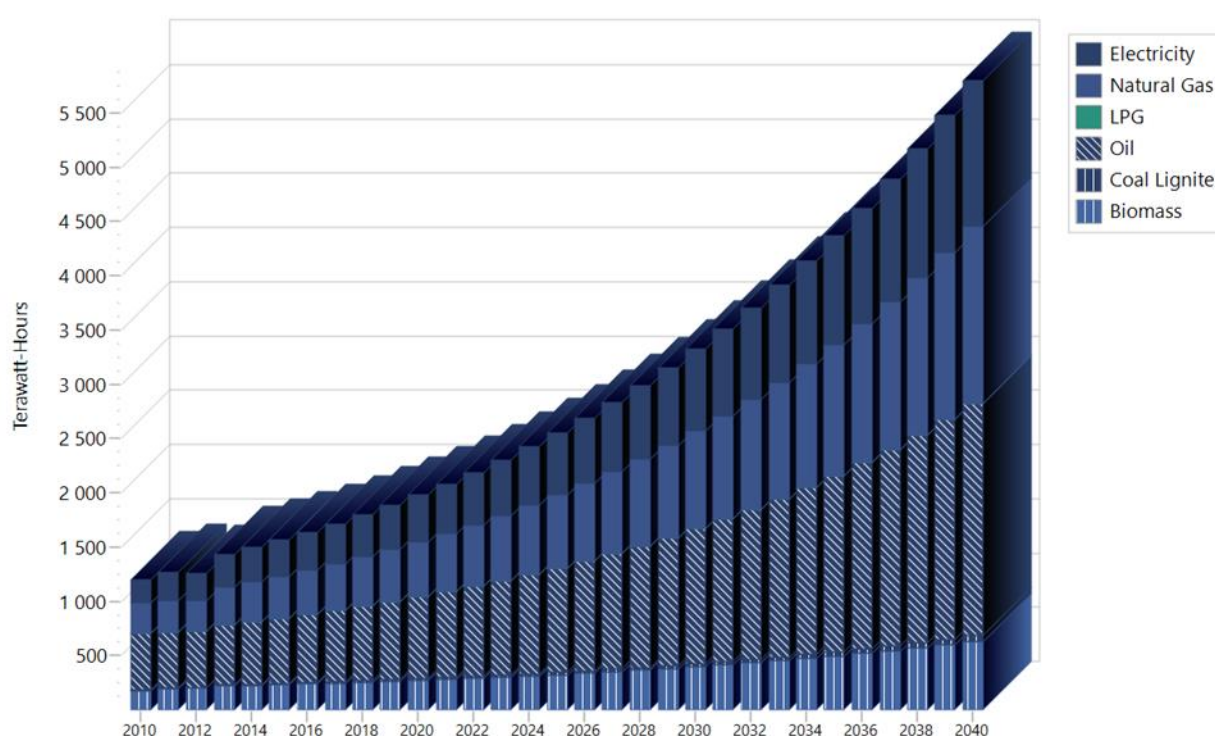
Source: LEAP simulation results, 2016.

The same consumption pattern is observed under the MEA and AEA scenarios. Biomass will still account for a large proportion of total energy demand in Africa, even if it decreases significantly under AEA (reduced by half between 2010 and 2040). If, under MEA, the shares of the different fuels consumed follow the same pattern and magnitude as BAU (except for a slight decrease in oil consumption and an increase in electricity demand), under AEA, a net change is observed in the trends and patterns in total demand (Figure A1 and Table B2). Under AEA, until 2025, a slight reduction in biomass, oil, and coal, a small increase in electricity, and a steady growth in natural gas consumption are observed. After 2025, the growth in electricity consumption continues, while a decrease in gas and oil and a slightly renewed growth in coal and biomass consumption are observed in SSA (Figure A2 and Table B2).

In North Africa, these figures are dominated by oil products, which will account for 35 per cent of total energy consumed in 2040 under the BAU scenario. The second most consumed fuel is natural gas (28 per cent), followed by electricity (23 per cent). However, a slight decrease in the share of oil (as well as biomass) in total consumption and an increase in the shares of electricity and gas are observed over time (Figure 8).

<sup>7</sup> In 2015, McKinsey projected electricity consumption in Sub-Saharan Africa of 1,600 Twh in 2040 (Castellano et al. 2015).

Figure 8: Energy demand final units BAU scenario, North Africa



Source: LEAP simulation results, 2016.

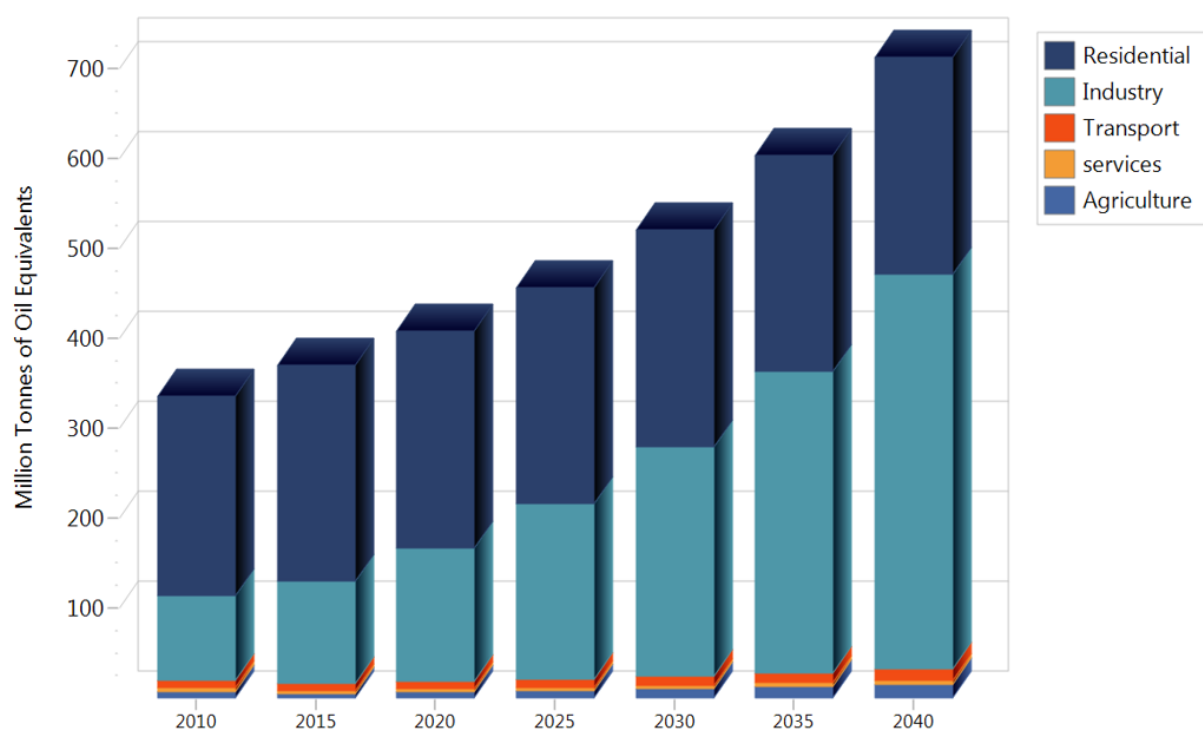
The same patterns and trends are observed under the MEA and AEA scenarios except for slightly higher shares for electricity consumption for both scenarios (Figures A3 and A4 and Table B2).

### *Sectoral analysis*

Among end-users, the industrial sector will have the largest share of the total energy consumed in 2040 (61 per cent—up from just over 30 per cent in 2015), followed by the residential sector (33 per cent). In terms of industrial energy consumption by fuel, following the trend of recent years, the use of petroleum products will increase (to 33 per cent of industry's total fuel consumption), which will help to drive the substantial increase in industrial energy demand.

By 2040, in the BAU case, the demand for electricity will account for 32 per cent of the total demand of the industrial sector. The second highest demand will be for biomass (12 per cent) (Figure 9 and Table B3).

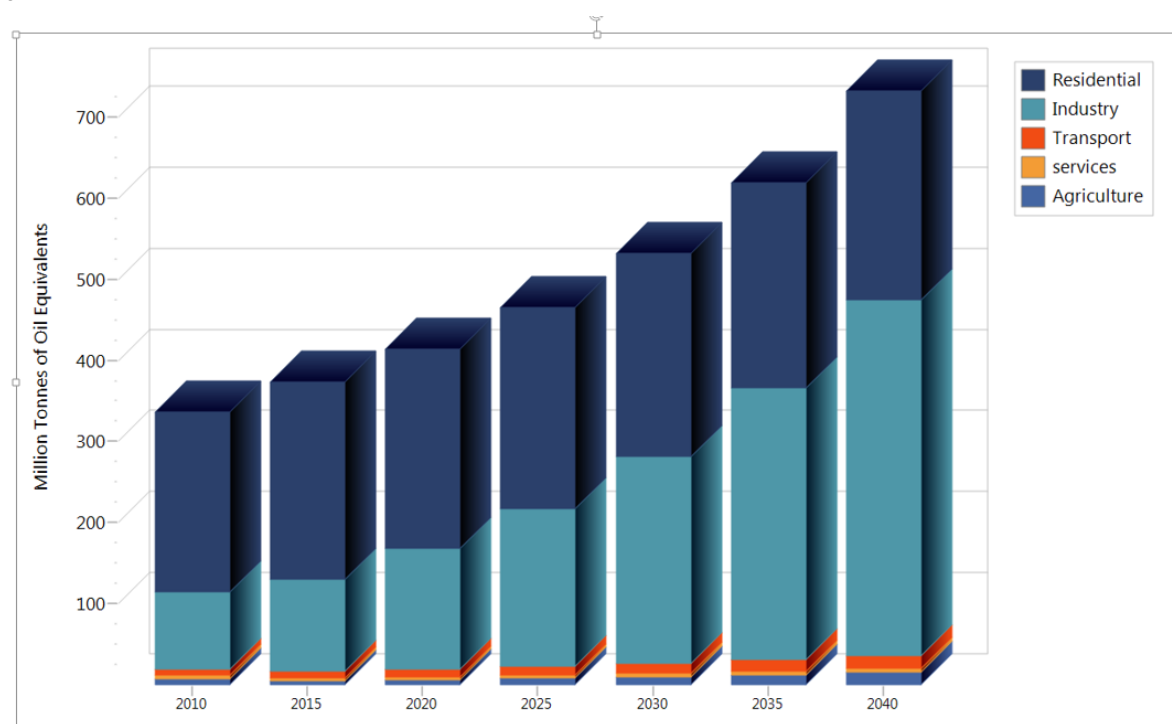
Figure 9: Sectoral demand BAU scenario, all fuels, SSA



Source: LEAP simulation results, 2016.

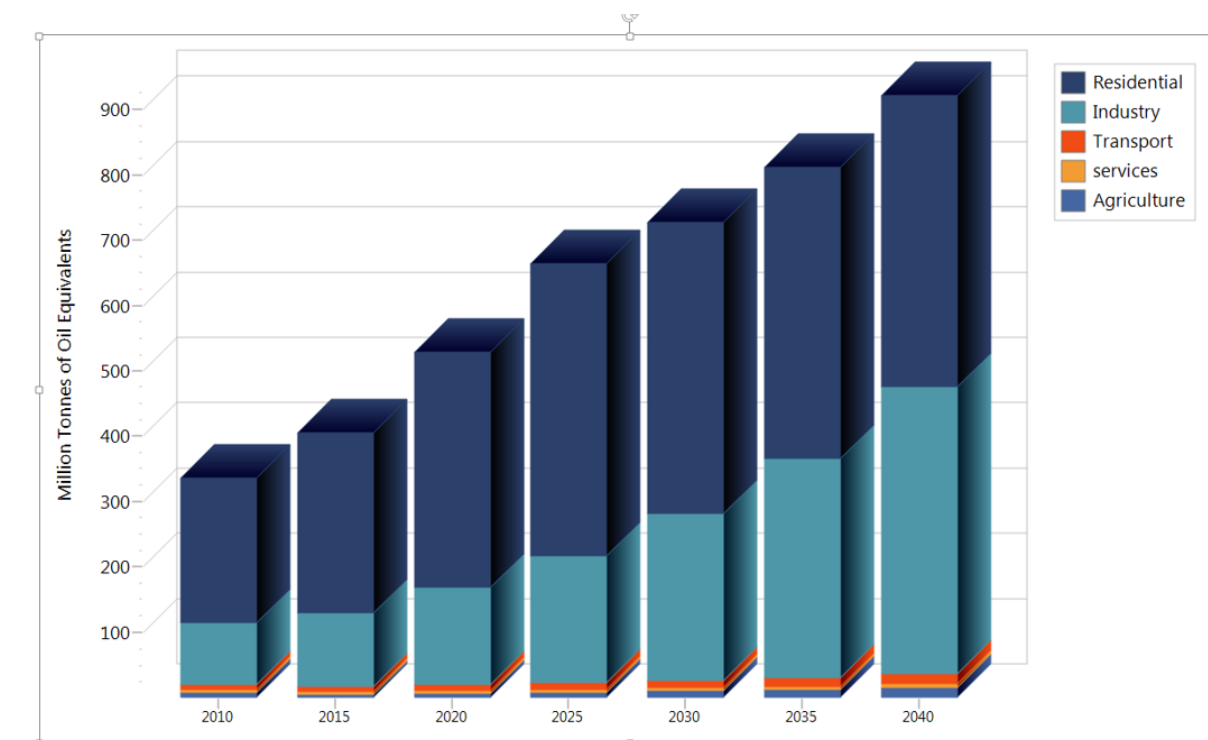
Under both the MEA and AEA scenarios, the residential sector will have the largest energy consumption by 2025. This sector will account for more than 50 per cent under MEA and 60 per cent under AEA by 2025. The improvement of access to electricity and to modern fuels by a large number of people explains the decrease in demand in this sector in 2025–2030 (Figures 10 and 11 and Table B3).

Figure 10: Sectoral demand MEA scenario, all fuels, SSA



Source: LEAP simulation results, 2016.

Figure 11: Sectoral demand AEA scenario, all fuels, SSA



Source: LEAP simulation results, 2016.

In terms of absolute growth rate, the industry sector has the highest rate of energy demand growth by 2040 (an average of 5.6 per cent in SSA and 6.7 per cent in North Africa), regardless of the scenario. The agriculture sector has the second highest growth rate (4.5 per cent in SSA and 5 per cent in North Africa), followed by the transport sector (2.5 per cent in SSA and 1.3 per cent in North Africa) (Table B3).

Despite the growth in the transport sector that Africa will experience, agriculture is and will continue to be the most important sector in the economy of most African countries (FAO/UNIDO 2008). However, agricultural mechanization has either stagnated or retrogressed in many countries of SSA. African agriculture still relies primarily on human muscle power and the use of hand tools. The transformation of agriculture from a subsistence to a commercial activity, made increasingly necessary by population growth and demographic shifts, will lead to growing mechanization of the agriculture sector in Africa, which will lead to a greater energy requirement.

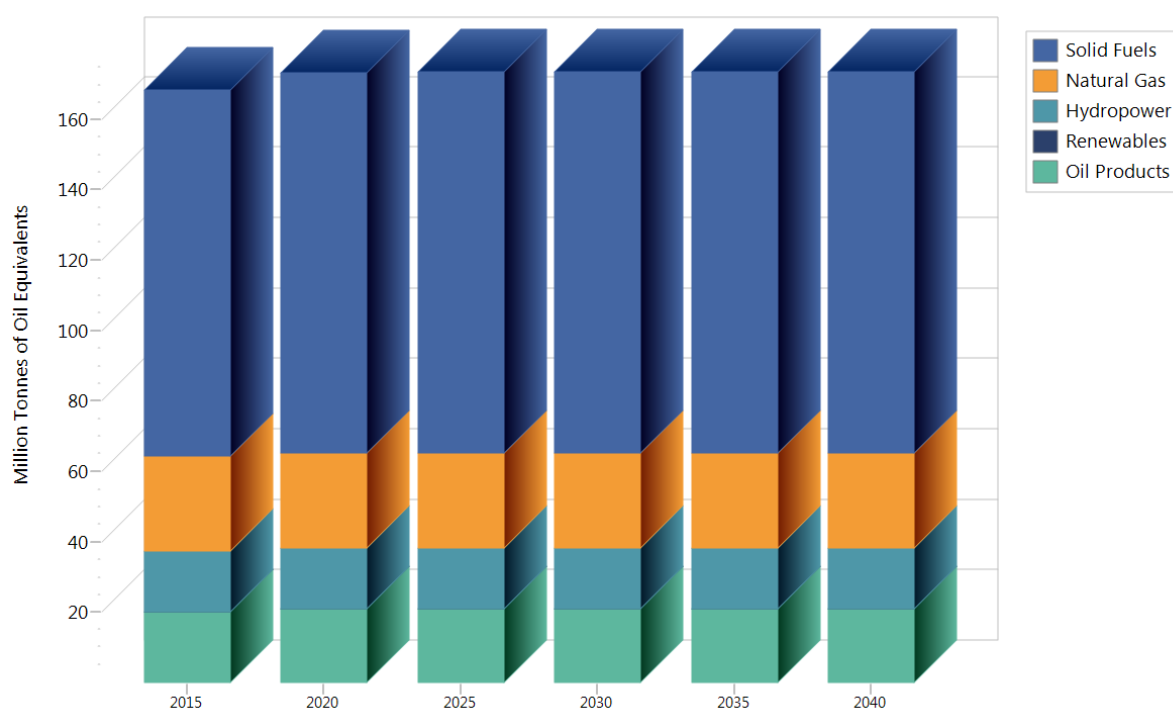
## 4.2 The power sector

Coal has the largest share in the electricity generation sector of SSA. It accounts for 47 per cent of the sector's needs. Hydraulic power has the second largest share (27 per cent), while gas represents 15 per cent of the total electricity generated and oil 10 per cent.

Electricity generation in North Africa is dominated by natural gas (63 per cent), followed by oil products (21 per cent).

The same trends and patterns are observed for the MEA, AEA, and ENEF scenarios, for both SSA and North Africa, and over time (Figure 12).

Figure 12: Electricity generation sector by share of input fuels, BAU scenario, SSA



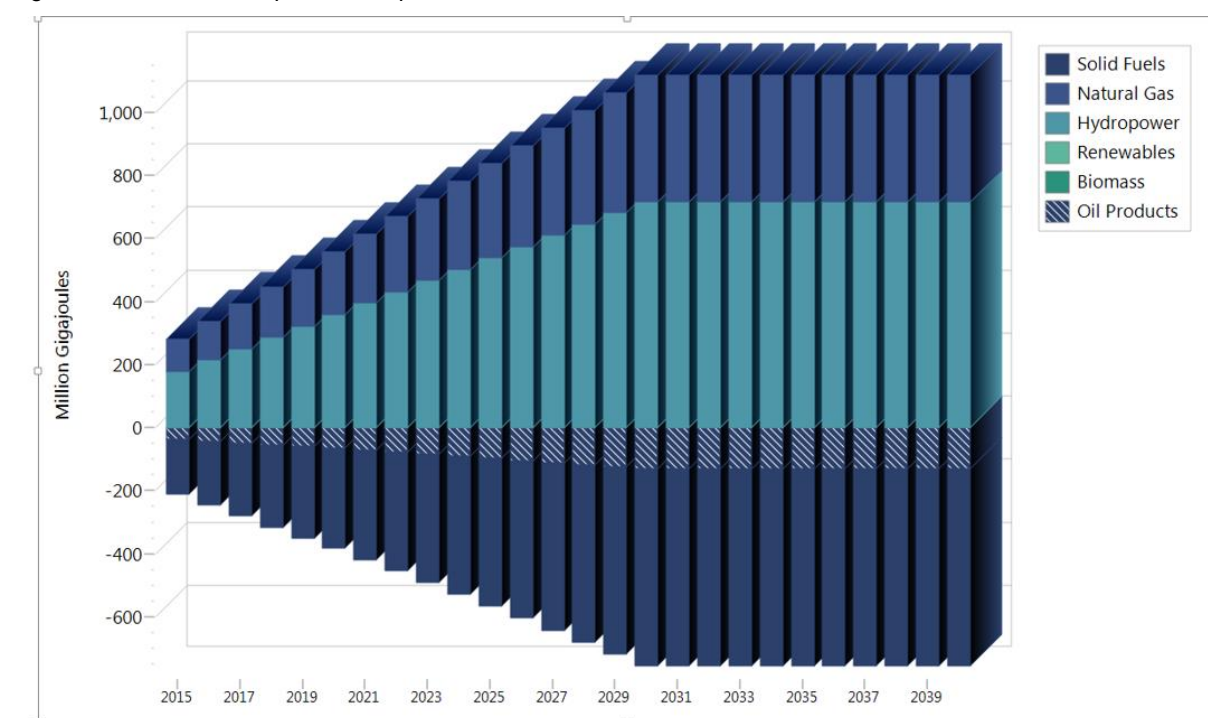
Source: LEAP simulation results, 2016.

It should be noted that these figures result partly from the dominant position in the region of South Africa, which depends largely on coal for its electricity generation (89.5 per cent of South African and 85 per cent of Southern African electricity production derives from coal). When South Africa is excluded, natural gas has the largest share in electricity generation in SSA.

In comparing the BAU with the ENEF and RENEW scenarios, we find that the share of electricity generation in coal consumption will decrease by 0.2–0.3 per cent annually in the case of the ENEF scenario and by 3–4 per cent in the case of the RENEW scenario, indicating that the use of coal in power electricity generation will decrease by 2040. The share of natural gas and oil in power generation will also decrease by 2040. The average annual percentage decrease of oil products in the electricity mix is 4–3.5 per cent, while the annual percentage decrease of gas is 3–2.5 per cent.

In comparing BAU with the RENEW scenario, we find that the proportions of coal and oil in power generation will decrease while the shares of natural gas, hydro, solar, and wind will increase until 2030 (Figure 13). The same figures are observed in North Africa.

Figure 13: Fuels consumption in the power sector, RENEW vs. BAU scenarios, SSA



Source: LEAP simulation results, 2016.

In addition, the primary energy requirements in the power sector (primary and secondary resources) will steadily decrease until 2035 (before levelling). Compared with BAU, under the RENEW scenario, countries will need less energy to produce the same amount of electricity (-30 Mtoe) (Table B4). These requirements are even less under ENEF, where a decrease of 350 Mtoe is observed. Energy efficiency will allow power sector needs to be met with a smaller amount of energy.

### 4.3 Sub-regional analysis

Under the BAU scenario, energy demand in SSA is driven by the growing demand for energy in East Africa, where energy consumption will grow at an average annual rate of 5 per cent. The largest increase in energy demand under the AEA scenario will come from West Africa.

### 4.4 Climate change dimension

Total carbon emissions under the different scenarios from 2015 to 2040 are shown in Tables 3 and 4. Under BAU, emissions will increase from 296 million metric tonnes (Mt-C) in 2015 to 842 Mt-C in 2040 with an annual growth rate of 4 per cent. The rate of carbon emissions is twice the rate of energy consumption forecast in this scenario. These figures show significant inefficiencies in energy use.

Table 3: Carbon dioxide (non-biogenic), all fuels, Sub-Saharan Africa (million metric tonnes)

Scenarios	2015	2020	2025	2030	2035	2040
AEA improvement	383.28	662.98	960.70	1,062.76	1,195.48	1,368.21
Energy efficiency	287.34	319.42	356.51	399.45	449.19	506.84
MEA improvement	303.21	370.61	456.65	566.86	708.44	890.83
Reference	295.58	356.10	434.65	536.71	669.43	842.16

Source: LEAP simulation results, 2016.

Table 4: Carbon dioxide (non-biogenic) all fuels, North Africa (million metric tonnes)

Scenarios	2015	2020	2025	2030	2035	2040
AEA improvement	243.52	323.92	427.89	549.39	714.69	939.71
Energy efficiency	208.71	240.67	279.95	328.12	387.04	459.03
MEA improvement	241.85	311.90	405.91	532.45	703.23	934.24
Reference	237.65	303.46	392.84	514.34	679.64	904.66

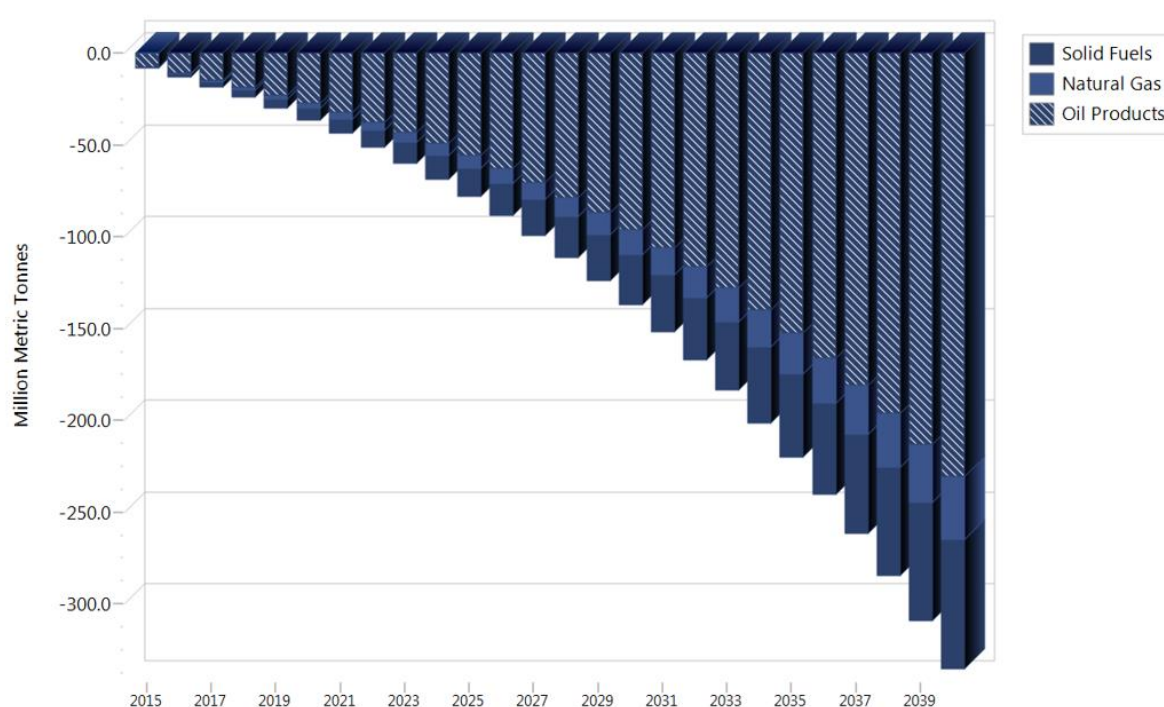
Source: LEAP simulation results, 2016.

Under the AEA scenario, emissions will increase annually by 10 per cent until 2030 and thereafter by 2 per cent to 1,368 Mt-C in 2040, which is in line with the increase of energy demand. Under this scenario, emissions will more than triple, while under the ENEF, emissions will less than double. The introduction of clean energy having been modelled from the production side, its effects cannot be observed here.

Under BAU, emissions in North Africa will increase from 237 Mt-C in 2015 to 906 Mt-C in 2040 with an annual growth rate of 5 per cent. Under the AEA scenario, emissions will more than triple to 940 Mt-C in 2040, while under ENEF emissions will only double.

Overall, the ENEF scenario results in the lowest carbon emissions, which will reach 335 Mt-C in 2040, with an average annual decline of 2 per cent (Figure 14). Under the ENEF scenario, emissions from the power sector will decrease to 113 Mt-C by 2040 (Figure 15).

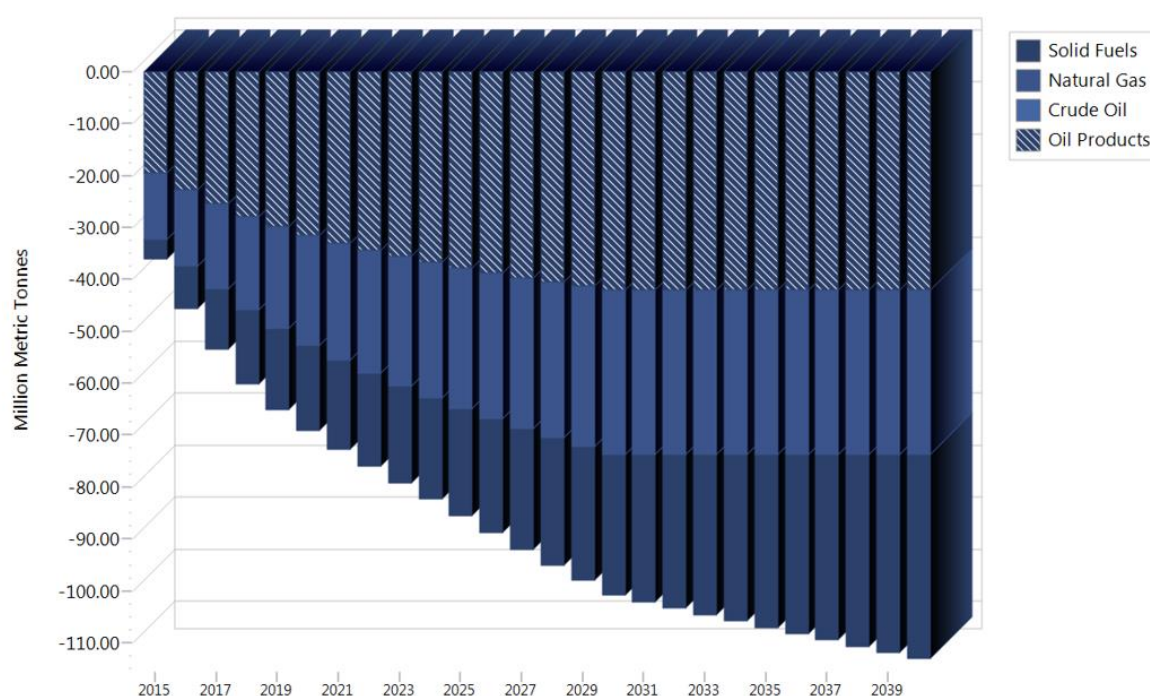
Figure 14: Carbon dioxide (non-biogenic) ENEF vs. BAU, SSA



Source: LEAP simulation results, 2016.



Figure 15: Electricity generation, carbon dioxide emission reduction, all fuels, ENEF scenario, SSA



Source: LEAP simulation results, 2016.

Interestingly, under the RENEW scenario, carbon emissions will decrease to 178 Mt-C by 2030 and then will level off until 2040. This turning point in the reduction of the emissions is most likely due to the end of the SE4All renewable energy policy.

## 5 Conclusions and policy implications

In this study, five scenarios were assessed using the LEAP modelling framework to represent alternative development pathways for Africa's energy future from 2010 to 2040. The results show that economic development policies implemented by national and regional governments and/or international bodies will have a significant impact on energy demand and GHG emissions.

Under the reference scenario, energy demand in 2040 will be three times that of 2015, with a corresponding increase in GHG emissions. This will increase the pressure on local and regional energy supplies as well as on carbon mitigation systems, accentuating the need for energy conservation and GHG emissions reduction actions. Under the Moderate Energy Access (MEA) scenario, energy demand and GHG emissions are barely higher than in the reference scenario. Thus, current government policies strongly influenced by the Sustainable Energy for All (SE4All) policy will not be sufficient to ensure universal access to affordable, reliable, sustainable modern energy in Africa by 2030 or even by 2040.

On the other hand, under the Accelerated Energy Access (AEA) scenario, energy demand and carbon emissions in 2040 will be 5–6 per cent higher than under the reference scenario. The AEA scenario, which aims to extend energy access to all by as early as 2025, limits the rapidly increasing trends of energy demand and environmental emissions.

Under the AEA scenario, oil will account for 33 per cent of total African energy demand in 2040, biomass 30 per cent, and electricity only 16 per cent. In contrast, under an energy efficiency policy,



oil and coal's contribution to global energy demand will decrease by 1 per cent, while the share of renewables will increase by the same amount. Moreover, the increase in energy use under the AEA scenario will be the slowest, at an average annual rate of 2 per cent for SSA and 3 per cent for North Africa. The same energy needs can be met with less energy. Indeed, the paradox of Africa, where people have limited access to modern energy, is that many of them have substantial potential for energy efficiency improvement on the demand side as well as the production side (Chevalier et al. 2009).

Overall, the promotion of energy-saving policies will ensure effective energy control for the coming years.

This study also shows that the industrial sector has the greatest potential in terms of carbon abatement, followed by the power sector. In the industrial sector, optimization of the structure of production is an option for reducing carbon footprints. Another option for reducing carbon footprints and improving energy efficiency is the substitution of natural gas for the existing coal- and oil-fired steam machinery used in industry.

In the power generation sector the best ways to reduce GHG emissions include the modification of existing oil and coal plants to run on natural gas, and the promotion of local renewable energy sources (Zhang et al. 2011). This strategy allows fuel diversification in power generation, which increases energy security and reduces GHG emissions (Ouedraogo 2012).

Moreover, high power transmission and distribution (T&D) losses, due to aging and inefficient power generation plants as well as aging and insufficient production transmission and distribution networks, affects both electricity availability and system reliability in Africa. Efficiency policies that seek to reduce T&D losses and improve the reliability of the system will increase energy access while reducing emissions.

Overall, in order to achieve universal access to modern energy services while contributing to climate change mitigation, a sound and integrated low-carbon sustainability strategy is required. The development of renewable energies and the improvement of energy efficiency are two major components of any strategic energy policy in the region (Ouedraogo 2013). Although the implementation of such policies requires large initial capital investment, they are crucial to ensure both universal modern energy access and emissions reductions.

Furthermore, low-carbon growth strategies offer important direct and indirect benefits. A focus on efficiency across all sectors will lead in the long term to substantial net savings (Stern 2010; Sathaye and Gupta 2010; IGCS 2014). For instance, investing in low-cost renewable energy options will provide environmental and social co-benefits. These include reduced health impacts from GHG emissions and improved livelihoods from services associated with renewable energy industries, as well as decreases in imports of fossil fuels. Small-scale manufacturing associated with renewable energy industries will also benefit from renewables development (IGCS 2014).

In summary, by using a transparent modelling framework to assess energy demand and supply options in Africa, this study demonstrates the challenges faced by African countries in providing sustainable modern and affordable energy access to meet the requirements of their fast growing populations and economies. It also demonstrates the socioeconomic and environmental benefits associated with the realization of this target. By developing both renewable energy and energy efficiency, it is possible for Africa to provide universal access to modern energy services sufficient to fuel continued socioeconomic development without increasing the emission of greenhouse gases.

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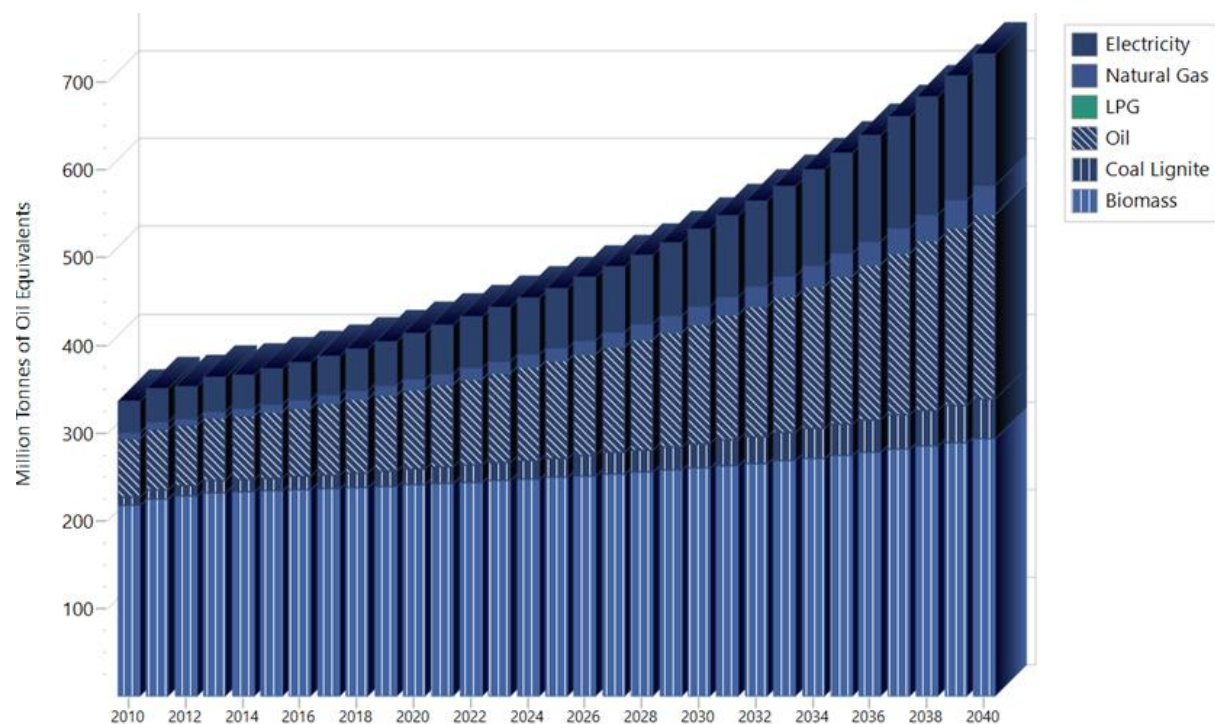
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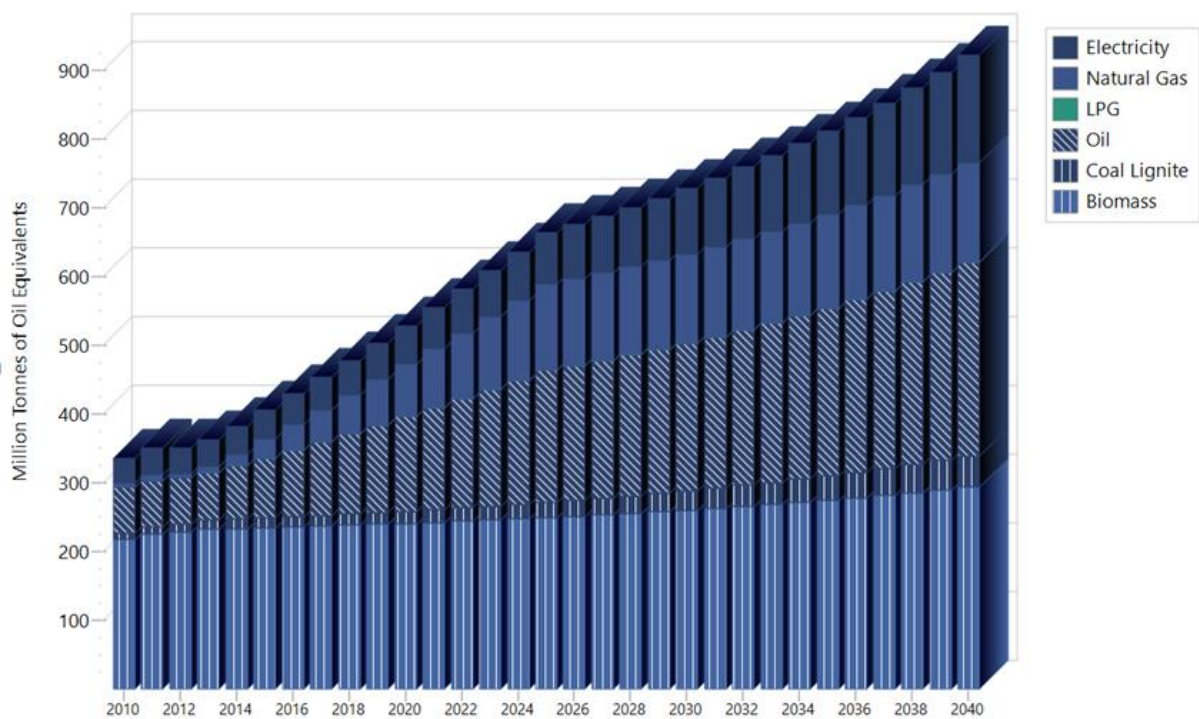
## Appendix A: Figures

Figure A1: Energy demand final units, MEA scenario, SSA



Source: LEAP simulation results, 2016.

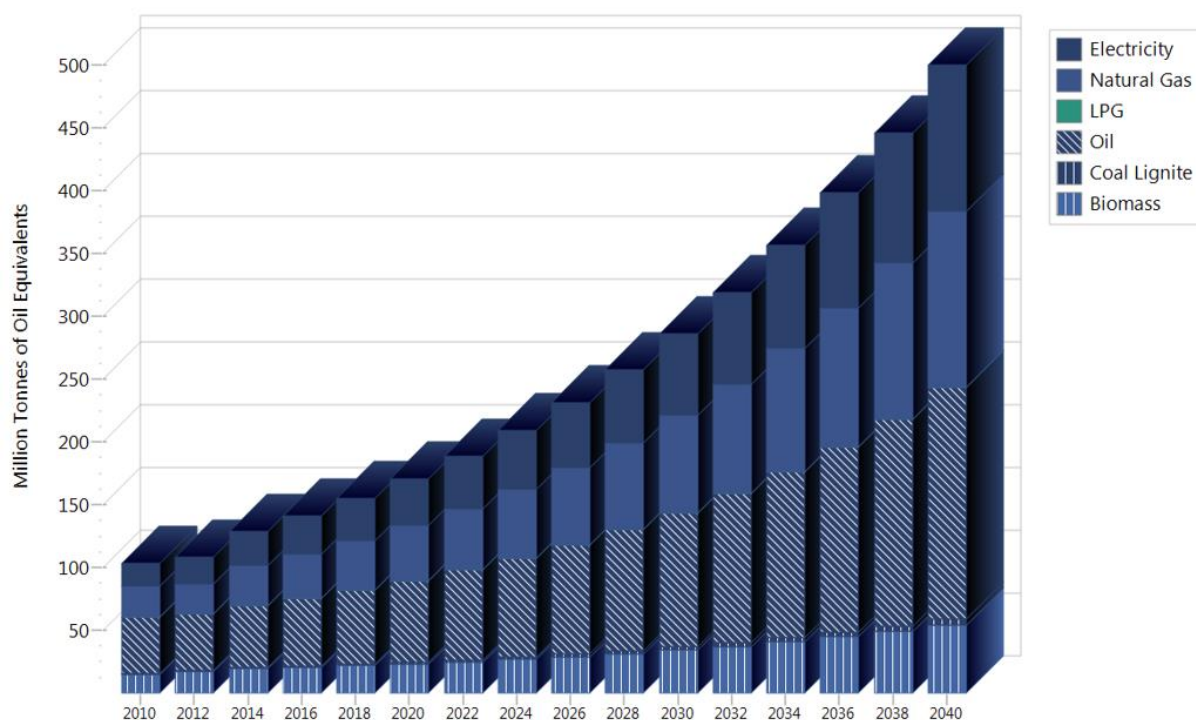
Figure A2: Energy demand final units, AEA scenario, SSA



Source: LEAP simulation results, 2016.

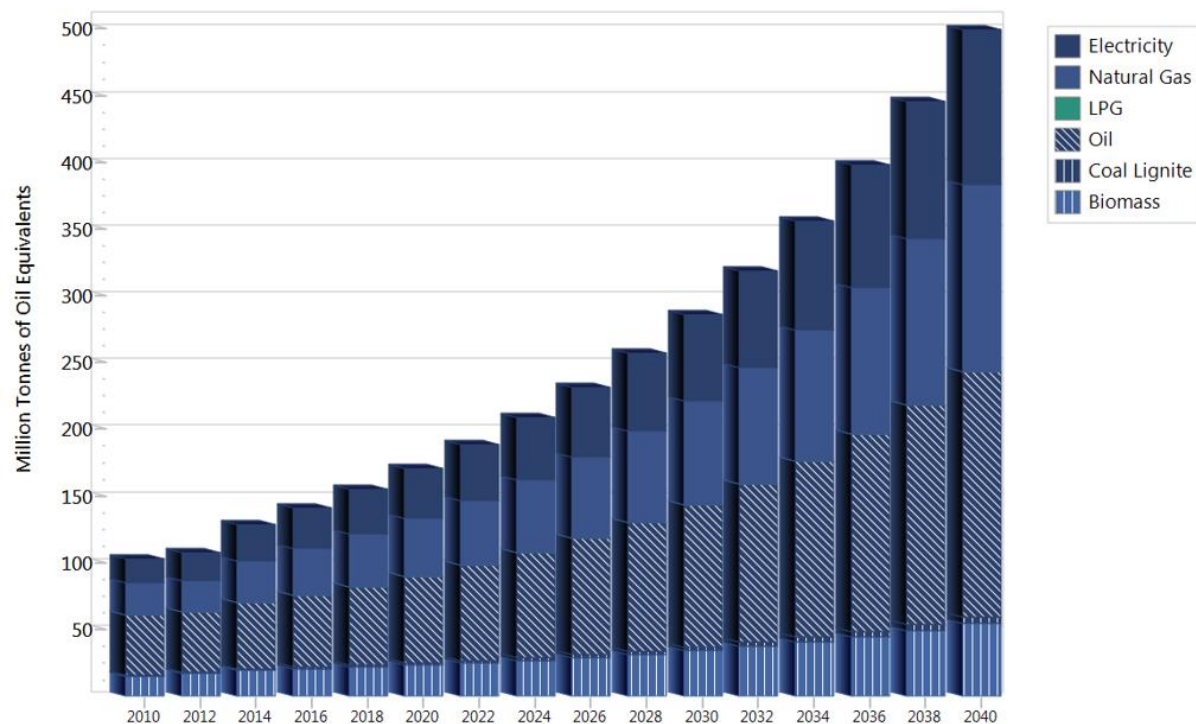


Figure A3: Energy demand final units, MEA scenario, North Africa



Source: LEAP simulation results, 2016.

Figure A4: Energy demand final units, AEA scenario, North Africa



Source: LEAP simulation results, 2016.

## Appendix B: Tables

Table B1: Regional grouping

East Africa	Central Africa	West Africa	Southern Africa	North Africa
Burundi	Angola	Benin	Botswana	Algeria
Comoros	Cameroon	Burkina Faso	Lesotho	Egypt
Djibouti	Central African Republic	Cape Verde	Namibia	Libyan Arab Jamahiriya
Eritrea	Chad	Cote d'Ivoire (Ivory Coast)	South Africa	Morocco
Ethiopia			Swaziland	
Kenya	Congo (Brazzaville)	Gambia		South Sudan (excluded)
Madagascar	Congo, Democratic Republic of the	Ghana		Sudan
Malawi	Equatorial Guinea	Guinea		Tunisia
Mauritius	Gabon	Guinea-Bissau		Western Sahara (excluded)
Mayotte (excluded from the modelling)	Sao Tome and Principe	Liberia		
Mozambique		Mali		
Reunion (excluded)		Mauritania		
Rwanda		Niger		
Seychelles		Nigeria		
Somalia (excluded)		Saint Helena (excluded)		
Tanzania, United Republic of		Senegal		
Uganda		Sierra Leone		
Zambia		Togo		
Zimbabwe				

Source: United Nations Country Grouping.

Table B2: Energy demand final by fuel type (Mtoe)

Sub-Saharan Africa							North Africa					
Reference scenario												
Fuels	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Electricity	40.31	52.11	67.53	87.68	114.03	148.49	28.74	37.45	49.21	65.12	86.69	115.93
Natural gas	8.68	11.38	14.91	19.54	25.61	33.56	33.19	43.62	57.87	77.35	103.97	140.36
Oil	72.27	85.60	102.85	125.21	154.22	191.90	51.68	64.88	82.74	106.91	139.69	184.18
Coal lignite	14.51	17.83	22.18	27.86	35.31	45.05	1.01	1.38	1.89	2.59	3.54	4.84
Biomass	234.45	240.86	249.25	260.23	274.58	293.37	19.92	23.29	27.87	34.12	42.64	54.26
Total	370.22	407.79	456.72	520.52	603.74	712.37	134.54	170.62	219.58	286.09	376.52	499.57
AEA scenario												
Fuels	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Electricity	42.94	56.92	74.52	94.67	121.02	155.48	28.73	37.41	49.15	65.07	86.64	115.89
Natural gas	72.18	171.10	270.87	275.50	281.57	289.52	33.19	43.62	57.87	77.35	103.97	140.36
Oil	110.66	221.28	335.82	358.17	387.18	424.87	51.70	64.95	82.84	107.02	139.80	184.28
Coal lignite	14.51	17.83	22.18	27.86	35.31	45.05	1.01	1.38	1.89	2.59	3.54	4.84
Biomass	234.45	240.86	249.25	260.23	274.58	293.37	19.92	23.29	27.87	34.12	42.64	54.26
Total	474.73	708.00	952.64	1016.43	1099.66	1208.29	134.56	170.65	219.62	286.14	376.58	499.63
ENEF scenario												
Fuels	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Electricity	40.29	52.10	67.53	87.69	114.05	148.52	28.33	36.96	48.66	64.51	86.02	115.21
Natural gas	8.68	11.38	14.91	19.54	25.61	33.56	32.46	42.73	56.84	76.17	102.66	138.92
Oil	70.92	84.70	102.40	125.22	154.70	192.86	49.96	62.81	80.32	104.17	136.63	180.81
Coal lignite	14.29	17.69	22.10	27.87	35.38	45.20	1.01	1.38	1.89	2.59	3.54	4.84
Biomass	221.93	232.45	245.04	260.30	279.02	302.27	18.32	21.35	25.61	31.55	39.78	51.12
Total	356.11	398.31	451.98	520.61	608.76	722.42	130.07	165.24	213.32	279.00	368.63	490.91

Source: LEAP simulation results, 2016.



Table B3: Sectoral energy demand (Mtoe)

Sub-Saharan Africa							North Africa					
BAU scenario												
Branches	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Residential	240.58	240.58	240.58	240.58	240.58	240.58	27.50	27.50	27.49	27.49	27.48	27.48
Industry	113.63	148.92	195.18	255.80	335.25	439.38	90.01	123.15	168.47	230.48	315.31	431.37
Transport	7.69	8.45	9.29	10.20	11.21	12.32	4.30	4.58	4.89	5.22	5.56	5.94
Services	3.16	3.41	3.67	3.95	4.26	4.59	4.30	4.63	4.99	5.38	5.79	6.24
Agriculture	5.16	6.43	8.01	9.98	12.44	15.50	8.43	10.76	13.73	17.53	22.37	28.55
Total	370.22	407.79	456.72	520.52	603.74	712.37	134.54	170.62	219.58	286.09	376.52	499.57
MEA scenario												
Branches	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Residential	243.10	245.38	247.86	250.56	253.50	256.70	27.51	27.51	27.52	27.53	27.56	27.59
Industry	113.63	148.92	195.18	255.80	335.25	439.38	90.01	123.15	168.47	230.48	315.31	431.37
Transport	7.69	8.45	9.29	10.20	11.21	12.32	4.30	4.58	4.89	5.22	5.56	5.94
Services	3.16	3.41	3.67	3.95	4.26	4.59	4.30	4.63	4.99	5.38	5.79	6.24
Agriculture	5.16	6.43	8.01	9.98	12.44	15.50	8.43	10.76	13.73	17.53	22.37	28.55
Total	372.74	412.59	464.00	530.50	616.66	728.49	134.56	170.64	219.60	286.13	376.60	499.69
AEA scenario												
Branches	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Residential	345.09	540.79	736.50	736.50	736.50	736.49	27.52	27.52	27.54	27.54	27.54	27.54
Industry	113.63	148.92	195.18	255.80	335.25	439.38	90.01	123.15	168.47	230.48	315.31	431.37
Transport	7.69	8.45	9.29	10.20	11.21	12.32	4.30	4.58	4.89	5.22	5.56	5.94
services	3.16	3.41	3.67	3.95	4.26	4.59	4.30	4.63	4.99	5.38	5.79	6.24
Agriculture	5.16	6.43	8.01	9.98	12.44	15.50	8.43	10.76	13.73	17.53	22.37	28.55
Total	474.73	708.00	952.64	1016.43	1099.66	1208.29	134.56	170.65	219.62	286.14	376.58	499.63
ENEF scenario												
Branches	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Residential	226.47	231.11	235.84	240.67	245.60	250.63	23.02	22.11	21.24	20.40	19.59	18.82
Industry	113.63	148.92	195.18	255.80	335.25	439.38	90.01	123.15	168.47	230.48	315.31	431.37
Transport	7.69	8.45	9.29	10.20	11.21	12.32	4.30	4.58	4.89	5.22	5.56	5.94
Services	3.16	3.41	3.67	3.95	4.26	4.59	4.30	4.63	4.99	5.38	5.79	6.24
Agriculture	5.16	6.43	8.01	9.98	12.44	15.50	8.43	10.76	13.73	17.53	22.37	28.55
Total	356.11	398.31	451.98	520.61	608.76	722.42	130.07	165.24	213.32	279.00	368.63	490.91

**RENEW scenario**

Branches	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Residential	243.10	245.38	247.86	250.56	253.50	256.70	27.51	27.51	27.52	27.53	27.56	27.59
Industry	113.63	148.92	195.18	255.80	335.25	439.38	90.01	123.15	168.47	230.48	315.31	431.37
Transport	7.69	8.45	9.29	10.20	11.21	12.32	4.30	4.58	4.89	5.22	5.56	5.94
Services	3.16	3.41	3.67	3.95	4.26	4.59	4.30	4.63	4.99	5.38	5.79	6.24
Agriculture	5.16	6.43	8.01	9.98	12.44	15.50	8.43	10.76	13.73	17.53	22.37	28.55
Total	372.74	412.59	464.00	530.50	616.66	728.49	134.56	170.64	219.60	286.13	376.60	499.69

Source: LEAP simulation results, 2016.

Table B4: Electricity generation sector by share of input fuels (Mtoe)

North Africa							Sub-Saharan Africa					
BAU scenario												
Branches	2015	2020	2025	2030	2035	2040	2015	2020	2025	2030	2035	2040
Existing oil combustion turbine	23.76	23.76	23.76	23.76	23.76	23.76	20.19	21.03	21.06	21.06	21.06	21.06
Existing coal steam	3.98	3.98	3.98	3.98	3.98	3.98	103.61	107.95	108.10	108.10	108.10	108.10
Hydro	4.75	4.75	4.75	4.75	4.75	4.75	17.07	17.07	17.07	17.07	17.07	17.07
Solar	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Wind	0.67	0.67	0.67	0.67	0.67	0.67	0.02	0.02	0.02	0.02	0.02	0.02
Natural gas	66.83	66.83	66.83	66.83	66.83	66.83	27.17	27.17	27.17	27.17	27.17	27.17
Total	100.03	100.03	100.03	100.03	100.03	100.03	168.07	173.26	173.43	173.43	173.43	173.43
RENEW scenario												
Branches	2015	2020	2025	2030	2035	2040	12.45	21.05	21.06	21.06	21.06	21.06
Existing oil combustion turbine	3.82	9.96	19.63	23.76	23.76	23.76	13.25	34.28	66.65	102.99	107.69	108.10
Existing coal steam	3.98	3.98	3.98	3.98	3.98	3.98	5.50	14.21	17.06	17.07	17.07	17.07
Hydro	3.69	4.75	4.75	4.75	4.75	4.75	0.02	0.02	0.02	0.02	0.02	0.02
Solar	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Wind	0.67	0.67	0.67	0.67	0.67	0.67	5.20	13.45	24.76	27.17	27.17	27.17
Total	20.91	42.08	73.77	100.03	100.03	100.03	36.45	83.03	129.58	168.33	173.03	173.43

Source: LEAP simulation results, 2016.