# A Guide to Sustainable Energy in West Africa

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By

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To the people of the least developed countries who do not have access to stable and reliable energy and a good standard of living, despite the fabulous potential for renewable energy in their countries.

The views expressed herein are those of the author and do not necessarily reflect the views of the United Nations.

# CONTENTS

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# INTRODUCTION

My love of science dates to my teenage years when I was in secondary school. I remember how I was fascinated by physics and chemistry experiments in the college's laboratory. My interest in science helped me score high enough that I was able to enter the Niamey Professional School of Water and Electricity (CMEE) upon passing the secondary school exam in 1978. I attended that school for one month (September) when I heard that I had passed the entrance test to the Agadez Mining School (EMAIR), which I had taken earlier in July 1978. As the Agadez Mining School was a reference school leading to a higher degree and designed to provide the mining industry with qualified personnel, I went there to start the four-year Programme, successfully graduating in June 1982. In those days, upon enrolling in a professional school, one already knew where one would be working after completing the program. After I got my degree, one month after graduation, I was employed by the Ministry of Water Resources and the Environment. I worked with the Ministry of Water Resources and the Environment for seven years, before entering the Bamako Engineering School (ENI) after successfully passing the entrance test. After completing my engineering degree in 1995, I rejoined the Ministry of Water Resources and the Environment. I worked in the Ministry from 1995 to 1998, before joining the United Nations. Since my first job in August 1982, my focus and interest has been on water resource and environmental management. Recently, in the 2000s, I noticed that the energy supply in West African countries was a challenge given that production relied mainly on the high-cost thermic equipment that consumed fossil fuels. Because of this limited capacity and high expense, industry has been limited; cold chain management in health facilities, offices, and trading distribution points has been affected; and household living standards have been negatively impacted. In an effort to complement actual production capacity, countries in West Africa are embarking on using renewable energy, mainly from solar plants and hydropower. Senegal is taking a leading role in the region in this direction.

In this book, I wish to analyze: the level of energy demand and the level of renewable energy potential and utilization in West Africa. The purpose is to identify to what extent the relevant technology is known, has been

introduced, and supplies energy demand in West African countries in general, and in Senegal in particular. I will also look at the regulatory frameworks and strategies designed to achieve a satisfactory level of green energy provision.

In the case of Senegal's renewable energy status, I note that its target power production is 1,264 MW by 2019, of which 20% should be from renewable energy. It had also set a target of cutting greenhouse gases (GHG) released by 5% (representing a reduction of 7 million metric tons of CO2 from total production) by 2030[1]. To reach this target, authorities have prioritized a mixed energy strategy in which clean energy has been identified as playing an important role. Several legal and institutional reforms have been initiated and some clean power infrastructure development projects have been started. Senegal inaugurated the first industrial-sized solar plant in West Africa, a 20 MW plant in Bokhol, 130 km west Saint Louis, on October 24, 2016. Senegal has several other plans for clean energy production. For solar energy, the following plants are currently undergoing installation: Santhiou Mekhe (29.5 MW); Merina Dakhar (29 MW); Kahone (20 MW); and Diass (15 MW). For wind energy, the following plants are current: Aloum Islands, Bassoul-Bassar, Bettenty, and Dionewar-Niodor. For Hybrid plants, Kidira, Goudiry, and Medina Gounass are undergoing installation.

Senegal also has a hand in some encouraging projects, including: The World Bank Scaling Solar Programme (100 MW); Wind Park (50 MW); Taiba Ndiaye (150 MW); Tobene power expansion (35 MW); Global Contour (30 MW); and Sendou (125 MW)[2]. The Emerging Senegal Plan has a vision for social development by 2035, including sectoral objectives of promoting private investment; ensuring enough quantity and quality of energy; a competitive power price (80 to 90 CFA francs, equivalent to 0.15 to 0.16 US$) to support economic growth; reducing household electricity bills; and to end power cuts by 2018[3]. To meet these objectives, the government intends to increase power production and implement a mixed energy strategy (hydropower, solar power, wind power, gas, and coal).

In the following, we will assess how clean energy can contribute to addressing the power demand of some 15 million Senegalese and mitigate the impact of climate change. We will also look at the leadership that Senegal is demonstrating in West Africa.

## Description

Energy generated from fossil fuels is putting a huge burden on the economies of West African countries because of the increasing costs associated with fuel imports. As a result, electrification in West Africa is amongst the lowest in the world, especially in rural areas where it varied from 1% to 70% in 2011[4]. This is despite the tremendous potential of renewable energy in the region, mainly in the form of biomass, hydropower, and solar. An average of 85.7% of each member country's population was still using solid fuels for cooking in 2014. While the above sources have been sufficiently assessed, there are few studies assessing the potential of ocean energy, wind energy (save in Cabo Verde), and geothermal energy in the region. Acknowledging the correlation between energy/fuel and human and economic development, many West African countries have begun setting ambitious objectives and policies related to the use of renewable technologies and energy efficiency as part of the Sustainable Development Goals pathway.

To help achieve these aims, in 2010 the Economic Community of West African States (ECOWAS) created a Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) to "contribute to the sustainable economic, social and environmental development of West Africa by improving access to modern, reliable and affordable energy services, energy security and reduction of energy related externalities" and established cooperation with the Canary Islands Institute of Technology (ITC) to assist technology transfer to West African countries[5]. ECOWAS has approved several policies, including: the ECOWAS Renewable Energy Policy (EREP); the ECOWAS Energy Efficiency Policy (EEEP); the Policy on Fiscal Incentives; the Feed-in Policy; the Net-metering Policy; the Renewable Energy (RE) Mix Policy; and various strategies for promoting renewable energy expansion and capacity building. ECOWAS member states also developed the National Renewable Energy Action Plan (NREAP), which sets clear renewable energy targets. It has also established a strong regional cooperation network, which includes: the West African Power Pool (WAPP); the ECOWAS Energy Protocol (EEP); the West African Gas Pipeline (WAGP); ECOWREX; and the ECOWAS Renewable Energy Facility (EREF), to facilitate energy cooperation among state members and address knowledge and information gaps.

During the last decade, international and regional awareness of renewable energy and climate change has contributed to the introduction and expansion of renewable technologies in the region. As a result, a number

of initiatives, including the establishment of photovoltaic (PV) plants, the construction of dams for hydropower, increased biofuel production, and domestic distribution of solar devices have all increased the use of renewable technology in West Africa. This expansion will continue given its high potential and increasing demand. Senegal was the first West African country to conduct a Renewable Readiness Assessment in 2011 and is home to the first 20 MW solar PV power plants in the region. It is demonstrating strong leadership and a commitment to renewable energy, with other additional PV power plants under construction and several major rural electrification solar projects. The Senegalese authorities are aiming to play a prominent role in the region.

With a population of 378,230 million people and a growth rate of 2.69% in 2018, West Africa's need for energy surpasses the region's electric production capacity (208 GW of electric capacity in 2011), leaving a big gap for expansion of the renewable energy market. With a favorable business environment, public-private partnerships could contribute to the development of renewable technologies in the region.

**Key words:** Climate change; renewable energy; energy efficiency; potential; integration; partnership.

# PART A.

# SUSTAINABLE ENERGY UTILIZATION IN WEST AFRICA

# CHAPTER ONE

# THE ISSUE

West Africa is a geographical entity of an estimated area of 5,112,903 $km^2$ located in the northwest of Africa. It is bordered by Western Sahara, Algeria, and Libya in the north; Chad and Cameroon in the east; and the Atlantic Ocean to the south and west.

West Africa, as defined in 1999, is comprised of 15 states forming the current regional organization for Economic Integration—the Economic Community of West African States (ECOWAS). ECOWAS was established in May 1975 by the Treaty of Lagos and aims at enabling economic integration within the region. Of these 15 countries, 8 Francophone countries have joined the West Africa Monetary Union (UEMOA in French) with a common currency called the CFA franc.

In February 2017, the Kingdom of Morocco applied to join the community, receiving a principle agreement in June 2017. It will have to wait until 2019 to get a final decision from the regional organization. Tunisia and Mauritania also applied to join the community in 2017. It is worth noting that Mauritania was part of the community until 2000, when it decided to withdraw and focus on the Arab Maghreb Union on the basis of a strong cultural relationship.

The population of West Africa was estimated to be 378,229,728[6] individuals in 2018, as per the breakdown by country in Table 1, with a density of 74 individuals per $km^2$.

Concerns over energy security have recently encouraged the promotion of biofuels and no-carbon energy generation technologies[7]. In its efforts to ensure clean and sustainable energy in the region, ECOWAS established a Center for Renewable Energy and Energy Efficiency (ECREE) in July 2010, with the objectives of promoting renewable energy (RE) and energy efficiency (EE); and creating conducive conditions for the mitigation of climate change and a reduction in greenhouse gas (GHG) emissions. In October 2012, ECOWAS became the second regional organization after

the European Union to embrace a regional green energy policy[8]. To address the gap in knowledge and information on renewable energy technologies and resources in West Africa, in 2012 ECOWAS created the ECOWAS Observatory for Renewable Energy and Energy Efficiency (ECOWREX).

In most West African countries, energy supply is unreliable both in terms of quality and quantity. Disruption is frequent resulting in load shedding so as to rotate supply—some areas of a town are supplied for a given time period followed by a cut in favor of other areas. When power is supplied, it is not always stable with frequent variation in supply, potentially causing damage to client equipment. Since client accountability is not considered sufficiently important in most West African countries, damage caused by poor power quality is not compensated and clients are often unaware that they can claim compensation.

Other challenges are as follows:

- A substantial disproportion between electricity supply and demand.
- Inequitable distribution of energy sources within the region.
- A weak setup base for electricity transactions.
- Instability in the Niger Delta region of Nigeria often affects the provision of natural gas to power plants resulting in cuts in power production.
- Limited access capacity in most of countries.
- Limited power trading between countries.
- Inadequate maintenance and ageing infrastructure.
- Low water levels in hydropower reservoirs (Akosombo and Kpong in Ghana; Kanji, Jebba, and Shiroro in Nigeria; Ayame I and II, Kossou, Taabo, Buyo, and Grah in Cote d'Ivoire) as a result of climate change affecting electricity generation capacity.
- Of the US$ 18 billion investment required for the development of infrastructure under the West African Power Pool (WAPP) project, 2004 to 2020, 90% has yet to be raised to set up new production capacity in hydro and diesel-based equipment, transmission equipment and distribution infrastructure.
- Difficulties in attracting investment in the electricity substructure.
- Frequent outages encouraging self-generation of electricity.
- Inadequacy of current prices.
- Theft and non-payment of bills of electricity in some countries.
- An estimated 173,396 deaths per year are due to coal air pollution in West Africa.

Other challenges related to Renewable Energy expansion include:

- Unidentified demand.
- Inadequate legal frameworks to interest investors in entering the sub-sector.

## Takeaway

The ECOWAS Center for Renewable Energy and Energy Efficiency promotes renewable energy and energy efficiency, creating conducive conditions for the mitigation of climate change and a reduction of GHG emissions.

The ECOWAS Observatory for Renewable Energy and Energy Efficiency addresses gaps in knowledge and information on renewable energy technologies and resources in West Africa.

## Action Item

Reflect on and write down the challenges related to the electricity supply in your location. How do they play out? What are the causes? What are the institutions responsible for promoting renewable energy in your country, if there are any?

# CHAPTER TWO

# ENERGY DEMAND IN WEST AFRICA

If we use the UN specified minimum energy requirement for substantive development of 500 kWh[9] per person per year, West Africa's annual energy demand stood at 189 TWh in 2018. However, if we consider the world average of 2,400 kWh, this figure increases to 907.75 TWh. In 2013, IRENA[10] estimated the final electricity demand of West Africa to be 608,257 GWh, as indicated in Table 2.1. In the following, we will look at demand country by country in order to clearly see the current gaps.

**Benin** had 11,363,546 inhabitants as of 8th February 2018 (UN estimate, 2018). If we consider the UN minimum energy requirement for substantive development of 500 kWh per person per year, Benin's annual energy demand stands at 5,681 GWh. In 2010, wood and charcoal accounted for 49.5% of total energy consumption, followed by oil products (48.3%), and electricity (2.2%) (World Bank). In 2012, 90% of the electricity consumed was imported from neighboring countries and the electrification rate was 28.2% across the country: 54.9% in urban areas and 4.5% in rural areas. In 2017, the electrification rate rose to 32%, with 11% in rural areas and 56% in urban areas (Power Africa, 2018).

**Burkina Faso** had 19,531,613 inhabitants as of 8th February 2018 (UN estimate, 2018). If we consider the UN minimum energy requirement for substantive development of 500 kWh, Burkina Faso's demand stands at 9,765 GWh. In 2016, 19.20% of the population had access to electricity (World Bank, 2017), leaving more than 80% without access to electricity. In rural areas, less than 5% had access to electricity. In 2017, the overall rate had reached 20.3%, with 1.5% in rural areas and 58.1% in urban areas (Power Africa, 2018).

**Cabo Verde** had 550,587 inhabitants as of 8th February 2018 (UN estimate, 2018). If we consider the UN minimum energy requirement for substantive development of 500 kWh, Cabo Verde's demand stands at 275.293 GWh. In 2017, overall access was 62%, with 31% in rural areas and 88% in urban areas.

**Cote d'Ivoire** had 24,665,259 inhabitants as of 8th February 2018 (UN estimate, 2018)[11] requiring 12,333 GWh based on the UN standard for substantive development. Gross demand of electricity was 6,000 GWh in 2012 and has risen by 10% every year since (Amelie Beaujard, 2016).

**The Gambia** had 2,138,440 inhabitants as of 8th February 2018 (UN estimate, 2018) and annual energy demand stands at 1,069 GWh. Energy consumption stood at 81-kilogram oil equivalent (koe) per person in 2007 (GEF/UNIDO, 2011). Wood consumption has grown from 430 tons in 1983 to 829.42 tons in 2004, due to population growth from 687,800 to 1,397,600 inhabitants over the same period (CILSS, 2012). Firewood supplies 97% of the total domestic energy consumption.

**Ghana** had 29,215,855 inhabitants as of 8th February 2018 (UN estimate, 2018)[12] and energy demand stands at 14.61 TWh based on the UN requirement for sustainable development. Electricity demand was 9,000 GWh in 2012, and increasing at the rate of 10% per year, bringing it to an estimated 24,000 GWh by 2020[13]. Ghana has set a target of 10% renewable energy production by 2020.

**Guinea's** population stood at 12,918,555 inhabitants as of 8th February 2018 (UN estimate, 2018)[14]. Its energy demand amounts to 6,459 GWh based on the requirement for substantive development of 500 kWh. It has set objectives of increasing access to electricity from 30% in 2016 to 75% by 2020, and to 100% by 2030. Production from hydropower is set to be increased from 368.1 MW in 2016 to 883.5 MW by 2020, and to 1,719.5 MW by 2030. Solar PV is to increase from 0 MW in 2016 to 100 MW by 2020, and to 500 MW by 2030. Bioelectricity will also increase from 0 MW in 2020 to 50 MW by 2030 (Alpha Ibrahima Diallo, 2016).

**Guinea Bissau** had 1,889,166 inhabitants as of 8th February 2018 (UN estimate, 2018)[15]. Its per capita energy consumption stood at 0.3-ton equivalent petroleum (tep; 1 tep = 41,868 GJ) per year in 1985, which is equivalent to 666 kg of wood per person per year (in total, 1.2 million $m^3$ of wood). This consumption is higher than the average (450 kg) for member countries of CILSS (Permanent Interstate Committee for Drought Control in the Sahel; in French: *Comité permanent inter-État de lutte contre la sécheresse au Sahel*): the Republic of Burkina Faso; the Republic of Chad; the Republic of the Gambia; the Republic of Guinea Bissau; the Republic of Mali; the Republic of Mauritania; the Republic of Niger; and the Republic of Senegal. This figure is increasing by 8.3% per

year (CILSS, 2012). Its electricity production capacity was 13 ktoe in 2015 entirely from wood fuel (World Bank, 2015).

**Liberia** had 4,804,940 inhabitants as of 8th February 2018 (UN estimates, 2018) and energy demand stands at 240.2 GWh. The successive civil wars of 1989 to 1997 and 1999 to 2003 destroyed all infrastructure, including power infrastructure. Its current countrywide electricity rate stands at 12%, with less than 20% having access in urban areas.

**Mali** had a population of 18,880,935 inhabitants as of 8th February 2018 (UN estimate, 2018). If we consider the UN minimum energy requirement for substantive development of 500 kWh, Mali's energy demand stood at 9.44 TWh in 2018. Per capita energy consumption was 0.2 tons of oil equivalent energy (toe) in 2007, which was met by biomass (80%), oil products (16%), electricity including hydropower (3%), and other renewable energy (1%)[16]. Demand is growing by 10% every year in urban areas, and although there are few estimates for rural communities, it seems to be higher because of a limited rate of access of 14.89% (Mali SREP, 2015). There is an unknown energy demand from privates, industrials, and mining companies. Unsatisfied demand decreased from 111 MW (45% of needs) in 2013 to 32 MW (13.5% of needs) in 2014 (AfDB, 2015).

**Niger** had a population of 21,981,691 inhabitants as of 8th February 2018 (UN estimate, 2018). Energy demand stands at 10.99 TWh. Currently some 3.8 million households lack electricity.

**Nigeria** had a total population of 193,881,803 inhabitants as of 8th February 2018 (UN estimate, 2018)[17]. Based on the UN minimum energy requirement for substantive development of 500 kWh, Nigeria's energy demand equals 96.94 TWh. In 2017, 20 million Nigerian households did not have access to power, but authorities have set a target of universal access by 2030.

**Senegal** has 16,116,738 inhabitants as of 8th February 2018 (UN estimates, 2018). The case of Senegal will be studied separately in Part B.

**Sierra Leone** had 7,655,818 inhabitants as of 8th February 2018 (UN estimate, 2018). Based on the UN minimum energy requirement for substantive development of 500 kWh, Sierra Leone's energy demand stands at 3.83 TWh.

**Togo** had a total population of 7,913,793 inhabitants as of 8th February 2018 (UN estimate, 2018). Based on the UN minimum energy requirement

for substantive development of 500 kWh, Togo's energy demand equals 3.96 TWh.

Although **Morocco** is located in North Africa, it has applied to join ECOWAS. Morocco is a market of 36,012,911 inhabitants as of February 8, 2018 (UN estimates, 2018).

## Takeaway

The UN specified minimum energy requirement for substantive development is 500 kWh.

The world average energy requirement for substantive development stands at 2,400 kWh

## Action Item

Please have a notebook and a pen to hand to note down your (or your family's) daily energy consumption over three months. Calculate your average monthly consumption (three months total consumption, divide by the total number of days, and multiply by 30 days).

Based on your monthly average consumption calculate your annual consumption. Compare your annual consumption to the UN specified minimum energy requirement. What conclusion can you draw?

Take a resolution to reduce your (or your family's) consumption: write down what you will do differently to save energy? Apply actions to save energy for one month and calculate the total saving you achieve. What is the cost of the energy saved (use your bills to find the unit cost of the kWh) in one month? What is your annual saving?

# CHAPTER THREE

# ENERGY SUPPLY IN WEST AFRICA

Adeola (2008) highlighted that power production in most West African countries was often from one source. Benin, Burkina Faso, and Niger produce most of their electricity from diesel-fueled machinery. Ghana, Guinea, and Mali produce most of their electricity from hydropower. In Nigeria, natural gas accounts for 60% of electricity production; in Cote d'Ivoire it accounts for 67%. Water shortages in reservoirs due to seasonal variations and weather patterns and insufficient electricity trading between West African countries increase the risk of constant power shortages (Adeola, 2008).

Regarding access to electricity (table 3.1), 50 to 60% of the population have access in Ghana; and 20 to 40% have access in Benin, Senegal, and Cote d'Ivoire. The figure is much smaller in other West African countries. In Liberia, which experienced war in the 2000s, only 1.4% of the population had access to electricity in 2015 (SE4All, 2015). Access varied from 40% in urban locations to 6 to 8% in rural communities (Adeola, 2008). West Africa has witnessed a significant dearth in power since the middle of 2006 due to issues of low economic growth, insufficient development of production capacity (Adeola, 2008), and war (Liberia, Sierra Leone). Below, we will analyze the situation country by country.

**Benin** had a total production capacity of 349 MW in 2017, of which 249 MW was from fuel and 100 MW from hydropower. The country's power utility company SBEE (meaning, in French, "Societe Beninoise d'Energie Electrique") faces significant operational and commercial issues. The enabling environment for independent power producers (IPP) is insufficient and the off-grid sector is embryonic.

In **Burkina Faso**, biomass contributes 80% of the total energy provision, with a daily per capita consumption of 0.69 kg of firewood[18]. Electricity from fuel generated plants stands at 70% and there are four hydropower plants. The strategy of Burkina Faso so far has been to import electricity from Cote d'Ivoire, Ghana, and Togo. Installed production capacity in

2017 stood at 300 MW, of which 253 MW was from fuel, 32 MW from hydropower, and 33 MW from solar. The actual access rate of electricity is 20.3%, with 1.5% in rural areas and 58.1% in urban areas. Current challenges include: the insufficient provision of energy; high electricity prices; a lack of regulation for independent power producers; and little experience with IPPs. Authorities have set a target to reach an access rate of 80% by 2020 and 95% by 2025. They intend to increase the installed capacity to 1,000 MW by 2020 and to 2,000 MW by 2025 (Power Africa, 2018).

**Cabo Verde** had a production capacity of 443 GWh in 2016, of which 81% was from fossil fuels, 17% from wind, and 1.7% from solar. In 2017, the country had an electricity access rate of 92.6%. The rate of access to modern energy cooking systems was 65% in 2015 (Anildo, 2015). Cabo Verde has set a target of 100% renewable energy capacity (485.2 GWh) by 2020 (ECREEE, SE4All 2016). It has renewable energy projects worth 600 MW.

According to the World Bank, in **Cote d'Ivoire**, as of 2014, 61.9% of the population had access to electricity—84% in urban areas and 36.5% in rural communities. 18.5% had access to clean fuel and cooking devices. RE consumption represented 70.8% of total final energy consumption, while RE output was 23.9% of total electricity output, and per capita electricity consumption was 280.8 kWh[19]. The main energy sources are hydropower, oil, gas, and biomass, which accounts for 70% of total energy consumption. In 2017, installed capacity was 2,178 MW, of which 60% was from thermal sources and 40% was from hydropower. The government of Cote d'Ivoire has set the objective that all citizens have access to electricity by 2020. It has also set a RE target of 16% in the energy mix by 2030, excluding big hydroelectricity sources, and reducing power from industry by 25% by 2030. The current major challenges include: a limited off-grid enabling environment, an ineffective procurement and project development process and the high cost of grid connection (USAID, 2017).

**The Gambia** had a total energy supply (TES) of 407.926 toe in 2010 (The Gambia SE4ALL, 2015). The annual deficit was 685.949 tons of fuel wood in 2004 and 60 to 80% of its wood consumption comes from imports[20]. Biomass contributes 77.8% of the energy supply, petroleum products contribute 20.6%, electricity contributes 1.6%, and solar power accounts for 0.03% (The Gambia SE4ALL, 2015).

In **Ghana**, biomass accounts for 50% of total primary energy supplied, followed by oil (40%), then hydroelectricity with 7%, and gas contributing 3%. In 2010, the primary energy supply was ensured by biomass (firewood and charcoal), which 90% of households used for cooking; 18.2% households had access to LPG; and 64.2% households had access to electricity for lighting[21]. Electricity is primarily provided by hydropower (64%) and oil-fired plants (36%). In 2017, Ghana had a generation capacity of 4,399 MW, of which 1,580 MW came from hydroelectricity, 2,796 MW from thermal generation, and 22.5 MW from other renewable energy sources. The access rate was estimated at 83% in 2017 with 50% in rural areas and 91% in urban areas. Authorities have set a target of 100% access to electricity by 2020.

In 2011, **Guinea's** energy mix was composed of biomass (77%), imported fuel (22%), hydropower (1%), and renewable energy including solar, wind, and biofuel (0.02%)[22]. 2013 baseline information showed an overall electricity access rate of 26% with 53% in towns and 11% in countryside areas. In 2016, Guinea had electricity coverage of 30%. Hydropower generation of 368.1 MW was connected to the grid, 202.2 MW was from fuel generated machinery, 2 MW from rural electrification, and 7% was from clean energy devices (Alpha Ibrahima Diallo, 2016). Installed capacity reached 566 MW with the addition of the Kaleta hydropower dam. The electricity sector in Guinea faces a number of challenges, such as dilapidated infrastructure, high technical losses, high commercial losses, and poor financial performance (Power Africa, 2017)

**Guinea Bissau** imports approximately US$ 8 million worth of oil products per year (INEC, 1997) for internal consumption. Wood satisfies 90% of energy demand. In 2017, the electricity access rate was 15% with a total generation capacity of 41 MW. Authorities have targeted 100% access to electricity by 2030, of which 70 MW (75% of the total power demand) will be from renewable energy.

**Liberia's** primary energy supply is ensured by biomass (93%), petroleum products (5.24%), electricity (1.39%), and hydropower (0.12%)[23]. In 2017, electricity access was 19.80% with a total generation capacity of 131 MW, of which 88 MW was from hydropower and 43 MW from diesel, leaving some 830,000 households without power. Liberia imports electricity from Ivory Cost to supply 36,000 people. Liberia's power demand is estimated to reach 350 MW by 2020. Authorities have set respective targets of 70% and 35% power access in the capital, Monrovia, and in the countryside by 2030. Challenges currently facing the electricity supply include: a weak

enabling environment, high prices and high losses in public service, slow extension of the delivery network, and an embryonic off-grid renewable energy sector.

In **Mali**, 78% of energy consumed is supplied by biomass, 21% is supplied by fossil fuels, and 1% is supplied by hydropower (IRENA, 2014). Hydropower worth 250 MW is generated by barrages located on tributaries of the Niger River (Selingue and Sotuba) and on tributaries of the Senegal River (Manantali and Felou); 90 MW is generated by oil-fueled plants. The Mali grid is connected to Cote d'Ivoire, Mauritania, and Senegal. EDM (2010) states that 57.3% of connected grid power was supplied by hydroelectricity plants and 42.7% by fuel-generated plants. In 2017, the access rate was 35%, with a connection rate of 60% in urban areas and 18% in rural areas (Power Africa, 2018). This figure contradicts the 62% rate in 2012 given by the government utility, EDM (EDM cited by AfDB, 2015)[24]. This could be due to a delay in ensuring completion of the ten-year cycle of equipment maintenance causing a reduction in generation capacity. The Malian power mix system is comprised of: government utility fuel-powered plants; hydropower plants harnessing the power of two major rivers (Niger and Senegal); rural solar and fuel systems; and fuel-based plants owned by the mining sector. EDM, the government utility company, has little experience of renewable energy and has issues managing three hybrid diesel/PV solar plants: one of 216 KWp inaugurated in 2011 and two in 2014. Challenges in the electricity production sector relate to delays in maintenance of production plants; the precarious financial situation of EDM; the high costs and quantities of fuel imports; and the vulnerability of hydropower systems to climate change impacting water flows in the Niger and Senegal River systems. In 2012, the average price of electricity was 0.19 US$ per kWh, compared to a generation price of 0.25 US$ per kWh—this is the main reason for the critical financial state of EDM. In isolated areas, the generation price is even higher, reaching 0.35 US$ per kWh at times.

In **Niger**, biomass contributes to 70% of the 2,747 ktoe of primary energy supply[25] and fulfills 83% of domestic energy need[26]. It is followed by oil products (18%) and coal (3%). In 2016, the status of the energy supply in Niger was as follows: countrywide electrification stood at 10%, with 0.04 MW PV connected to the grid and 0 MW of hydropower and biomass power plants connected to the grid; rural electrification was 0.12%; 15% had access to efficient cooking equipment; and fuel-powered plants generated 200 MW[27]. In 2015, domestic electricity production capacity was 458 GWh and imports stood at 779 GWh. This means that domestic

electricity production fulfilled 43% of the total electricity consumed. The access rate was 16.22% in 2015. Niger's crude oil production was 13,000 barrels in the same year. Niger has recoverable uranium reserves amounting to 450 Kt, coal reserves of 90 Mt, and oil reserves of 20 Mt. Exploitation of uranium in Niger started in 1970 with the Air Mining Company (SOMAIR), followed by the Akouta Mining Company (COMINAK) in 1974, and the Azelik Mining Company (SOMINA) in 2010. A fourth company, IMOURAREN created in 2009, was supposed to start uranium exploitation in 2012, but due to institutional changes this did not materialize (Can & Gado, 2016). Total production of uranium was 5,000 T placing Niger fourth in the world behind Australia, Canada, and Kazakhstan (Can & Gado, 2016). Once extraction by IMOURAREN starts (with an estimate production capacity of 5,000 tons), Niger will be the second placed global producer of uranium. Coal reserves amount to more than 90 million tons, with 70 million tons in Sakadalma (Tahoua region) and 80 million tons in Anou-Araren (Agadez region) and other sites in Solomi in the Agadez region (Can & Gado, 2016). The Tahoua coal is planned to be used for power production and briquette production for domestic energy cooking. Coal has been exploited in Anou-Araren since 1976 for electricity production in thermic plants.

Oil production was started in Agadem in 2011 by a Chinese company, CNPC. Oil produced in Agadem is transported to a refinery in Zinder (420 km) where it is transformed into finished products. The Zinder refinery has a capacity of 20,000 barrels per day. Finished products include benzene, fuel, and natural gas. Can & Gado (2016) state that natural gas is used for internal consumption (7,000 barrels per day) and export (13,000 barrels per day). 235 MW of hydropower potential has not yet been tapped into. The Niger energy sector is facing technical capacity limitations, security challenges, and issues with the creditworthiness of its utility companies (Power Africa, 2018). Authorities are targeting universal access by 2035.

In **Nigeria**, natural gas contributes 5% to total energy consumption, compared to 83% from biomass, 11% from oil, 1% from hydropower, and an insignificant amount of coal[28]. Electricity generation capacity was 6,000 MW in 2012, of which 1,270 MW was from hydropower and 4,730 MW from fossil fuels. Net production was 26 million kWh (Presidential Task Force on power, 2013). In terms of domestic energy consumption, most Nigerians use biomass products (wood, waste, charcoal) for food preparation and heating. In 2016, Nigeria had a national electrification rate of 40% with targets of 75% by 2020 and 90% by 2030. The rural electrification rate was 28% against a target of 60% by 2020 and 85% by

2030. PV power generation connected to the grid was 0 MW, with targets of 2,050 MW by 2020 and 6,000 MW by 2030. Hydroelectricity generated 1,245 MW against a target of 2,805 MW by 2020 and 5,900 MW by 2030. Biomass power generation connected to the grid contributed 0 MW against a target of 300 MW by 2020 and 1,100 MW by 2030. Finally, 10% of households had access to clean cooking equipment against a target of 50% by 2020 and 80% by 2030[29]. Between 2007 and 2008, despite its huge oil reserves, Nigeria faced an average of 46 days per year of electricity disruption (Daly J., 2013)[30]. Power Africa (2018) reports that Nigeria had an installed capacity of 12,522 MW in 2017, of which 10,142 MW was from thermal plants and 2,380 MW from hydroelectric plants. The electricity access rate was 45% (36% in rural areas and 55% in urban areas). Although electricity demand is high due to Nigeria's large population (186 million inhabitants as of 2017), the lack of investment in the sector and weak infrastructure are both major challenges. Other challenges include: macroeconomic forces; a lack of creditworthy companies involved in the sector; and the lack of a transparent/independent regulator (Power Africa, 2018).

**Senegal** had an installed capacity of 864 MW as of the end of 2017. 733 MW of this came from thermal sources; 60 MW came from hydropower; and 50 MW came from solar. The actual access rate was 64%, with 43.5% of people in rural areas and 90% in urban areas having access to electricity. Currently, some 1.1 million households do not have access to electrical energy in Senegal. Power Africa (2018) identified some challenges in Senegal's power system, such as: the weakness of procurement processes; a lack of creditworthy utility companies; and insufficient planning. Government authorities have a target of universal access by 2025.

In **Sierra Leone** the total generation capacity was 356.3 MW as of May 2012: 37 MW from thermal oil plants; 50 MW from large hydropower plants; 6.75 MW from small hydropower plants; 135 MW from auto-generators; 39 MW from energy imports; 88.5 MW from mining company generation; and 0.025 MW from solar (MEWR, NPA, NRA, UPS, 2012). In 2011, less than 10% of families had access to electricity. By 2016, the electrification rate was 12.5%, with targets of 44% by 2020 and 92% by 2030. The rural electrification share was 2.5% against targets of 14% by 2020 and 37% by 2030. RE contributed 56 MW to the grid, against targets of 650 MW by 2020 and 1,200 MW by 2030. 15% of the population was using improved cooking ovens, against targets of 26% by 2020 and 48% by 2030. 2% of households were using LPG, against targets of 16% by 2020 and 25% by 2030 (Benjamen Camara, 2016). Wood and charcoal are

the main sources of fuel for household cooking, and are also used, to a lesser extent, in industrial sectors. Biomass accounts for 80% of energy consumed in the country.

**Togo** had a total production capacity of 85 MW in 2008: 78.8% from hydroelectricity and 21.2% from thermal sources (REEEP Policy Database, 2012). For the same year, the total primary energy provision was 2,563 Ktoe with 83.1% from biomass and waste, 0.4% from hydroelectricity, 14.3% from oil, and 2.2% from imports (REEEP Policy Database, 2012). In 2017, Togo had a total production capacity of 230 MW: 164 MW from fuel sources and 66 MW from hydropower, of which 19.94% was imported from Nigeria and Ghana (2014 data). In 2017, the electricity access rate was 46.93%. In 2010, the growth of independent power producers had contributed to an increase in generation capacity. In 2017, the government with the support of the International Finance Corporation started doing business with off-grid private companies to promote rural electrification through the installation of 800,000 solar home systems over five years (500,000 systems by Power Africa BBOX and 300,000 by Greenlight Planet). Authorities have set a target of 100% access by 2030.

**Morocco**, a candidate to join the West African Economic Community, has the potential to increase power generation from biomass, hydropower, solar, and wind energy. By December 2017, its renewable energy installed capacity had reached 34% (Moustapha Bakkoury, 2018), with a target of 42% by 2020[31]. Morocco has high wind energy potential (9.5 to 11 m/s at 40 m height in Essaouira, Tanger, and Tetouan; from 7.5 m/s to 9.5 m/s in Dakhla, Tarfaya and Taza areas.

In 2012, Morocco was already producing 5.87 petajoules (PJ) from hydropower and 2.64 PJ from geothermal and solar sources. In 2015, it had 787 MW of installed wind power capacity, with another 1,000 MW to be installed by 2020. In 2018, Tiyou (2018) said that Morocco was the second biggest wind market in Africa, with an operational capacity 1,030.92 MW and a 60.35 MW system under construction. It also plans to develop a 160 MW concentrated solar plant.

## Perspective on energy supply in West Africa

There are two important power projects in West Africa: The West African Power Pool (WAPP) and the West African Gas Pipeline Project (WAGPP). WAPP was set up in 1999 by ECOWAS to address issues relating to a feeble substructure base for energy transactions, transmission, and distribution between West African countries. A major objective was the interconnection of national grids, stretching 5,000 km, and including Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, Niger, Nigeria, and Togo. The vision was to:

1. improve interconnection and energy give-and-take between countries;
2. synchronize regulations and standards for energy sector processes;
3. encourage and safeguard private venture investment in power projects;
4. use flare-gas in Nigeria to feed power plants in bordering countries;
5. form an open and inexpensive regional power market.

It is estimated that some US$ 18 billion will be invested in the WAPP infrastructure between 2004 and 2020, of which 90% will be used to increase hydropower and thermal generation ability[32].

The WAGPP aims to set up a 687 km pipeline to use some of the flared-gas in Nigeria to feed thermal power stations in Benin, Togo, and Ghana with an overall capacity of 3,000 MW in 20 years. It is estimated that the project will cost US$ 635 million. WAPCO is managing the project in partnership with Chevron West Africa Gas pipeline Ltd (36.7%), NNPC (25%), Shell Overseas Holdings Ltd (18%), Takorady Power Company Ltd (16.3%), and Bengaz (Benin) and Sotogaz (Togo) (together hold 2%).

A partnership mechanism between the European Union and Africa, called the Renewable Energy Cooperation Programme (RECP), has the ambitious objective of promoting renewable energy in the continent. The targets set by this Programme include the construction of 10,000 MW of hydroelectric capacity, 5,000 MW of wind power, and 5,000 MW from solar plants and other RE sources (like geothermal) by 2020. This Programme supports the efforts of the ECREE in setting up policies on renewable energy in West Africa. The RECP supports the development of a political and legal framework for the renewable energy market. It supports the launch of flagship RE projects and capacity development in education and vocational training institutions so as to train the next