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Sustainable Electricity Supply Scenarios for West Africa



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SUSTAINABLE ELECTRICITY SUPPLY
SCENARIOS FOR WEST AFRICA

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SUSTAINABLE ELECTRICITY SUPPLY SCENARIOS FOR WEST AFRICA

A CASE STUDY CONDUCTED BY IAEA MEMBER STATES IN
WEST AFRICA WITH THE SUPPORT OF THE IAEA

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2016

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FOREWORD

The West African region is richly endowed with diverse energy and mineral resources. Although these resources can support meaningful industrial activity, and thus promote sustainable socioeconomic development, the region lags behind many developing parts of the world in overall human development. For instance, 13 out of the 15 countries are classified as least developed countries and 60% of the total population of 300 million live on less than one US dollar per day. Against this background, access to energy, and in particular to electricity, is of prime importance for continued and sustainable socioeconomic development in the region.

This publication is an outcome of a study carried out by the IAEA Member States in West Africa in 2012 and 2013 on future options for sustainable electricity supply in the region. The study was supported by the IAEA Technical Cooperation Project RAF/2/009: Planning for Sustainable Energy Development, in particular through the training of experts in participating Member States in the use of IAEA energy assessment tools, which were then used to conduct the study, through the provision of expert support for conducting the national and regional analyses, and through the provision of overall coordination and support for the preparation of this publication.

The objectives of the study were to conduct model supported national electricity demand and supply analyses and to develop scenarios of cost optimal expansion strategies for electricity generation. The study specifically addressed the problem of very limited electricity access in the region and disparities in the availability of modern energy services between and within the countries, with the objective of working towards universal access to electricity. Models of individual national electricity supply systems were developed and incorporated into a larger model on the regional level to allow for an analysis of electricity trade flows between countries, of impacts of regional integration of electricity transmission on the national choices of electricity generation technologies, and of national and regional electricity supply scenarios.

The findings of both the national and the regional analyses are presented here. These findings can serve as a starting point for future higher level discussions and can facilitate the development of strategic plans for building the required electricity infrastructures in West Africa. The IAEA officers responsible for this publication were A.I. Jalal and M. Tot of the Division of Planning, Information and Knowledge Management.

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1. INTRODUCTION

1.1. BACKGROUND AND APPROACH

Responding to the interest in investigating all energy production options expressed by several leaders from the West African sub region, drawing on past experience in assisting countries and regions in energy planning and preparation of energy plans including all technological options, it has been proposed to use a scenario based analysis approach, supported by a mathematical model of the national and regional electricity systems, as basis of the present study.

The principal approach used in the study is scenario analysis supported by a mathematical model of the national and sub regional electricity systems. According to the Intergovernmental Panel on Climate Change [1], "Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future outcomes and to assess the associated uncertainties. Any scenario necessarily includes subjective elements and is open to various interpretations". A scenario is not a prediction of the future, but an internally consistent description of a future state or trajectory that is as comprehensive as needed for the purposes of the analysis.

A scenario based approach was chosen because the future is inherently uncertain. It was considered preferable to analyse and understand the implications of different potential development paths, rather than to try to predict the future, with a risk to irrevocably stick to solutions that are less robust, less flexible and more sensitive to uncertainties.

1. As the first step, basic assumptions were made regarding demography and economic growth, based on available UN and national information.
2. As the second step, two electricity *demand* scenarios were developed (Reference and Universal Access). These scenarios contain detailed information only on the demand side for electricity, until 2030, on country level.
3. As the third step, possible *supply* scenarios to *meet this demand* were modelled by applying IAEA's energy system assessment tool and modelling framework MESSAGE, a flexible and versatile tool specifically designed for complex energy system analyses.
4. In the fourth step, these electricity supply scenarios were analysed as a basis for the final overall conclusions.

The time horizon covered by the study is from 2010 until 2030.

1.2. OBJECTIVE

The primary goal of the study was to understand and assess future options for electricity supply at the lowest costs in the West African sub region. The study also examines energy resources and investment requirements for achieving universal access to electricity in the region by 2030/35.

The West African sub region is richly endowed with diverse energy and mineral resources. Although these resources can support meaningful industrial activities, and thus promote sustainable socio economic development, the region lags behind many developing parts of the world in terms of overall development.

The sub region's socio economic development challenges have been linked to limited access to energy services for most inhabitants to meet their basic human needs and engage in income generating activities. In 2010, the average access to grid electricity for the whole region was estimated at 34.2%. In other words, about 197.4 million people were living without access to electricity. Other challenges are energy affordability and reliable supply of electricity. In many cases, people and enterprises have to rely on expensive diesel power generation to meet their electricity needs, which cost some countries between 1–5% of the national GDP [2] annually. Besides, reliance on expensive diesel powered generation is not a sustainable option to support large scale industrial activities. Consequently, the sub region has a low electricity use per capita of about 88 kW·h in 2010 compared to about 563 kW·h for the rest of Africa and 2596 kW·h for the world [3].

The sub region is currently experiencing rapid urbanization, high population and economic growth rates. To sustain the current economic growth and leapfrog along the socio economic development path, it is crucial to adequately and sustainably meet future electricity demand. As the challenges facing many West African countries in terms of electricity supply delivery are similar, an integrated approach to achieve economies of scale and overcome logistical constraints in the effort to improve electricity access is needed.

This study was conceived based on the idea of providing a coherent sub regional platform for the development of a robust joint policy framework for an enhanced and sustainable provision of electricity services to support socio economic growth. This understanding resulted in three detailed objectives:

- To develop national as well as an integrated sub regional strategic plans for building future electricity infrastructure, which will ensure a cost optimal and sustainable provision of electricity;
- To analyse plausible national and sub regional electricity supply options concerning power market, the potential role of nuclear power and renewable energy sources;
- To present a summary of findings of national as well as the integrated sub regional analyses for discussion at a higher, decision making level.

2. ELECTRICITY SYSTEMS IN WEST AFRICA

The study analyses electric systems of 14 countries in the sub region¹. National teams from 8 countries contributed to the conduct of analysis and preparation of the report (Burkina Faso, Ghana, Cote d'Ivoire, Mali, Niger, Nigeria, Senegal, and Sierra Leone). The primary data for other countries were taken from the different public sources.

This chapter presents country summaries and profiles as prepared by the national experts of participating countries, starting with a regional overview.

2.1. REGIONAL OVERVIEW

The current level of development of the energy system is a bottleneck for the social, economic and industrial development throughout the West African sub region. Countries face challenges to energy access and energy security that are characterized by power shortages in urban areas and very limited access to modern, affordable and reliable energy services in rural areas. Solutions to these challenges are related to a set of economic, social, environmental and political problems.

2.1.1. Energy poverty

West Africa, with nearly 300 million people, about a third of the Africa population, has one of the lowest consumption of modern energy forms in the world. While urban areas tended to use diverse energy solutions (electricity, charcoal, LPG, oil and others), rural areas still rely on traditional biomass for their energy needs for cooking and lighting. Traditional biomass (firewood and charcoal) is the principal source for final energy consumption, its share reaching 70-85% in some countries. The use of wood energy has a negative impact on the health and quality of life, particularly for women and children, and negative environmental consequences.

In 2009, it was estimated that nearly 175 million people lacked access to electricity (25% of them live in urban areas and 75% in rural areas). In most of the countries, less than 10% of the rural population has access to electricity. In very optimistic scenarios, it is estimated that 75% of the population will be connected to the grid by 2030. If this trend is confirmed, the region is far from reaching a goal of universal access [4].

2.1.2. Underdeveloped electricity sector

Energy poverty is reflected in the electricity sector by national power systems in crisis and stalemate. These electrical systems are characterized by the following significant findings:

- Low electricity access;
- High electricity supply cost;
- Shortage of supply (relative to demand);
- A difficult financial situation for most of the national utility operators.

¹ Cabo Verde was not included into the analysis, as it is not connected to the mainland electricity network of West Africa.

2.1.2.1. Low electricity access

Although different sources give different numbers on electricity access, according to a UNDP study [5], it is estimated that in 2008 only about 38% of the population in West Africa had access to electricity, with a marked imbalance between urban and rural areas. Excluding the islands of Cabo Verde, only several countries, i.e. Nigeria, Ghana, Cote d'Ivoire and Senegal have national electricity access above 40%. Those four countries account for about 72% of the total population. More importantly, the number of people with electricity access in four countries is almost 90% of the overall population having electricity access in the sub region. Figure 1 to Figure 3 illustrate a large gap between the national efforts in electrification projects and indicate that strong actions are needed to increase electricity access rates, especially in smaller countries.

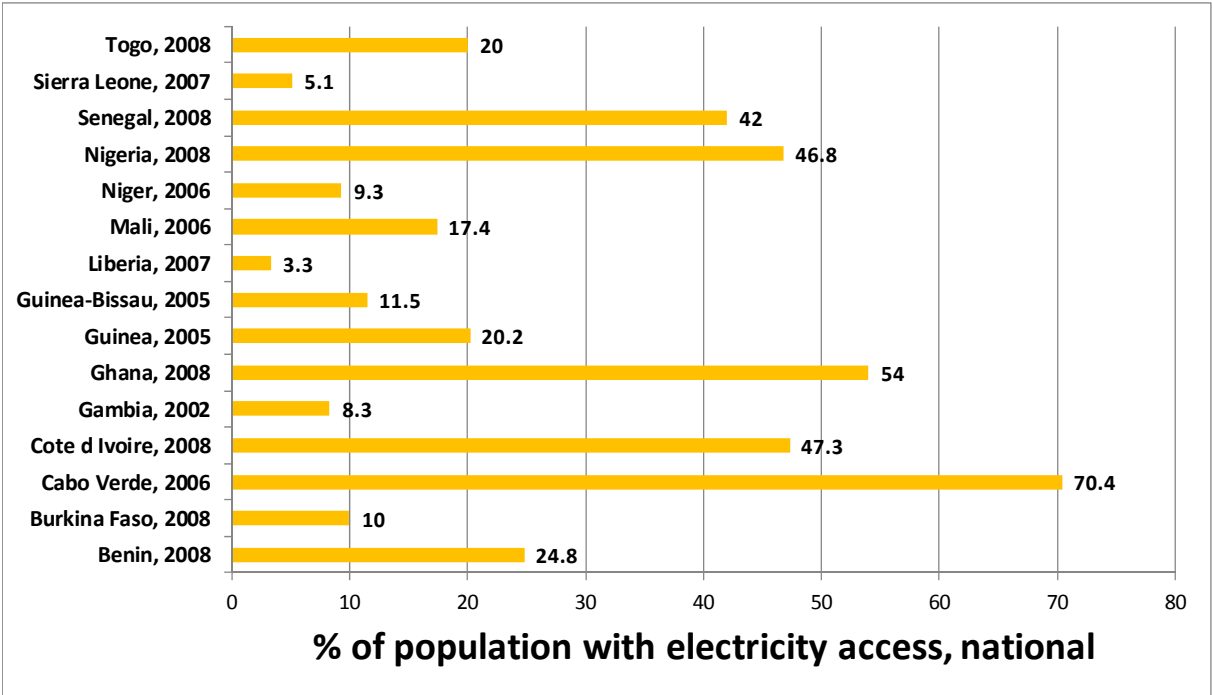


FIG. 1. Percentage of population with electricity access by country. (Data Source: [5])

Electricity access situation in urban areas is steadily improving, and by the end of 2008 only four countries (Sierra Leone, Liberia, Guinea Bissau and Burkina Faso) had access rate below 40%. Still, overall access rate in urban areas is only 65% leaving around 42.8 million inhabitants in cities without electricity.

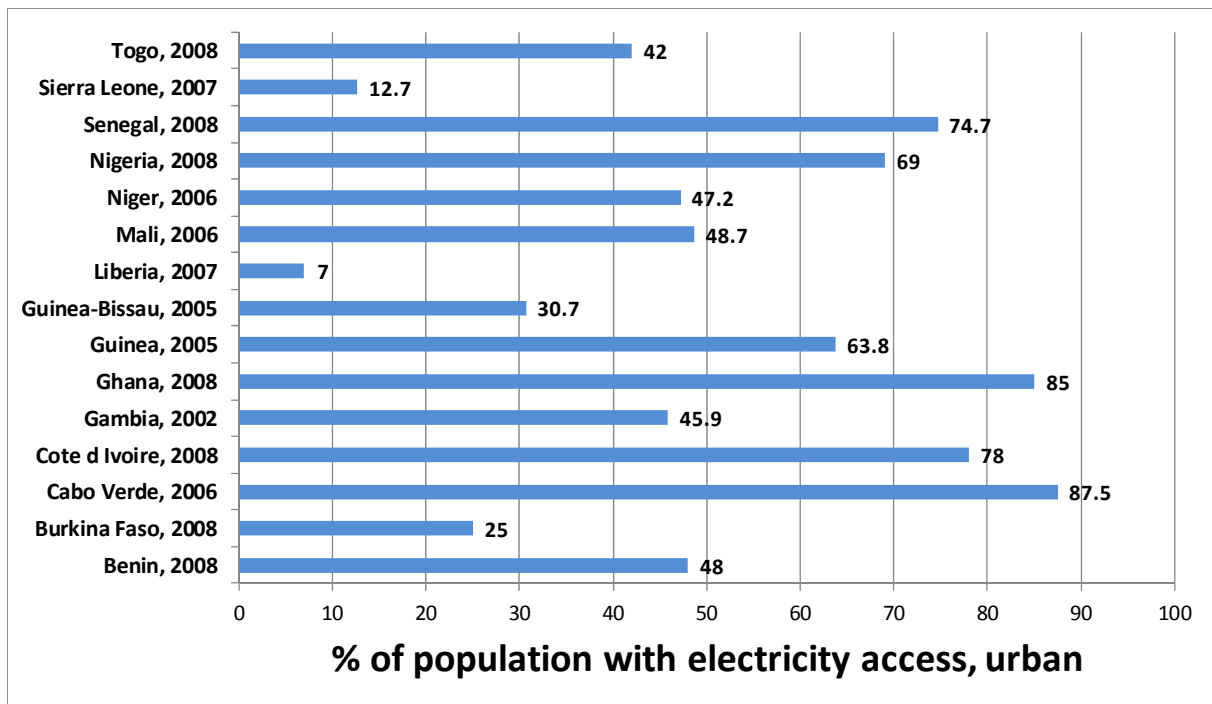


FIG. 2. Percentage of population with electricity access by country in urban areas. (Data Source: [5])

The situation in rural zones is worse compared to urban/peri-urban areas. Due to a higher cost of electrification in low density areas and low income of households in rural parts, the overall regional electricity access in these zones is just above 17%. In other words, more than 134 million people in rural parts do not have electricity and rely on the use of biomass, which can cause different health and environmental issues.

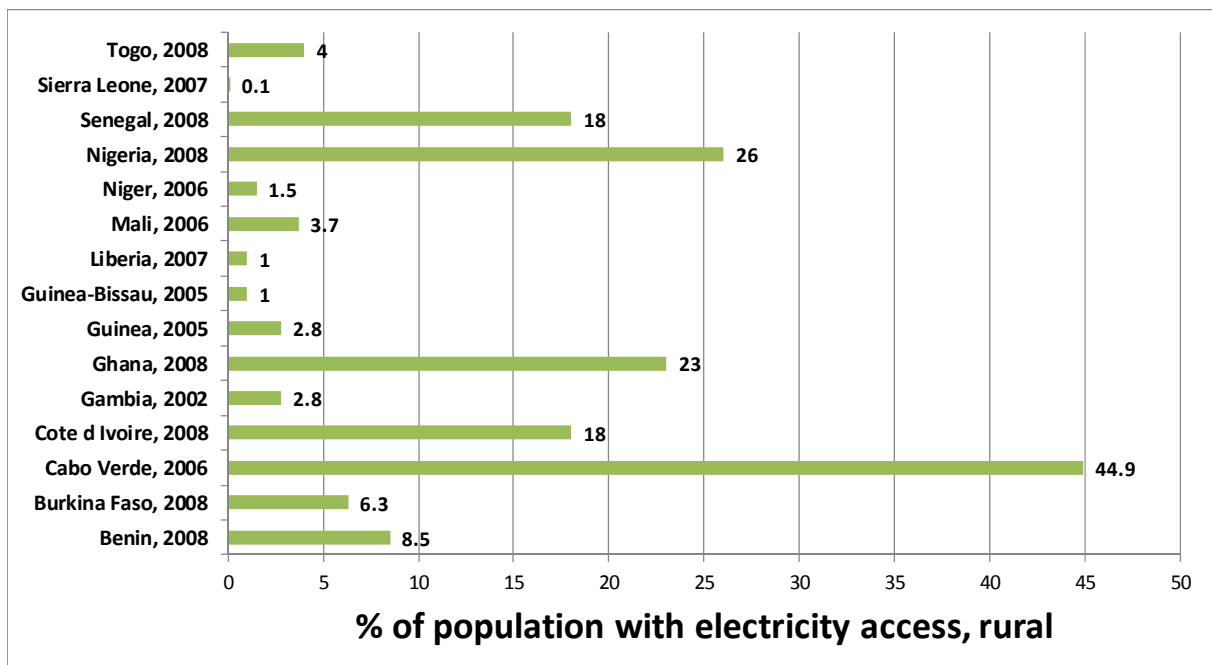


FIG. 3. Percentage of population with electricity access by country – in rural areas. (Data Source: [5])

2.1.2.2. High electricity supply cost

Electricity cost in West Africa is one of the highest in the world as presented by Figure 4. This is mainly due to reliance on thermal power and obsolete generation assets. More than half of the centrally operated generation facilities are over twenty years of age, with very low efficiency. Besides, transmission and distribution losses are extremely high, which aggravates the problem.

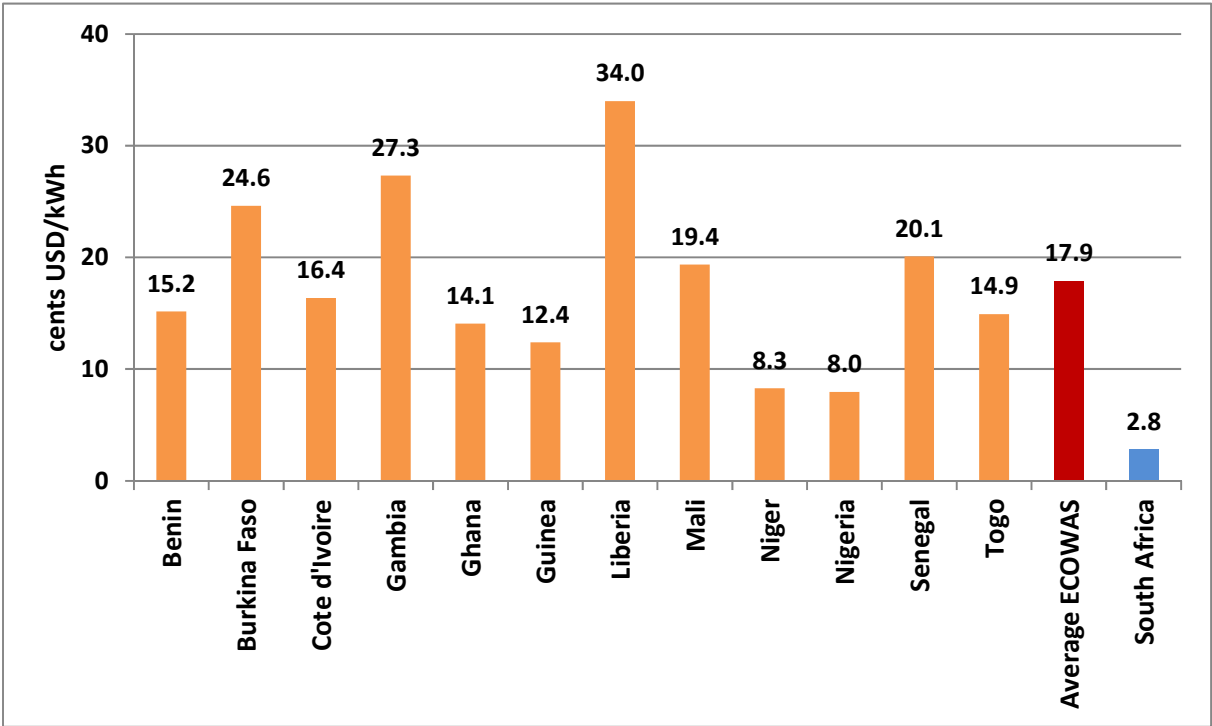


FIG. 4. Comparison of electricity prices for medium voltage users in West Africa. (Data Source: [6])

Figure 5 illustrates the difficult situation in many West African countries that at the same time suffer from high electricity supply cost on one side, and low income levels on the other side. These two factors create a very challenging development framework for industry, services and the population as a whole.

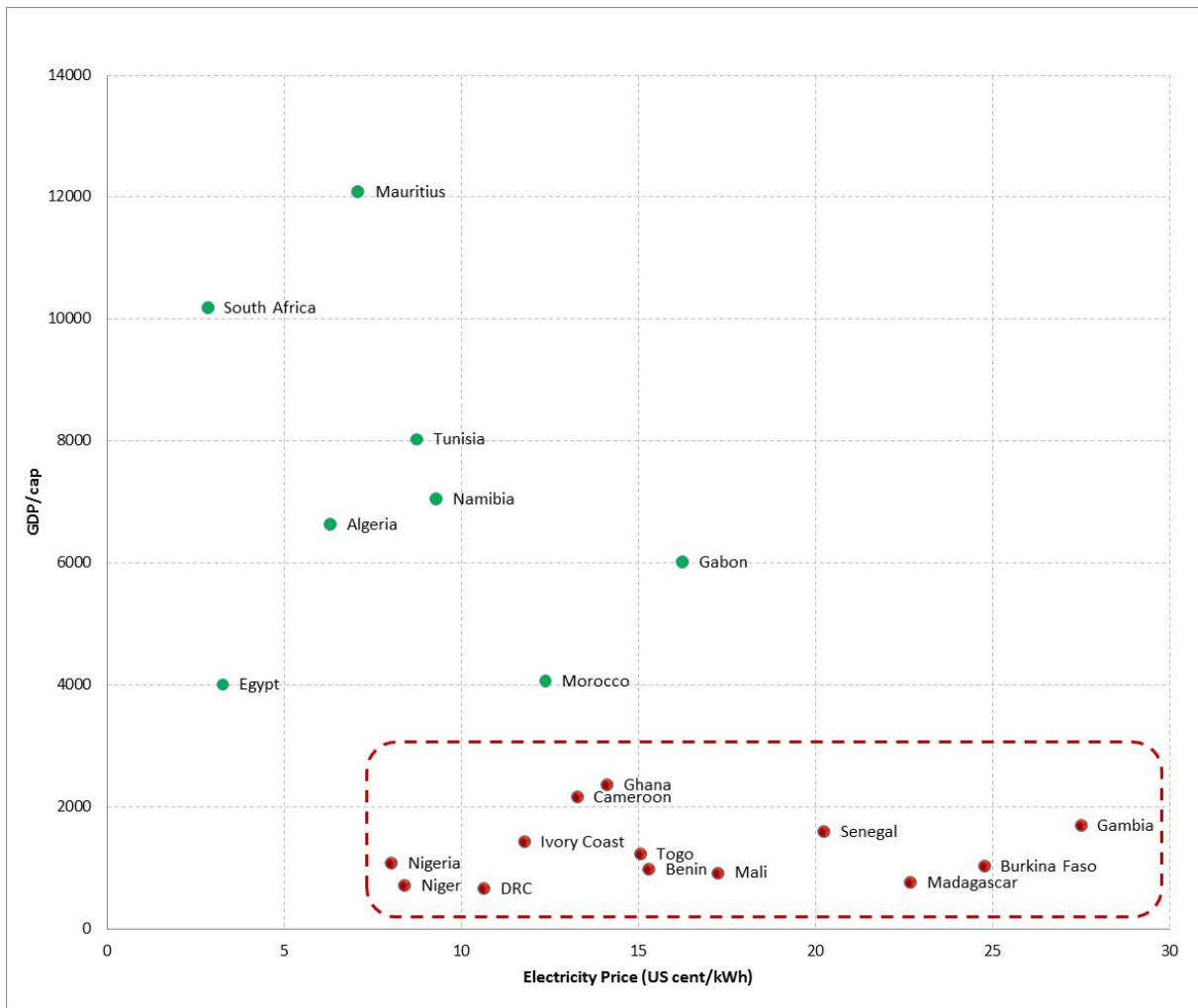


FIG. 5. Low GDP per capita and high electricity supply prices in West Africa. (Data Source:[7])

2.1.2.3. Electricity supply shortages

Chronic shortages of supply are reality in almost all West African countries. Public electricity operators are facing challenges due to the growing gap between projected demand and existing supply capacity, and limited financial resources. Electricity shortages regularly lead to service interruptions and outages, which have an enormous economic and social cost. In 2010, the unsupplied energy was estimated at 870 GW·h [8]. Based on forecasts from 2009, in 2010 a power deficit of 4049 MW and energy deficit of 3334 GW·h were expected [8].

2.1.2.4. Difficult financial situation in utilities

Most electric utilities operators are in a precarious financial situation. They are handicapped in their daily management by their mode of governance, by their tariff structure (the average tariff in some countries is below the average production cost) and by inadequate billing/collection effectiveness. Despite a high potential for local hydropower, many utilities are becoming more and more dependent on oil for electricity production.

2.1.2.5. Significant potential of primary energy

The precariousness and energy insecurity seems to contradict the high primary energy potential. West Africa has significant energy resources, although unevenly distributed across countries:

- 30% of proven African crude oil reserves (3017 million tons) and 31% of natural gas (3581 billion m³): Nigeria owns about 98% of proved crude oil and natural gas reserves in West Africa;
- 23.9 GW of exploitable hydropower: 91% of the hydropower potential is concentrated in five countries: Nigeria (37.6%), Guinea (25.8%), Ghana (11.4%), Cote d'Ivoire (10.9%) and Sierra Leone (5.2%);
- Solar irradiation higher than 5 kW·h/m²/day, available practically in all countries.

The use of primary energy potential is low while many resources are exported to the world market (oil and gas).

2.1.3. Electricity generation assets

Data on installed and available electricity generation power and on the production/consumption in West Africa (without Cabo Verde) are given by Figure 6, Figure 7 and Table 1.

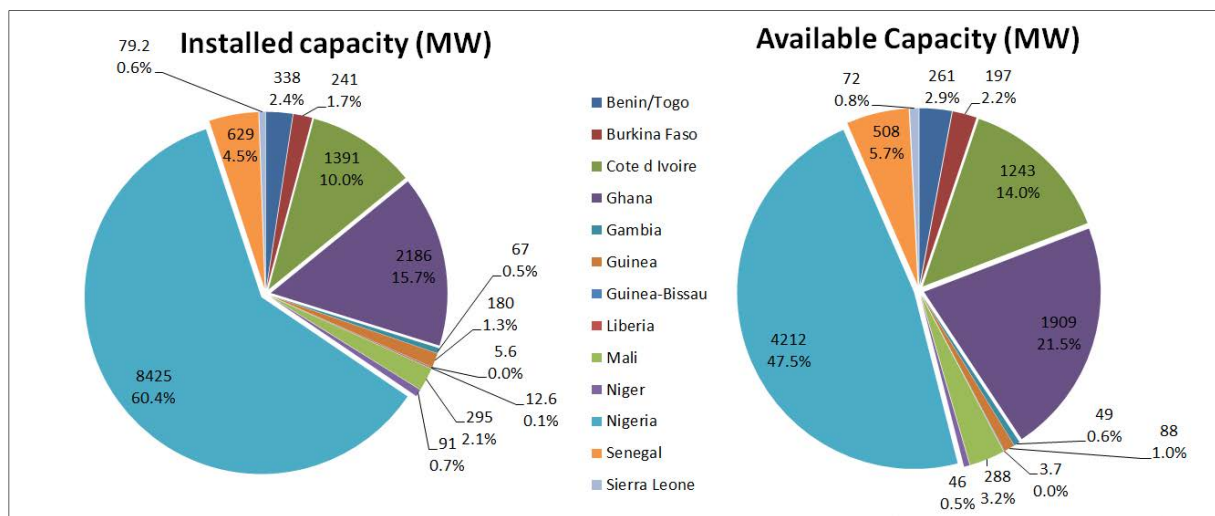


FIG. 6. Installed and available capacity in West Africa. (Data Source:[8])

The total installed capacity in 2010 was 13.9 GW, but the available capacity was only 8.9 GW. The largest part of unavailable generation capacities is in Nigeria, where practically half of the thermal power plants are not operational due to different problems. Still, Nigeria dominates the electricity market of West Africa with 47.5% of available capacity located there, followed by Ghana (21.5%) and Cote d'Ivoire (14.0%). These three countries account for 82.5% of the market in terms of capacity and almost 90% in terms of electricity generation.

Although the potential for local hydropower is huge, the generation capacity is dominated by thermal power plants. About two thirds of the electricity is generated in thermal power plants, and one third comes from hydro.

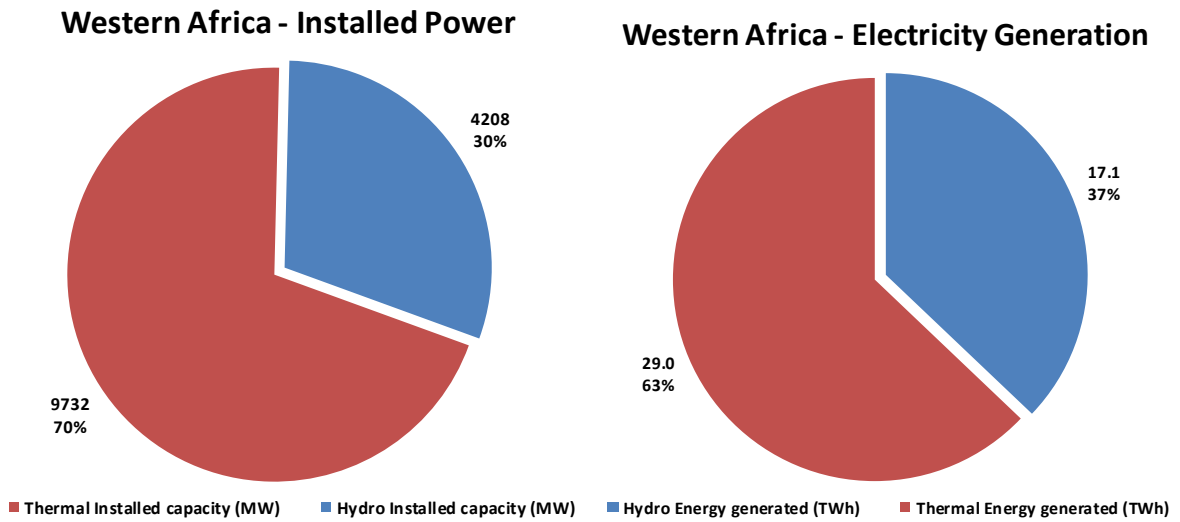


FIG. 7. Hydro and thermal capacity and generation in West Africa. (Data Source: [8])

The total electricity consumption in 2010 was 46.4 TW·h, and the registered peak load reached 7500 MW. The amount of suppressed demand is high, in some countries reaching 50% of the total demand. The reported estimated unserved energy in 2010 was 870 GW·h (without Nigeria), but real quantities are probably much higher and are around 3300 GW·h.

TABLE 1. MAIN CHARACTERISTICS OF WEST AFRICAN ELECTRICITY GENERATION IN 2010. (DATA SOURCE: [8])

Country	Installed capacity (MW)	Thermal Installed capacity (MW)	Hydro Installed capacity (MW)	Available Capacity (MW)	Energy imported (GW·h)	Energy exported (GW·h)	Hydro Energy generated (GW·h)	Thermal Energy generated (GW·h)	Total Energy generated (GW·h)	Gross Consumption (GW·h)	Peak load (MW)	Unreserved energy (GW·h)
Benin/Togo	338	272	66	261	1636	0	185	193	378	2015	324	54
Burkina Faso	241	205	36	197	385	0	118	448	566	950	159	17
Cote d'Ivoire	1391	787	604	1243	143	482	1618	4269	5887	5548	912	224
Gambia	2186	1006	1180	1909	107	1036	6995	3171	10166	8811	1506	380
Ghana	67	67	0	49	0	0	0	250	250	250	0	0
Guinea	180	78	102	88	0	0	474	141	615	615	12	12
Guinea Bissau	5.6	5.6	0	3.7	0	0	0	NA	0	NA	NA	NA
Liberia	12.6	12.6	0		0	0	0	NA	0	NA	0	0
Mali	295	139	156	288	581	0	284	343	627	1207	210	3
Niger	91	91	0	46	552	2	0	268	268	818	150	NA
Nigeria	8425	6477	1948	4212	0	1323	7416	17629	25045	23722	3804	NA
Senegal	629	569	60	508	253	0	0	2246	2246	2500	429	177
Sierra Leone	79.2	23.2	56	72	0	0	NA	NA	0	NA	2.5	2.5
West Africa	13940	9732	4208	8877	3657	2843	17090	28958	46048	46436	7509	870

2.1.4. Initiatives and policies to improve energy services access

Realizing and recognizing the multi sectorial scope of energy, a sector that supports practically all economic and social activities, West African countries started with the implementation of a development strategy aimed at harmonized regional policies and strengthened cooperation and integration. The policy is implemented through two institutions, the Economic Community of West African States (ECOWAS) and the West African Economic and Monetary Union (WAEMU), with the aim of creating additional institutional and physical regional infrastructure to reinforce energy development. The strategy has enabled many notable achievements:

- The establishment of the West African Power Pool (WAPP);
- The establishment of the ECOWAS Regional Regulatory Authority (ERERA);
- The establishment of the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE);
- The development of the Common Energy Policy (CEP) of the WAEMU².

2.1.4.1. West African power pool (WAPP)

The ECOWAS has established a specialized institution in the field of electrical energy – the West African Power Pool (WAPP). Created in 1999, the WAPP has the objective to improve energy supply within the ECOWAS by integrating national power system operations into a unified electricity market. WAPP's primary purpose is to find technical and economically optimal balance between:

- The development of large projects of electricity production on a regional scale;
- The creation of regional energy interconnections between the ECOWAS countries. Generation coming from these projects may be directed to the deficit countries.

The first ECOWAS Energy Plan was prepared in 1999 and was updated in 2004. ECOWAS Energy Plan is a high level framework for the development of priority electricity projects in the sub region. Its implementation is coordinated by WAPP through three years business plans and annual work plans. A supplementary Act on the emergency power supply security plan (EPSSP) was adopted in 2008.

The revised Master Plan of WAPP was approved in September 2011, and it provides thirty power generation projects, with a total capacity of 10.3 GW and a cost equal to 18 billion USD. The most of this new capacity will be available between 2017 and 2019. Projects selected are mostly based on large scale hydropower (21 projects) with 7093 MW, on natural gas (3 projects) with 1300 MW, on coal (2 projects) with 1075 MW and the renewable (4 projects) with 800 MW.

2.1.4.2. The ECOWAS regional regulatory authority (ERERA)

ECOWAS Member States established legal and institutional environment for the development of the power sector in West Africa. In January 2008, ECOWAS organised the Regulatory

² Member States of the WAEMU are: Benin, Burkina Faso, Côte d'Ivoire, Guinea Bissau, Mali, Niger, Senegal and Togo.

Authority for Regional Electricity Sector of ECOWAS (ERERA). ERERA's main objective is the regulation of West African electricity market and provision of support to the national regulatory bodies or equivalent entities of the ECOWAS Member States. The support is provided through [9]:

- Regulation of interconnected lines and electricity market/exchanges;
- Establishment of transparent methodologies for regional power market and related prices/tariffs;
- Facilitation of regulatory and economic framework for the development of the sub regional electricity market;
- Regulation of technical issues for sub regional electricity trade, and monitoring of the market;
- Assistance in exploring and defining the joint sub regional strategy and energy policy;
- Resolution of disputes among market participants;
- Assistance, capacity building and resolution of technical issues at the request of the national regulatory entities.

2.1.4.3. The ECOWAS regional centre for renewable energy and energy efficiency (ECREEE)

The ECREEE is a specialized agency of ECOWAS, whose role is to promote renewable energy sources (RES) and energy efficiency (EE). In 2010, the ECREEE Secretariat was established in Praia, Cabo Verde, supported by the ECOWAS Commission, Austrian and Spanish governments, and technical assistance from the UNIDO. In 2011, the United States' Agency for International Development (USAID) and the Government of Brazil provided additional funding. ECREEE's mandate and actions are aligned with the strategic objectives of the *ECOWAS Vision 2020* [10], with a specific focus on implementation of two components:

- Regional development with a focus on sustainability in all socio economic areas, including development strategies for mineral resource base and industrial activities. Regional infrastructure and services should be accessible to all citizens and enterprises;
- Management and conservation of sub region's environment and resources, promotion of equitable and sustainable development, and contribution of the sub region to an effective resolution of global challenges.

The ECREEE is assisting the ECOWAS Member States in the different phases – preparation, analysis, adoption and implementation of coordinated national policies for renewable energy and energy efficiency, development of regulatory framework, standardisation (e.g. labelling for appliances), establishment of incentives schemes (e.g. tax reductions) and financial mechanisms (e.g. feed in tariffs, investment subsidies).

The ECREEE is dealing not only with the electricity sector, but also with other areas (e.g. cooking, sustainable biofuels). All applications are taken into account, from the grid connected issues (e.g. independent power producers, losses reduction strategies and management) to off grid problems and solutions relevant to rural zones (e.g. final standalone production and use, micro and mini grids etc.).

During 2011-12, the ECREEE has developed the ECOWAS Renewable Energy Policy (EREP) [11] and the ECOWAS Energy Efficiency Policy (EEEP) [12]. Both policy documents were adopted by the ECOWAS Ministers on Energy during the ECOWAS High Level Energy Forum, in October 2012, in Accra, Ghana.

EREP policy focuses on the electricity sector with the main objective to ensure increased use of renewable energy sources such as solar, wind, small scale hydro and bioenergy for grid electricity supply, and to increase access to energy services in rural zones. EREP complements other potential sources of electricity. EREP objectives are aligned with the UN Secretary General's global initiative on Sustainable Energy for All (SE4ALL) – reaching universal access to electricity by 2030. EREP outlines three groups of targets and two of those are related to the electricity sector as presented in Table 2 and Table 3.

TABLE 2. EREP TARGETS FOR GRID CONNECTED RES (DATA SOURCE: [11])

In MW installed capacity	2010	2020	2030
EREP renewable energy options in MW	0	2 425	7 606
EREP renewable energy options in % of peak load	0%	10%	19%
Total renewable energy penetration (including medium and large hydro)	32%	35%	48%
In GW·h	2010	2020	2030
EREP renewable energy production in GW·h	0	8 350	29 229
EREP renewable energy options in % of energy demand	0%	5%	12%
Total renewable energy production (including medium and large hydro)	26%	23%	31%

TABLE 3. EREP TARGETS FOR OFF GRID APPLICATIONS (DATA SOURCE: [11])

Least cost option	2010	2020	2030
Off grid (mini grids and standalone) share of rural population served from renewable energy in %		22%	25%

The EREP includes the development of national action plans for RES implementation. The plan is that ECREEE facilitates and monitors the implementation of the sub regional and national policies over the next few years. The sub regional policies oblige states to prepare the national action plans and measures aligned with the sub regional goals by 2030.

2.1.4.4. The Common energy policy of the WAEMU

Common Energy Policy (CEP) of the WAEMU was adopted in 2001, and focuses on:

- The establishment of an integrated energy system planning;
- The promotion of renewables;
- The acceleration of the electrical interconnection in collaboration and under the ECOWAS.

As part of CEP, the WAEMU has established an initiative called Regional Initiative for Sustainable Energy (IRED). This IRED is based on three main axes:

- The rehabilitation and extension of large scale hydropower generation;

- The transition from diesel to heavy fuel oil or to gas in existing thermal power plants, rehabilitation and construction of large gas fired combined cycle units (450 MW);
- Regional power sharing through sub regional interconnections.

2.1.5. Legal and regulatory framework for electrical energy

Energy sectors of a number of West African countries were or are being reformed, but the majority of these countries is still using a vertically integrated system, i.e. generation, transportation and distribution are grouped into one single utility.

However, the creation of an open and competitive market for regional electricity requires the existence of an appropriate institutional and regulatory framework, including – inter alia – national legislation, technical and commercial standards, harmonized rules and the promotion and protection of investments. Thus, in terms of energy, as a result of the revised ECOWAS Treaty and the Energy policy, an Energy Protocol was signed in 2002 by ECOWAS Member States. This protocol has been used as a general framework for the adoption of various laws for the development of an exchange system in the West African Power Pool (WAPP).

2.1.5.1. The ECOWAS Treaty and the Energy protocol

The *ECOWAS Treaty* sets out the basic principles relating to the promotion, cooperation, integration and development of the energy sector in Member States. In order to facilitate the development of regional energy projects, governments have adopted a specific annex to the Treaty related to the energy sector, called the *ECOWAS Energy Protocol*.

The *ECOWAS Energy Protocol* was adopted in January 2003, was ratified in 2007 and became a regional law. The protocol aims at promoting long term cooperation in energy field, at increasing investment in energy and at increasing energy trade in the West African sub region. Key provisions of this legislation include:

- The protection of foreign investments;
- Non-discriminatory conditions for trade in energy;
- Dispute resolution procedures.

The ECOWAS Member States are gradually introducing market for energy. Governments adopted a number of organizational and operational principles for a regional electricity market and created two institutions: the West African Power Pool (WAPP) and the Regional Regulatory Body (ERERA).

2.2. BURKINA FASO

2.2.1. Geography and demography

Burkina Faso is a country located between the Sudano Sahelian and Guinea. As essentially plain country, it covers 274 000 km² and is wedged between Mali and Niger to the north and Côte d'Ivoire, Ghana, Togo and Benin to the south.

The population was estimated at 15.7 million in 2010, which corresponds to a relatively low average density of 57 inhabitants per km². The country is characterized by:

- High population growth – Between the general censuses of the Human Population (RGPH) of 1996 and 2006, the Burkinabe population increased from 10.3 to 13.8 million, realizing an annual growth rate of 3%. Forecast of the National Institute of Statistics and Demography (INSD), shows that the population will reach 21.5 million in 2020, an average annual growth rate of 3.1% over the period 2006 2020.
- Young population – The high birth rate has resulted in a very large young population. Children under 15 years constituted 46.3% of the total population in 2006 and are expected to maintain a similar until 2020.
- Accelerated urbanization – The urban population was estimated in 2006 at 22.7% of the total population against only 6% in 1960. The acceleration of urbanization is due to rural exodus, but also to a much higher natural increase in cities. The share of urban population is 61.7% today. Urban centres consist of two major cities, Ouagadougou (1.5 million in 2006) and Bobo Dioulasso (0.5 million), and 32 other urban locations.

2.2.2. Economy

Burkina Faso's economy is highly vulnerable to external and climate shocks. This is especially visible through export prices of cotton and gold, and import prices of food and oil. The economy is not diverse and many economic activities are carried out in the rural areas.

In 2010, acceleration in economic activity was recorded, with the real annual GDP growth reaching 7.9%. Favourable climatic conditions, increased production, higher gold prices and increased public investments have fostered economic recovery.

In 2011, growth remained strong although slower compared to 2010 and reached 5.1%. For 2013 the *PEA 2012 report* [13] outlines favourable economic prospects for Burkina Faso, with a projected growth between 5.3% and 5.5%.

Agriculture, practiced extensively in the rainy season, is one of the pillars of the economy. It represents more than 35% of GDP (2010) and occupies over 80% of the labour force. It is dominated by cotton production. Burkina Faso is the largest exporter of cotton in Africa.

The secondary sector is dominated by food processing (sugar, flour, beverages and oil), cotton ginning, mining and public construction. In recent years the industry has experienced a dynamic growth, promoting a gradual transformation of the country's economy structure. Thus, with an 11% growth in 2010, the secondary sector share in GDP reached 21.4% against 17.7% in 2009. This growth was achieved mainly due to mining (24.9% increase compared to 2009) and manufacturing (9.5% increase compared to 2009).

The tertiary sector contributed to 43.2% of GDP in 2010. The tourism industry has been growing continuously for more than ten years. Telecommunications and trade, meanwhile, are experiencing a slight slowdown after a major boom in the early 2000s.

The trade balance of Burkina Faso is in deficit with low export diversification. In 2010, due to the strong increase in gold exports (40% increase compared to 2009), the deficit of the trade balance was reduced to 2.8% of GDP, against 5.8% in 2009.

The external debt represents 75% of the public debt of the country and 25% of GDP. In terms of debt sustainability, Burkina Faso is still in the category of countries with risk of debt due to the high ratio of debt to exports. This ratio would reach its maximum at about 203% in 2036 [14], which is significantly higher than the acceptable threshold of 150%.

The acceleration of the development for a landlocked country like Burkina Faso is limited by the structural constraints such as lack of basic infrastructure, high dependence on climate fluctuations combined with fluctuations in the prices of exported commodities (particularly cotton) and imported goods (particularly fuel). In energy sector, the lack of electricity supply in 2010 created big problems, with continuous outages throughout the first half of the year.

2.2.3. Social development

Poverty remains one of the main problems in Burkina Faso, despite good economic performance and improved social indicators. According to the results of the last Survey on the Living Conditions of Households (EICVM³ in 2009), poverty still strikes 43.9% of the population, with 50.7% in rural areas and 19.9% in urban. GDP in purchasing power parity (PPP) was estimated at 1 187 USD in 2009 and places the country at 160th position out of 180 countries. In nominal terms, the average income (in 2009) per capita per year is 245,000 FCFA or ~500 USD.

With regard to social indicators, the gross school enrolment rate reached 77.1% in 2010. At the same time the rate of access to drinking water has reached 76% in urban and 56.6% in rural areas. In terms of access to electricity, the EICVM survey reveals that only 13.9% of the population had access to electricity, 2% in rural and 46% in urban.

2.2.4. Country development strategy

2.2.4.1. General strategy

Following the Strategic Framework for Fight against Poverty (CSLP⁴), in December 2010 national authorities adopted the Strategy for Accelerated Growth and Sustainable Development (SCADD⁵), constituting the central policy for economic and social development of the country for the period 2011 2015. The new strategy aims to accelerate growth and strengthen programs to reduce poverty. In this context, it defines policies aimed at consolidating macroeconomic stability and fiscal sustainability, support debt reimbursement, aiming to remove barriers or constraints to growth and consolidate the progress towards meeting the UN Millennium Development Goals (MDGs).

³ L'Enquête Intégrale sur les Conditions de Vie des Ménages.

⁴ Cadre Stratégique de Lutte contre la Pauvreté.

⁵ Stratégie de Croissance Accélérée et de Développement Durable.

The SCADD overall objective is to achieve strong, sustainable and quality economic growth, generating multiplying effects on income increase, the quality of life of the population and cares about principle of sustainable development.

During 2011–2015, SCADD aims to accelerate growth and to pursue the MDGs. One objective is to reach an average growth rate of real GDP of 10%.

2.2.4.2. The pattern of accelerated growth

Growth will be based in particular on a good performance in agriculture, livestock and mining, as well as the dynamism of the service sector, through the modernization of production, improving competitiveness and productivity of the economy as well as the diversification of activities.

In the primary sector, improving yields and productivity will lead to an average growth rate of the value added by 10.7% due to good rainfall and improvements in (i) water management, (ii) subventions of agricultural inputs, (iii) technical training of producers, (iv) support to agricultural research for development and introduction of adapted species/varieties and (v) access of agricultural producers to mechanization and credit lines.

In the secondary sector, expected increase of global prices of mining products such as gold, zinc, copper and manganese, combined with the production industries, should lead to an average annual increase in added value of 11.8%. This increase is attributable to the mining industry and dynamism of the construction sector.

Expected average annual growth in tertiary sector is 12.5%. This development will be mainly driven by trade, financial services and ICT, as well as tourism, culture and related activities boosted by strengthening the reputation of the Burkina Faso as a tourist destination.

2.2.4.3. Macroeconomic outlook by IMF

In its report on the second review of the three year arrangement under the Extended Credit Facility [15], the IMF estimated that the medium term macroeconomic outlook is positive. It estimates that economic growth will reach 6.5% by 2015, supported by more public investment and increased efficiency, particularly in terms of better developed infrastructure, and improved performance of agriculture, mining and service sectors.

In this report, the IMF outlines that the growth targets within SCADD are too ambitious. Given the current barriers to growth and funding constraints, it will be difficult to bring economic growth significantly above 6% by 2015.

2.2.5. Energy sector

Landlocked without fossil energy sources and with limited financial resources to invest in energy infrastructures, Burkina Faso is characterized by:

- Heavy dependence on wood energy (about 82% of total energy, nearly 100% in rural areas);
- Total dependence on imports of fossil fuels;
- Electricity mix dominated by imports from Côte d'Ivoire (and from Ghana in the near future) and thermal energy produced from imported diesel and fuel oil;

- Access to modern energy services concentrated in large urban centres, mainly Ouagadougou, Bobo Dioulasso and Ouahigouya. The national electrification rate stood at 14.6% in 2011;
- Still marginal use of other renewable energy sources in general and solar energy in particular. The potential of Burkina Faso in solar energy is considerable, i.e. around 5.5 kW·h per square meter per day.
- Significant energy demand from households and mining.

The energy situation in Burkina Faso is characterized by low energy consumption per capita, approximately 0.180 toe in 2008 distributed as follows: 82% biomass, 16% of hydrocarbons, 2% of electricity and negligible share of renewables.

2.2.5.1. Strategy for energy sector development

Recognizing the need to ensure access to electricity at a lower cost to meet the challenge of accelerated growth and sustainable development, SCADD has set the following priorities for the energy sector:

- Establish an institutional and regulatory framework, in addition to fiscal measures that enable the mobilization of actors and resources;
- Secure energy supply and reduce energy costs;
- Open up rural areas by extending networks and pre electrification to reach a coverage rate of 60% by 2015;
- Mobilize and develop national energy potential;
- Improve the efficiency of energy consumption.

The strategy also gives special attention to the development of renewable energies, especially solar energy, the development of interconnections with the countries in the sub region and promotes cooperation.

In terms of access to modern energy services, strategy aims to: (i) connect large portion of the population to grid, (ii) install power plants in major centres outside the network, (iii) develop multifunctional platforms with mini network providing access to energy for the sparsely populated localities and (iv) use of the photovoltaic system for people in low density areas.

The priority project of the Government, in the context of mobilizing funding for the SCADD, is the construction of a petroleum products pipeline between Bolgatanga (Ghana) and Bingo (Burkina Faso).

Other project ideas are born of the opportunities offered by current and future construction of pipelines (oil and gas pipelines) in the sub region: the West African gas pipeline and the oil pipelines Niamey Zinder, Bolgatanga Bingo and Abidjan Ferkessedougou.

2.2.6. Electricity system

Several electrification programs are being conducted by the authorities and operators in the electricity sector (SONABEL and FDE), with the support of technical and financial partners.

2.2.6.1. Electricity Demand Projections

In recent years, several electricity demand projection studies have been elaborated and different scenarios assessed:

- A scenario based on high GDP growth rates from SCADD;
- A scenario based on the low GDP growth rates from IMF;
- An intermediate scenario considering the average of high and low scenarios.

The main results of these scenarios on the horizon 2040 are summarized in Figure 8.

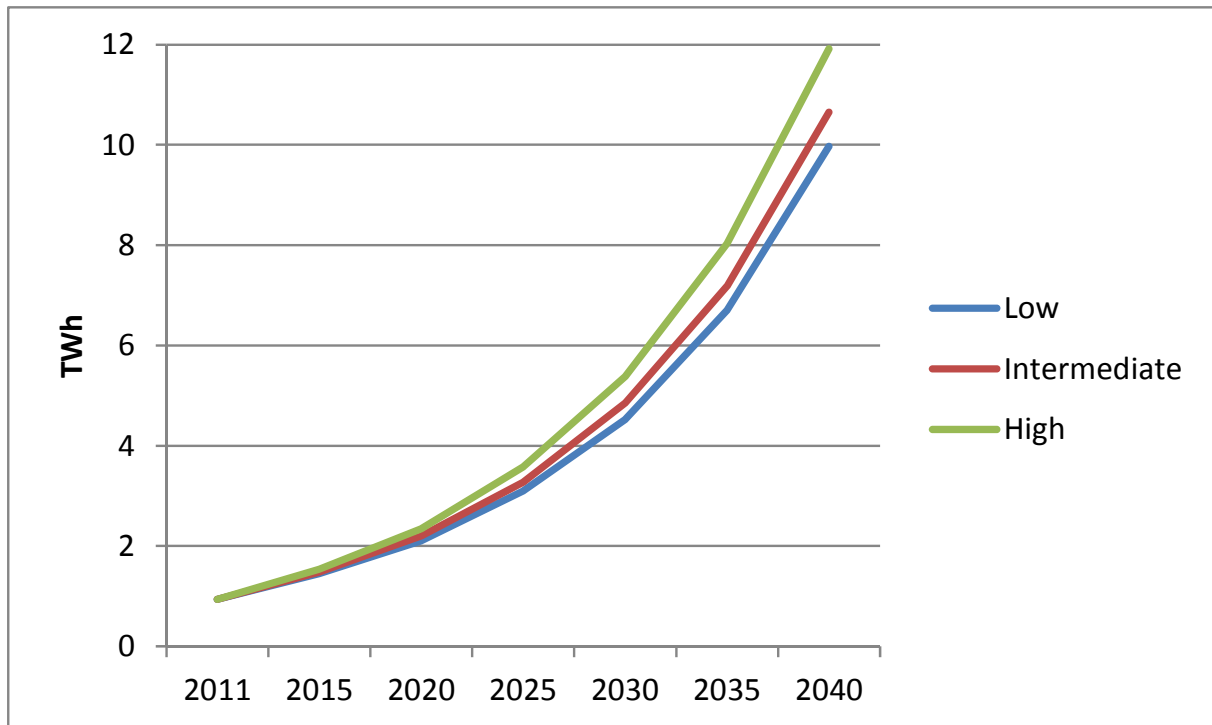


FIG. 8. Electricity demand projections for Burkina Faso.

2.2.6.2. Electricity Infrastructure

The National Interconnected Network (RNI) is powered by seven thermal power plants with a total installed capacity of 132 MW and four hydropower plants with a total installed capacity of 23 MW. Isolated centres are supplied by thermal power plants of small size or connected to networks of neighbouring countries (Ghana and Togo). The total installed thermal capacity in 2011 was 242 MW. Current or planned SONABEL generation projects include the construction of four thermal plants, one solar photovoltaic power plant and one hydroelectric power plant with total combined capacity of 110 MW by 2016.

The main electricity transmission network in Burkina Faso with a total length of 2 100 km consists of five main lines:

- 225 kV interconnection line between Ferkéssédougou in Côte d'Ivoire in Bobo Dioulasso, Burkina Faso, length 225 km and 121 MW;
- 225 kV line Bobo Dioulasso-Zagtouli (Ouagadougou) length 338 km;

- 132 kV line connecting hydro to Bagré Kompienga and Patte d'Oie (Ouagadougou), length 315 km;
- 90 kV line operated 33 kV Zagtouli-Koudougou length 85 km;
- 90 kV line Kossodo-Ouaga 1-Ouaga 2-Zagtouli total length 28 km.

Proposed transmission and interconnection projects are:

- Internal connection line Ouagadougou-Ouahigouya – with a length of 170 km, the line will be 90 kV and will connect North Regional Consumption Centre (CRCN) and National Interconnected Network (RNI). The construction is underway for commissioning in early 2015;
- Interconnection Bolgatanga (Ghana)-Ouagadougou(Burkina Faso) – total length of 206.1 km. It will be operated at 225 kV with 100 MW of transit power. The construction of the line should start shortly, for commissioning in early 2015;
- Interconnection North Ridge spans four countries between Bembéréké (Benin)-Birnin Kebbi (Nigeria)-Niamey (Niger)-Ouagadougou (Burkina Faso). Technical and economic feasibility study conducted in 2007 provides that the line will be operated at 330 kV and should provide 108 MW in Ouagadougou for the first part and eventually 245 MW. SONABEL provides the implementation of the project on the period from 2017 to 2019 for commissioning service in early 2020;
- Interconnection Han (Ghana)-Bobo Dioulasso-Sikasso (Mali)-Bamako (Mali) – total length of 740 km. Feasibility study of the project conducted in 2009 recommended a line dimensioned to operate at 225 kV with maximum transit power of 150 MW. The construction is planned for the period 2015-2016 for commissioning in 2017.

The distribution network of a total length of 6900 km consists of three voltage levels, a 33 kV distribution network, two 33 kV and 15 kV medium voltage distribution (33 kV to 15 kV) and 220 to 380V for low voltage distribution.

2.3. GHANA

2.3.1. Geography and demography

Ghana is located midway along the West African coastline between Cote d'Ivoire on the west and Togo on the east. The country also shares boundary with the Gulf of Guinea in the south and Burkina Faso on the north. The total land area is 239,460 km² of which 8,520 km² is covered with water [16].

The total population in 2010 was 24.66 million inhabitants [17]. This is 30% more than the population of 18.91 million in 2000 [18]. The average annual growth rate over the last decade was about 2.69%. The national population policy goal is to reduce the average annual growth rate to 1.50% in 2020 [19]. If achieved, the total population is expected to increase to about 32.66 million in 2030.

In 2010, the urbanization rate was about 51% compared to 43.8% in 2000. Hence, the average annual urban population growth rate is about 4.28%. This trend is expected to continue, with an urbanization rate of about 68% in 2030 [20].

The country has experienced significant reduction in poverty rates in the last decade. Poverty rates have reduced from 51.7% in 1991/92 to about 28.5% in 2006/07 [21]. Despite this impressive reduction in poverty rates, pockets of poverty still exist in some peri-urban and rural communities. The country's Human Development Index (HDI) has also increased from 0.502 in 1990 to 0.556 in 2010. The HDI in 2012 was 0.571 (ranked 138 out of 187) with a life expectancy at birth of 61.0 years [22]. If the current trend in poverty reduction continues, the country will achieve the MDG target of 26% poverty rate before 2015.

2.3.2. Economy

The economy depends on the country's natural resource endowments (e.g. timber, cocoa, gold, diamond, bauxite, manganese and petroleum) and a nascent industrial sector. In mid-December 2010, the country began producing commercial quantities crude oil from the Jubilee Fields. This spurred a strong economic growth rate of 14.3% in 2011, making the country one of the fastest growing economies in the world.

The total GDP in 2010 was 31.3 billion USD with a growth rate of 7.7% compared to 5.3% for sub Saharan Africa [23]. The high growth rate was mainly driven by service sector, which grew by 9.8% compared to industrial sector growth rate of 6.9% [24]. The agriculture sector which employs 56% of labour force on the other hand grew at 5.3%. The country's economic performance over the last decade has been impressive. The average annual GDP growth rate from 2003 to 2012 was 7.0% compared to 5.5% from 2000 to 2010. According to IMF medium term forecast, the average annual economic growth rate from 2013 to 2017 is expected to be about 10.0% [25].

In 2010, the service sector accounted for 51.1% of gross output compared to 19.1% by the industrial sector. Share of the agriculture decreased to 29.8% of gross output in 2010. The per capita GDP in 2010 was 1343 USD, which puts the country in the lower middle income bracket, ranking the third largest in the ECOWAS sub region. The government's goal is to move the country into upper middle income bracket in the medium term.

The government's socio economic policy agenda for 2010–2013 is expressed in the Ghana Shared Growth and Development Agenda (GSGDA). The main focus of the GSGDA is to enhance macroeconomic stability and ensure sustainable exploitation of the country's natural

resources. This strategy is expected to initiate an economic transformation and a sustained achievement of a projected average annual GDP growth rate of 6–8% in the long term [26].

2.3.3. Energy resources and sources

2.3.3.1. Hydropower

The exploitable hydropower potential is about 2420 MW of which about 1180 MW has already been exploited at two sites; Akosombo (1020 MW) and Akuse (160 MW) along the Volta River. Another 400 MW of hydropower potential at Bui on the Black Volta is currently being developed at a cost of 700 million USD⁶. When completed in 2013, 1580 MW or 65.3% of the total exploitable potential would have been exploited.

The remaining 840 MW of the exploitable hydropower potential is made up of medium to small hydropower schemes, all below 100 MW and located at about 21 different sites. The country's hydropower systems sometimes suffer from low capacity utilization due to perennial droughts.

2.3.3.2. Hydrocarbon resources

Hydrocarbon resources in the country are located in four sedimentary basins. In 2007, commercial quantities of light crude oil were discovered 63 km off shore Cape Three Points. Field appraisal indicated presence of 1.8 billion barrels of crude oil originally in place with about 800 million barrels of reserves⁷. Intense exploration efforts thereafter have yielded increased number of new discoveries. The current total crude oil resource is about 3.8 billion barrels, with reserves of about 1.7 billion barrels and 985 million barrels of condensate. Some of the oil discoveries have associated natural gas. Natural gas deposits are estimated to above 10.0 TCF gas in place, with about 6.396 TCF as recoverable.

2.3.3.3. Renewable energy source

The country experiences between 1800 to 3000 hours of sunshine per year [27]. Solar irradiation varies between an average of 4.4 and 5.6 kW·h/m² per day across the country. However, higher irradiation levels of about 6.5 kW·h/m² per day occur in the north and along the coastal belt of the country. Wind resources have also been identified along the coast of the country east of the Meridian. A resource assessment undertaken by Energy Commission indicated that wind speeds of about 5.5m/s to 6.2 m/s are common over the country. An evaluation of this wind resource by experts from Risø indicated that 300–400 MW of electricity generation capacity can be harnessed.

2.3.4. Energy sector

2.3.4.1. Energy situation

The total primary energy supply (TPES) in 2010 was about 9113 ktoe of which biomass accounted for about 52.1%. Hydropower, net crude oil imports, natural gas imports and imported petroleum products accounted for rest of the TPES. About 60% of the crude oil imported in 2010 was processed at the refinery into oil products whilst the rest was used to

⁶ www.buipowerauthority.com, accessed January 13, 2015

⁷ www.gnpcghana.com, accessed January 13, 2015

generate electricity. About 138 GW·h of electricity was also generated using imported natural gas.

Net oil products imports accounted for about 60.2% of the total of 2448.8 ktoe consumed in 2010. The transport sector alone accounted for about 76.4% of total oil products consumption. This was followed by 9.5% for industries and 6.5% for agriculture and fisheries. The household sector accounted for 6.0% of the total consumption of oil products and 1.6% for commercial and service sector.

In 2010, 871.9 ktoe of electricity was generated in addition to 9.1 ktoe of imports. On the other hand, 89.1 ktoe of electricity was exported. About 13.5% of the total electricity generated was lost during transmission and distribution. The household sector accounted for about 46.6% of the total final electricity followed by 40.9% for industries and 12.5% for commerce and services. The lower share of the industrial electricity use was due to suspension of Volta Aluminium Company's operation as a result of inadequate electricity supply.

The total final energy consumption in 2010 was 6894.3 ktoe. This comprised biomass (firewood and charcoal) 54.8%, oil products 35.5% and electricity 9.6%. The household sector accounted for 48.6%, followed by the transport sector 27.1% then industries which accounted for 18.5%. The commerce/service and agriculture sectors accounted for 3.5% and 2.3% respectively. The total final energy consumption per capita in 2010 was 0.280 toe compared to TPES per capita of 0.370 toe.

2.3.4.2. Energy trade

The country depends to a large extent on imports of crude oil, oil products and natural gas. In 2010, these imports accounted for about 44.8% of the TPES. About 961.1 kton and 700.5 kton of crude oil were imported in 2010 for refinery processing and electricity generation respectively [28]. The country also imports large volumes of refined oil products due to inadequate refinery capacity.

As a result of operational problems at the refinery in 2010, only 1068.4 kton of crude oil, about 53.4% of the installed capacity. Consequently, about 1589.9 kton of refined oil products, higher than normal was imported. The cost of importation of crude oil and petroleum products accounted for about 28% of total value of merchandise exports in 2010 [29]. The country exports all the crude oil from the Jubilee Fields. In 2010, about 181.1 kton of oil was exported compared to 3394 kton in 2011. About 557.9 kton of oil products was also exported to countries in the sub region.

Natural gas importation through the West African Gas Pipeline for electricity generation began in 2009. In 2010, about 15.6 billion mmBTU (i.e. 14.62×10^3 mmscf) of gas was imported, which was about 33% of the expected volume of 43.8×10^3 mmscf. The imports in 2011 increased to 30.5 billion mmBTU (i.e. 28.58×10^3 mmscf). However, it covered only 65% of the expected volume.

2.3.4.3. Energy policies

The current energy policies seek to address the major challenges constraining reliable and adequate energy delivery in the country. The key elements of the policies are following:

- Secure long term fuel supplies for electricity generation from thermal power plants by utilizing domestic natural gas reserves;

- Intensify exploration for oil and gas resources in the country's sedimentary basins;
- Diversify the national energy mix by promoting renewable energy sources, nuclear power and coal;
- Promote the production, efficient delivery and use of renewable energy in order to achieve 10% renewable energy (excluding large hydropower) share in the total energy supply mix by 2020;
- Develop mini hydropower sites to supply electricity mainly to the surrounding communities;
- Support the modernization and expansion of energy infrastructure (e.g. increase refinery capacity from 45 000 barrels per stream day (BPSD) to 145 000 BPSD and generation capacity from 2 170 MW in 2010 to about 5 000 MW by 2015/2020) to foster reliability and timely meet the growing demand;
- Increase access to modern forms of energy (e.g. increase electricity access from 72% in 2010 to at least 80% electricity access by 2015 and achieve universal electricity access by 2020 and increase LPG access from 18% in 2010 to 50% in 2015);
- Reduce technical and commercial losses in electricity distribution from 27% in 2010 to 18% in 2015;
- Minimize the environmental and social impacts as a result of energy supply and use;
- Promote productive and efficient uses of energy;
- Promote total cost recovery of energy supply and delivery;
- Improve the overall management, regulatory environment and operation of the energy sector;
- Promote and encourage participation of private investments into the energy sector.

2.3.5. Regional energy projects

2.3.5.1. West African gas pipeline

The West African Gas Pipeline is a 680 km backbone infrastructure for transporting and distributing natural gas in the sub region. The pipeline is operational since April 2009. Until December 2012, only 30% of expected gas delivery to Ghana was transported, due to different technical issues.

2.3.5.2. West African power pool

The country is a member of the West African Power Pool, a platform for the future development of a unified sub regional electricity market. A segment of the 330 kV WAPP Coastal Transmission Backbone Project, which falls within the country, the 330 kV Aboadze Volta line, has been completed and activated in 2010. A second project is being pursued to construct 210 km of a 225 kV between Bolgatanga in northern Ghana and Ouagadougou Burkina Faso.

2.3.6. Electricity system

2.3.6.1. Generation

Table 4 shows the generating plants in the country in 2010.

TABLE 4. POWER PLANTS OPERATING IN GHANA (AS OF 2010)

Power Plants	Type of Plant	Fuel Type	Installed Capacity (MW)	Available Capacity (MW)
Akosombo	Hydro	river	1020	900
Kpong	Hydro	river	160	140
Subtotal for Hydro			1180	1040
Takoradi Power Company	Thermal_CC	LCO*/NatGas	330	300
Takoradi International Company	Thermal_SC	LCO/NatGas	220	200
Sunon Asogli Power (Ghana)	Thermal_CC	Nat Gas	200	180
Tema Thermal 1 Power Plant	Thermal_SC	LCO/NatGas	110	100
Tema Thermal 2 Power Plant	Thermal_diesel	Diesel	49.5	45
Mines Reserve Plant	Thermal_diesel	Diesel	80	40
Subtotal for Thermal			989.5	865
Grand Total			2169.5	1905

* LCO – Light Condensate Oil

Thermal power accounted for about 45.6% of the total capacity. In 2000, this was about 33% of the total capacity. This trend towards greater proportion of thermal power share in the electricity generation mix is expected to continue into the future

The total installed capacity increased from 1420 MW in 2000 to 2170 MW in 2010 or at rate of 4.4%/yr. The low growth rate in capacity additions can be attributed to lower demand due to the absence of Volta Aluminium Company and inability to attract adequate investments for generation capacity expansion. The situation of inadequate generation capacity has been compounded by inadequate gas imports. This resulted with country wide load curtailments. The results of a recent study [30] indicate that the generation capacity should increase from 2200 MW in 2010 to 8220 MW in 2030 at an annual growth rate of 6.8%.

In 2010, the country generated 10 167 GW·h or about 40% more than in 2000. The average annual growth rate of electricity generation over the period is about 4.5%. The lower rate of electricity generation was due to inadequate capacity and droughts which depressed hydro electricity generation in 2003 and 2007. In 2010, hydropower accounted for about 69% of the total generation compared to 92% in 2000. Total generation is expected to increase to ~39TW·h in 2030 at average growth rate of 6.9%/yr.

2.3.6.2. Transmission

The total length of the transmission system is 4515.5 km with transformer capacity of 2915 MVA. The network comprises of 219.5 km of 330 kV lines, 73.4 km of 225 kV lines, 3888.1 km of 161 kV lines and 132.8 km of 69 kV lines. Losses on transmission have ranged between 2.8% and 4.7% of net generation. The system is interconnected with the networks of CIE (Compagnie Ivoirienne d'Electricité) of Cote D'Ivoire at Elubo via a 225 kV transmission line, CEB (Communaute Electrique du Benin) of Togo and Benin at Lome via a 161 kV transmission lines in the south and Dapaong in the north via a 33 kV low voltage lines.

Connection to the SONABEL network of Burkina Faso is realised at Po and Leo via a 33 kV transmission line.

2.3.6.3. Distribution

Electricity distribution is managed by the following two public utilities, Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDCo) and a private company Enclave, which operates in the Tema Free Export Zone area.

At the end of 2010, the network of Electricity Company of Ghana comprised 26 bulk supply points, 98 of 33/11 kV primary substations and 8 787 secondary substations. The distribution network consists of 14 177 km of 33 kV lines, 15 521 km of 11 kV lines and 1 458 355 km of LV lines. During 2010, ECG distributed 6 771.3 GW·h of electricity, 26.9% was accounted for as losses compared to 3 989 GW·h in 2000 with 27% losses (commercial and technical)⁸.

In the case of Northern Electricity Distribution Company Ltd. (NEDCo), the network is made of 5 bulk supply points and 7 832 km of low voltage lines and 5 486 km of medium voltage lines. During 2010, NEDCo distributed 635 GW·h of electricity, 25.5% was accounted for as losses compared to 330 GW·h in 2000 with 30% losses (commercial and technical).

The country's electrification rate in 2010 was 72%, which was the second highest in the after Cabo Verde. The high electrification rate is as a result of the government's National Electrification Scheme policy that started in 1990, when the electrification rate was 28% [31], with a plan to electrify country by 2020. As at 2012, over 4000 communities have been electrified with on-going electrification projects in 3515 communities⁹.

2.3.6.4. Electricity policy and decision making process

The main electricity policies are formulated by the Ministry of Energy. The Energy Commission, a quasi-independent body established by Energy Commission Act 1997 (Act 541) is the energy policy advisor and prepares energy policy recommendations for the Ministry of Energy.

The electricity sector was reformed in mid 1990s to attract private sector investment into electricity generation. The Volta River Development Act, 1961 (Act 61) was revised in 2005 into Volta River Development Amendment Act, Act 692. The new Act 692 ceded electricity transmission function from VRA to a new company Ghana Grid Company (GRIDCo) Limited established to manage the transmission network and act as the Independent System Operator (ISO).

The reform policy also mandated the establishment of a Wholesale Electricity Market. Wholesale Electricity Market was established in 2008 by two acts: Technical Rules (Legislative Instrument no. 1934) and Operational Regulations (Legislative Instrument no. 1937) on Wholesale Electricity Market.

2.3.6.5. Development paths and projects

The main electricity sector development paths are guided by the current challenges of high dependency on unreliable hydropower generation, inadequate generation capacity and

⁸ Responses to a data request from the Electricity Company of Ghana and Northern Electricity Distribution Company by the Energy Commission, Ghana

⁹ www.energymin.gov.gh, accessed January 13, 2015

absence of reserve margin. This situation is compounded by erratic natural gas imports, inability to quickly develop domestic natural gas reserves to bring domestic gas online for electricity generation.

In order to address the challenge of inadequate generation capacity and reserve margin, a number of generation projects are under consideration at different stages. These are listed in Table 5.

TABLE 5. COMMITTED AND CANDIDATE POWER PLANTS

Committed Power Plants	Installed Capacity (MW)	Dependable Capacity (MW)	Average Energy (GW·h)	Fuel Type	Expected Date of Commissioning	Status
Bul Hydropower	400	340	969	Water	Q2 2013	Under construction
Takoradi (T3) Thermal	132	120	894	LCO/Gas	Q1 2013	Under construction
Kpone Thermal Power	220	200	1489	Gas/Diesel	Q1 2013	Under construction
Takoradi (T2) Thermal	110	100	745	Steam	Q1 2013	Under construction
VRA solar Power	2	0	4.6	Sunshine	Q1 2013	To be commissioned
VRA solar Power	8	0	18.4	Sunshine	Q4 2013	Under construction
Candidate Power Plants						
CENIT/TTIPP Expansion	100	100	745	Steam	Jan 2016	Under discussion
Domonli Thermal	450	410	3046	Gas/Diesel	Jan 2017	Under discussion
KTPP Expansion	110	100	745	Steam	Jan 2017	Under discussion
T3 Expansion	120	110	894	Gas/LCO	Jan 2016	Under discussion
Pwalugu Hydropower	48	48	184	Water	Jan 2018	Feasibility studies
Juale Hydropower	87	87	405	Water	Jan 2021	Feasibility studies
Daboya	44	44	100	Water	Jan 2012	Under consideration
Wind	150	0	35	Wind	Jan 2012	Under consideration

To address the challenge of fuel supply for electricity generation, the Volta River Authority commissioned a study to evaluate the feasibility of imported liquefied natural gas (LNG) for electricity generation. The government is also making efforts to bring natural gas from Jubilee Field online as early 2015 and the gas from TEN and Sankofa fields in 2017.

2.4. COTE D'IVOIRE

2.4.1. Demography

The estimated population of Cote d'Ivoire in 2010 was 21.8 million, with a very dynamic demographic development as the result of natural growth and intense immigration. The growth rate of around 4% per annum at first years of independence has slowed down to 2.95% in 2001. Currently the growth is about 2.83%, due to several factors and demographics policies that have been undertaken by the Government. These include:

- Improving school enrolment especially for girls;
- Increased time enrolment among girls, delaying marriage and thus the age of the first pregnancy;
- Decline in fertility rate, which fell from 7.1 children per woman to 3.82 children per woman;
- Methods of family planning disseminated through public campaigns;

The economic development of Cote d'Ivoire has led to a rapid increase of urbanization. Whereas in 1965 the ratio of rural to urban population was three to one, in 2010, it was only 1.07 rural per 1 urban person, i.e. rural and urban populations tend to balance (48.37% people in urban and 51.63% in rural areas, with national urbanisation rate of 2.84% per year). In the coming years, Cote d'Ivoire will certainly face an increased demand for energy, especially for urban areas.

2.4.2. Economy

Cote d'Ivoire is a country heavily dependent on agriculture, which employs about 68% of its labour force. Country is the largest producer and exporter of cocoa and a significant producer of coffee and palm oil. Therefore, country economy is highly dependent on fluctuations in the price of agricultural commodities.

Cote d'Ivoire is ranked among the top three producers of cotton in the sub region with about 105 thousand tons of cotton fibre produced each year. The country produces rubber and is also the largest producer of cola nuts with a total production of about 65 thousand tons per year. Sugarcane, pineapple and banana, play an important role in fruit exports (mango, papaya, citrus mouths). The cashew and apple, mainly cultivated in the north, in the last few years are extending to the centre and centre west of the country.

Food crops, which are dedicated to traditional market, remain an important economic product for the country especially in the field of maize, rice, yam, cassava and plantain.

The industrial sector, which is dominated by the food industry has not yet reached its dynamism and represents about 15% of GDP. However, Côte d'Ivoire's vision is to be an emerging economy in short term. Thus, the Government has identified several projects for this purpose:

- The development of good industrial infrastructure;
- The promotion of creation of agro industrial enterprises;

- The promotion of private investment opportunities in the field of processing of agricultural raw materials.

Cote d'Ivoire accounts for about 32% of the West African Economic and Monetary Union (WAEMU) activities. 85% of the country's economic activities are concentrated in the south, and small and medium enterprises represent 61% of companies. Since the military political crisis of 2002, Côte d'Ivoire has seen very little foreign investment.

In 2010, the GDP amounted to 22.42 billion USD. The service sector accounted for 45.9% and Agriculture 29.6%, while Industry and Mines accounted for 14.6% and 2.4% respectively. GDP per capita was 1028 USD, i.e. lower than 2008 value.

The growth rate of the economy is very low (between 2 and 3% per year). 2011 was exceptionally difficult with a negative growth rate, because of the socio political situation in the country. In 2012, the growth rate again increased to more than 8%.

2.4.3. Energy sector

In 2010, primary energy production in Côte d'Ivoire was 10.9 Mtoe, including biomass energy, crude oil, natural gas and hydropower. The five oil and gas fields (Lion, Panthère, Espoir, Foxtrot and Baobab) gave a total production of 1.564 billion cubic meters of gas and 14.562 million barrels of oil (1.972 million tons). Final energy consumption per capita in 2010 was 0.242 toe, slightly lower compared to 2009 (0.250 toe).

It is estimated that biomass energy (firewood, charcoal, crop waste) represents nearly three quarters of the final energy consumption. Commercial energy sources, namely oil products, electricity and natural gas, represent 16.07%, 6.95% and 3.5% of final energy consumption respectively.

Households represent the largest energy consuming sector with 71.4% of national consumption. These households consume 89.5% of biomass, 43.3% of electricity and 16.3% of petroleum products. The increase of biomass use is connected to the population growth (2.7%/yr) and its estimation is based on the consumption per person and per year, in urban areas and in rural areas. Household consumption of LPG had a constant average annual growth of 8% in period 2000-2008. In 2009 and 2010 this growth was 3.1% (the lowest in the last ten years).

The national electricity consumption is growing at 5.8% on average over the past seven years. Hence, per capita annual consumption increased from 161.35 kW·h in 2004 to 195.49 kW·h in 2010. Connection of new communities to the grid is increasing as well as the number of household sector subscribers – 3% per year over the past seven years. 2819 villages were connected to the electricity grid out of 8513, which means 33.11% electrification rate.

2.4.3.1. Energy policy

To meet the energy challenges of the country, eight major topics of Côte d'Ivoire energy policy programme are defined:

- Develop the hydroelectric potential and thermal gas power plants;
- Strengthen the position of Côte d'Ivoire in the sub regional electricity market by its involvement in electricity networks interconnection;

- Improve electricity access to 90% by 2020;
- Strengthen energy saving actions as well as energy efficiency actions and promote eco energy business;
- National reforestation using high productive and fast growing species;
- Improve use of biomass and agro industrial waste for energy purposes;
- Develop oil exploration and increase the share of the state in exploration production contracts;
- Further popularize use of LPG.

2.4.4. Electricity outlook

With a total installed capacity of 1391 MW in 2010, (43.4% hydro and 56.6% thermal) electricity generation provided to the grid reached 5876.7 GW·h. Hydro production was less than a third of total generation (27.5%). The remaining 72.5% were assured by thermal power plants using natural gas, which consumed 1.342 billion m³ of gas. Of this production, 490.7 GW·h was exported to Ghana (19.7%), Burkina Faso (72.1%), Benin (7.6%) and Mali (0.6%). At the same time, Côte d'Ivoire has imported 145 GW·h from Ghana.

National gross electricity demand in 2010 was 5549.7 GW·h. Of 5166.4 GW·h delivered to the distribution network, the final consumption of different economy sectors was 4159.3 GW·h, which means 19.5% of overall distribution losses. Côte d'Ivoire now has more than a million electricity subscribers to low voltage electricity among which 88.7% are households and 3255 subscribers to medium and high voltage.

2.4.4.1. Network

Côte d'Ivoire has 4390 km of transmission network, comprising 1849 km of 225 kV and 2541 km of 90 kV lines. 109 transformers provide the connection of the transport network with centres of production and distribution. Three interconnection lines connect Côte d'Ivoire with Ghana, Mali and Burkina Faso.

The distribution network consists of 19 377 km of medium voltage lines (33 kV and 15 kV) and 16 133 km low voltage. 7 760 transformer stations provide various connections.

2.4.4.2. Challenges and future projects

For several years, the power sector in Côte d'Ivoire is experiencing structural deficit. Many projects and programs have been initiated to make the sector viable and assure sustainable balance.

The financial restructuring is conditioned by the reduction of costs in the energy sector, especially:

- Renegotiation of natural gas procurement contracts;
- Negotiation of AGGREKO (independent power producer) contract terms;
- Revision of the current tariff structure;

- Reduction of technical and nontechnical losses.

To improve balance between supply and demand (i.e. increase supply), the purpose is to ensure sufficient supply of electricity through the following actions:

- Import of liquefied or compressed natural gas;
- Rehabilitation of broken thermal (21 MW) and hydro (55 MW) units;
- Increase in the short term of hydropower (270 MW) and thermal (1030 MW) generation capacity;
- Improvements and extension of transmission and distribution networks.

According to the national strategic plan, there is a commitment or plan to construct 1832 MW thermal and 1071 MW hydro power plants until 2030.

2.5. NIGER

2.5.1. Geography and demography

Niger is a landlocked country covering 1.27 million km², with over 80% of the area under Sahara desert. Even non desert portions of the country are under constant pressure of periodic droughts and consequent desertification.

The country's population in 2010 is estimated at 15.2 million inhabitants. Most of population lives in the far south and west. Population increase in period from 2001 to 2010 was 3.3% annually. Urban areas account for 20.4% of the total population. The capital city is Niamey.

2.5.2. Economy

Niger is a poor country, and poverty level in 2008 was estimated to 59.5% [32], with nominal GDP per capita in 2011 estimated to 405 USD. The situation is however changing since the exploitation of oil resource started at the beginning of 2011. Mining activities have also picked up in recent years. According to 2011 statistics, the national economy is dominated by the primary sector (39% share), followed by service sector (37%). In 2011 Niger occupied 186th place on the Human Development Index (HDI) list (out of total 187 countries).

2.5.3. Energy sector

2.5.3.1. National overview

Niger is characterized by low final energy consumption (one of the lowest in the world). Only 0.140 toe per capita in 2010¹⁰. The main reason for such a low consumption is the very low access to the modern energy services.

The main energy form used in Niger is fuel wood that makes 80% of the total final consumption. The rest is dominated by oil products, electricity and negligible use of coal.

The largest share in the final consumption is in households – 82.4%, while the rest goes to transportation (13.0%), industry (3.8%), agriculture and services.

There is a large disparity in terms of availability of modern energy services between urban and rural areas. In urban areas, access to electricity service is close to 40%, but is negligible in rural areas resulting in an average national level of electricity access of less than 9%. The rural area, where 80% of total population is concentrated, has a marginal access of households to modern energy services, while 50% of urban household have access to these types of energies

After 2000 a new policy for development of the energy sector was adopted. This policy is focused on larger use of domestic resources and foreign investments in order to speed up the overall country development. The institutional, legal and regulatory frameworks were strengthened to improve investments into energy sector and increase access to energy services in urban and rural areas. This has brought some important public private projects into the oil and electricity sub sectors, but there is still long way to go and to make energy sector a driving force of the economy.

¹⁰ Compared to 0.5 tep/capita for Africa average and 1.2 tep/capita for World average.

2.5.3.2. Regional context

Niger is a member of l'Autorité du Bassin du Niger (ABN) and benefits from the regional programme for the infrastructure development through the construction of the Kandadji dam (the project is included into the ABN investment plan for period 2008-2027). Development of the national electricity transmission network and Kandadji project are also included into the WAPP Master plan for Electricity Generation and Transmission.

2.5.3.3. Energy resources and sources

Niger has some important energy resources:

- Coal – several locations were identified and put into exploitation in the northern part of the country (location Anou Araren – 15 million tons with calorific value of 3650 kcal/kg and location Salkadama – 70 million tons with calorific value of 6000 kcal/kg). Other potential locations were identified in the l'Aïr area.
- Hydro potential – several locations were identified on the River Niger and its tributaries:
 - Kandadji – 130 MW;
 - Gambou – 122.5 MW;
 - Dyodyonga – 26 MW;
 - Several small hydro power plants locations on rivers Sirba (annual quantity of 4.4 GW·h), Gouroubi (2.2 GW·h) and Dargol (1.2 GW·h);
- Hydrocarbons – potential locations are divided into two main basins that cover 90% of the national territory: western (basin Iullemeden) and eastern (basin Tchad). Most of the proven potential, estimated at 700 million barrels of oil and 14 billion m³ of gas is located in the eastern basin. Oil exploitation has started and crude oil is refined in local refinery. Oil products are sold on domestic market and are exported. There are also projects to export crude oil.
- Biomass – there are no reliable data on the wood/biomass potential in Niger, but there are important quantities of agricultural, vegetal and animal waste located mainly in the southern part of the country;
- Solar – abundant source with the average irradiation of 6 kW·h/m²/day. Average daily duration of insolation is between 7 and 10 hours;
- Wind – average wind speeds in Niger are between 2.5 and 5 m/s. This range is suitable for pumping applications (irrigation and water supply), but not for electricity production.
- Uranium – reserves are estimated to 500 000 tons in 2012.

2.5.4. Electricity system

2.5.4.1. Sources of supply

The electricity supply in the country is mainly provided by domestic production and imports from Nigeria. The domestic production is carried out by the Niger Electricity Company

(NIGELEC) with 66.3 GW·h and the Niger Coal Corporation of Anu Araren (SONICHAR) with 208.3 GW·h in 2010.

Imports from Nigeria (supplied by Power Holding Company of Nigeria) in 2010 amounted to 525.0 GW·h. National electricity demand in the same year reached 800 GW·h. The total installed capacity of 138.6 MW is divided as follows: thermal Diesel: 102.6 MW and thermal coal: 36 MW. The import of power from Nigeria to Niger was limited to 130 MW in September 2012.

2.5.4.2. Network organization

Niger's electrical grid is divided into five zones:

- Zone 1: The River Zone is powered by the 132 kV interconnection line Birnin Kebbi (Nigeria)-Niamey (Niger) with a contractual capacity of 120 MW (currently limited to 80 MW) and installed diesel thermal power of 57.6 MW. This area represents 65% of the total energy provided by NIGELEC and 74.5% of the energy imported from the Power Holding Company of Nigeria (PHCN) with 410.5 GW·h and a peak of 65 MW in 2012;
- Zone 2: the Niger's Central East Zone (NCE), which includes the regions of Zinder, Maradi and Tahoua is powered by a 132 kV interconnection line Katsina (Nigeria)-Gazaoua (Niger) with a contractual power of 60 MW (currently limited to 40 MW) and installed thermal capacity of 13.8 MW. This area represents 20% of the total energy provided by NIGELEC and 23% import from PHCN with 127.2 GW·h and peak load of 28.6 MW in 2012;
- Zone 3: North Zone, which includes the towns of Agadez, Arlit and Tchirozérine and mining companies is supplied from the coal power plant SONICHAR and Agadez diesel power plant with installed capacity of 37 MW. The energy provided by NIGELEC in this area is 34.5 GW·h representing 2% of the total energy produced with peak load of 6 MW in 2010;
- Zone 4: the East Diffa region is connected to the 33 kV network of Nigeria from Damasak with capacity of 5 MW and installed diesel generators of 2.3 MW. This area represents 1.2% of the total energy provided by NIGELEC and 1.4% of imported energy with 7.5 GW·h and peak load of 2.1 MW in 2012.
- Zone 5: Zone Gaya/Malanville which is powered by a 33 kV interconnection from Kamba in Nigeria with a contractual capacity of 7 MW (currently limited to 5 MW) and a diesel thermal plant of 0.5 MW. The imported energy in this area is 6.2 MW·h or 1.1% of total imported energy with 1.3 MW peak load in 2012.

Zones 1, 2, 4 and 5 are supplied from Nigeria and Zone 3 (North Zone) is supplied by the SONICHAR's power plant. There are several other isolated centres supplied by thermal power plants with an installed capacity of about 6 MW.

It should also be noted that from 2011 the refining of crude oil started in the Niger by Société de raffinage de Zinder (SORAZ) and a gas power plant with installed capacity of 24 MW supplies the refinery. The excess electricity produced will be used to supply Zinder.

2.5.4.3. Future projects

The share of electricity in the national energy balance in 2010 was only 3%. The household electricity access was about 10% in 2010.

The following power plant projects are under consideration:

- A thermal power plant of 100 MW in 2013;
- Construction of Kandadji dam (on the Niger river) with a 130 MW hydroelectric plant in 2016;
- Construction of the thermal power plant coal Salkadamna (Tahoua) of 200 MW by 2015. This project would allow the exploitation of coal deposit Salkadamna;
- Project to strength generation and transmission capacity in the northern zone. This project aims to build two 25 MW units for SONICHAR and two 132 kV lines to supply electricity to uranium mining at Imouraren and Azelik sites;
- Construction of a 132 kV line SorazZinder;
- Construction of a 132 kV line MaradiMalbaza;
- Construction of a 330 kV line between BirninKebbi (Nigeria)-Niamey (Niger)-Ouagadougou (Burkina Faso) with a ramp between Zabori (Niger)-Malanville (Benin), also called the North Ridge of the WAPP.

2.6. NIGERIA

2.6.1. Demography

The provisional result of the 2006 National census released for the states and local government levels in Nigeria in May 2007 gave the population of Nigeria as 140.0 million as at 2006 and annual growth rate of 3.2%. The population for 2010 was estimated to be 158.80 million people.

Approximately 48% of the population lives in urban areas, while the rest 52% lives in rural areas. The urbanization rate is high, with people migrating from the rural to urban areas in search of better living conditions, and cities expand rapidly.

The Economic Transformation Blueprint known as *Nigeria Vision 20: 2020* [33] assumes that the current urbanization rate of 5.3% per annum will decline to 4% per annum by 2015 and 2% per annum by 2020. Projections by the National Population Commission gave Nigeria's population as 188 million people by 2015 and 221 million people by 2020 and to increase to 230 million by year 2030 (Power Sector Roadmap).

The fraction of the population living below the poverty line increased significantly from 1980 to 2010. According to the National Statistics Office, estimated poverty incidence increased from 27.2% in 1980 to a very high level of 69% in 2010.

The fraction of the unemployed ranged between 12.3% and 21.1% in the period 2000- 2012. The situation is heightened largely by the poor power and energy infrastructure in the country, as industrial production is hampered by poor energy facilities. Increased domestic production can be facilitated by accessible, affordable and available energy and electricity, which in turn will reduce unemployment and poverty.

2.6.2. Economy

The GDP was 225.573 billion USD at current market prices as of 2010 [34] and is projected to increase to 400 billion USD by 2015 and 900 billion USD by 2020. The GDP per capita in 2010 was 1420.5 USD¹¹ and it is expected to increase to 4000 USD/capita by 2020. The real GDP growth rate within the 2006-2010 period ranged from 6.0% in 2006 to 7.9% in 2010.

The Nigerian economy is dominated by agriculture which includes crop production and livestock, forestry and fishing. Over 60% of the population is engaged in this sector with an average of 41% contribution to the real GDP. Despite the dominance of agriculture, the crude petroleum sub sector contributes over 80% of Nigeria's foreign exchange earnings. The manufacturing sector's contribution to the economy is minimal, with an annual average of 3.0% between 2006 and 2010. Also the communication sector has witnessed a tremendous growth in recent times with an average contribution of 5.50%.

2.6.3. Energy resources and sources

Nigeria has various energy resources which can be harnessed to generate electricity. These include crude oil reserve of 36.2 billion barrels, 187 trillion standard cubic feet of natural gas, 2.734 billion tonnes of coal and lignite and 31 billion barrels of oil equivalent of tar sand. Others are 11 250 MW and 3 500 MW of large and small hydropower potentials. It also

¹¹ Central Bank of Nigeria, 2010 Annual Report

include solar radiation of 3.5-7.0 kW·h/m²/day and wind energy potentials of 2-4 m/s at 10 m height. Moreover, there are vegetal and animal biomass resources and nuclear energy resources that can be harnessed for electricity generation.

2.6.4. Energy sector

The main principle of Nigerian Energy Policy (NEP) is to promote diversification of energy resources and ensure optimal energy promoting sustainable and environmentally friendly energy. NEP envisages restructuring of the energy sector and greater participation of private actors.

Nigeria owns the 10th largest oil reserve and 7th gas resource in the world. Nigeria exports about 2.4million barrels of crude oil per day and 25.94 million standard cubic meters of natural gas per year, mainly in form of LNG. Total energy consumption in 2010 was about 74.8 million toe with traditional fuels accounting for about 71% while electricity and petroleum products account for the balance.

The West African Gas Pipeline (WAGP) project of 678 km pipelines was commissioned in March 2011 as against the initial plan of December 2007 due to some technical issues. The pipeline carries a volume of 170 mmscfd and within 15 years will reach a maximum capacity of 460 mmscfd (potential for 2500- 3000 MW). The main pipeline has been transporting gas from Lagos (Nigeria) to Takoradi (Ghana) with laterals extending to Cotonou (Benin), Lome (Togo) and Tema (Ghana). The essence of the project is to boost economic development of the sub Saharan region by using natural gas for generating electricity and for industry. About 85% of the gas is being used for electricity generation. The pipeline was closed in August 2012 due to a loss of pressure around Lome. The West African Gas Pipeline Company (WAPCo) is carrying out rehabilitation of the pipeline to ensure safety before restoring the supply.

Nigeria and Algeria are discussing development of a Trans Saharan Gas Pipeline (TSGP or NIGAL). The project, which would stretch over a distance of 4,300 km across the Saharan desert would be shared among Nigeria (1050 km); Niger (750 km), and Algeria (2500 km) is estimated at about 21 billion USD. The pipeline will carry natural gas from oil fields in Nigeria's Delta region to Algeria's Beni Saf export terminal on the Mediterranean. The Algerian state oil company, Sonatrach has been in support of the Trans Saharan Pipeline project, but the project hasn't been able to get finances required for its construction.

2.6.5. Electricity system

The country is currently facing acute problems in the supply of electricity which have hindered its development despite the nation's vast natural resources. The demand for electricity far outstrips supply. The reality is that by 2010, Nigeria had total on grid installed electricity generation capacity of 8425.4 MW made of 1938 MW hydro plants, and of 6487.4 MW natural gas powered plants while average available capacity in the year was 4212 MW.

The national power infrastructure is either in a poor state or lacks adequate natural gas supply. Transmission and distribution grids are not well maintained and are operated inefficiently. While the Energy Commission of Nigeria forecasts a generation capacity demand of about 100 000 MW in 2030 for a 7% growth rate of the GDP per annum, the Presidential Task Force on Power which is charged with the responsibility for fast tracking the development of the power sector in Nigeria projects that Nigeria would only be able to achieve about

8 072 MW by 2013, 12 142 MW by 2015 and 28 300 MW by 2020, taking into consideration the financial, technical and other enabling factors for electric power infrastructure development.

Access to electricity in both urban and rural areas was about 52% in 2010 while per capita electricity consumption was 106.63 kW·h. Most rural areas of the country do not have access to grid electricity. This is due to the high cost of extending the grid to remote locations and the inability of rural dwellers to pay commercial prices because of their income. In 2005, the Federal Government established the Rural Electrification Agency (REA) to increase access to electricity in the country. The REA was created with the mission to increase electricity access in rural zones, keeping in mind economic viability and income levels of average rural consumer. The Federal Government through the Rural Electricity Agency is working to increase the electrification rate of rural and peri-urban access to from the current estimated level of 35% to 75% by 2020 and hopefully to achieve 100% electrification in consonance with the United Nations goal of Sustainable Energy For All (SE4ALL) by year 2030. To achieve this, the Federal Government is promoting on grid and off grid projects. Part of the projects of the REA includes renewable energy projects involving solar, wind and small hydro projects both grid and off grid.

2.6.5.1. Generation

In 2010 Nigeria had a total installed capacity¹² of 8387 MW with average availability of 4212.68 MW. The available thermal capacity is 2978 MW (installed 6478 MW) and hydro is 1234 MW (1900 MW). The availability of approximately 50% of installed capacity is mainly due to gas constraint and aging of turbines.

2.6.5.2. Transmission System Network

The transmission system in Nigeria covers part of the national territory. The government is the sole owner of the transmission grid as provided in the Electric Power Sector Reform, (EPRS) Acts of 2005. Transmission system capacity is 6534.8 MW (7688 MVA) at 330 kV and 7716 MW (9130 MVA). The following is an overview of the network at the end of 2010:

- 72 Circuits of 330 kV transmission lines of total route length of 5515 km
- 186 Circuits of 132 kV transmission lines of total route length of 6801.49 km
- 33 No. 330/132 kV substations with transformation capacity of 7688 MVA (equivalent to 6534.8 MW)
- 106 No. 132/33/11 kV substations with total installed transformation capacity of 9130 MVA (equivalent to 7716 MW)
- Average transmission loss is 9.75%
- National Control Centre
- Regional Control Centres (three)

The above can guarantee evacuation capability of above 5000 MW on 330 kV and 8000 MW on 132 kV network.

¹² PHCN Annual Report 2010.

Transmission Company of Nigeria (TCN) has developed a plan for the electricity transmission expansion. The plan is to be implemented in three phases, i.e. short, medium and long term. The short term plan is increase transmission capacity to evacuate 10 000 MW, medium term will evacuate 15 000 MW and long term will evacuate 20 000 MW [35]. The plan is not time dependent due to the uncertainty of funds to execute the projects so identified. Short term plan has been approved by the government and is in the implementation stage.

2.6.5.3. Distribution System Network

Nigeria's electricity distribution sector was recently privatized into 11 distribution companies, in line with EPRS, Act of 2005. These are Abuja, Benin, Eko, Enugu, Ibadan, Ikeja, Jos, Kaduna, Kano, Port Hacourt and Yola distribution companies. The system has a total number of 827 injection sub stations with a total capacity of 11,360.2MVA, according to Distribution Companies (DISCOs). The distribution system consisted of the following:

- 827 Injection substations with a capacity of 11 360.2MVA
- 69 607 Distribution transformers with a capacity of 20 056.39MVA
- 33 kV lines with a length of 54 948.85 km
- 11 kV lines with a length of 51 467.45 km
- 0.415 kV lines with a length of 255 728.90 km

With 52% of the population connected to the electricity grid, there is considerable opportunity for the expansion of the distribution networks. The new distribution companies are required to plan for and implement the installation of additional distribution infrastructure as well as maintain existing infrastructure in their operational areas.

2.6.5.4. The Electric Power Sector Reform

The Electric Power Sector Reform (EPSR) Act entered into force on March 2005. It provides the legal framework for the reform of the sector, which includes the unbundling of Power Holding Company of Nigeria (PHCN) into 6 Generation Companies (GENCOs), one Transmission company (TCN) and eleven Distribution Companies. Part of the reform also includes the establishment of the Nigerian Electricity Regulatory Commission (NERC) and the National Electricity Liability Management Company (NELMCO) Limited.

While NELMCO Ltd will inherit and manage stranded PHCN liabilities, the NERC was required to establish a tariff that balances fair pricing for the consumers with cost reflective pricing for the sector operators. As such, NERC rolled out a revised Multi Year Tariff Order (MYTO 2) in June of 2012. The new tariff is critical, if there is to be an infusion of private capital, efficiency and creative entrepreneurial energies into the sector. In Nigeria, the true cost of electricity production is not reflected in the consumer tariff. MYTO 2 is intended to be cost reflective and provide financial incentives for urgently needed increased investments in the industry. These investments, in turn, lead to a significant and continuous improvement in the quantity of energy and quality of service enjoyed by the consumer. NERC has awarded over 22 licenses to the independent power producers (IPPs) for grid electricity generation.

2.7. MALI

2.7.1. Geography and demography

Mali is a landlocked country of the Sahel belt of West Africa. It borders seven countries: Algeria, Niger, Burkina Faso, Mauritania, Senegal, Cote d'Ivoire and Guinea. Its surface is 1.24 million km², including 60% of desert grounds. The climate is characterized by one rainy season; one average season with duration from 1 to 5 months depending on the zone and a long dry season for the remainder of the year. The shortest distance to the sea coast is about 800 km.

The population of the country passed from 9.81 million in 1998 to 15.37 million in 2010. The population growth reached average annual rate of 3.6% over the period 1998 2009. The rate of urbanization reached 36.5% in 2010. The population is unequally distributed on the territory – north areas of the country (Tombouctou, Gao and Kidal) which cover more than 60% of the territory count only 10% of the total population.

2.7.2. Economy

During the last decade, Mali made significant progress in the economic, political and social domains. The GDP (constant prices) has tripled in less than ten years passing from 2.43 billion USD in 2000 to 8.74 billion USD in 2008. In 2010, the GDP reached 9.44 billion USD. The GDP per capita increased from 603 USD in 2009 to 669 USD in 2011 with a growth rate of 5% in 2010, and 5.3 % in 2011. Inflation in 2011 was 3%.

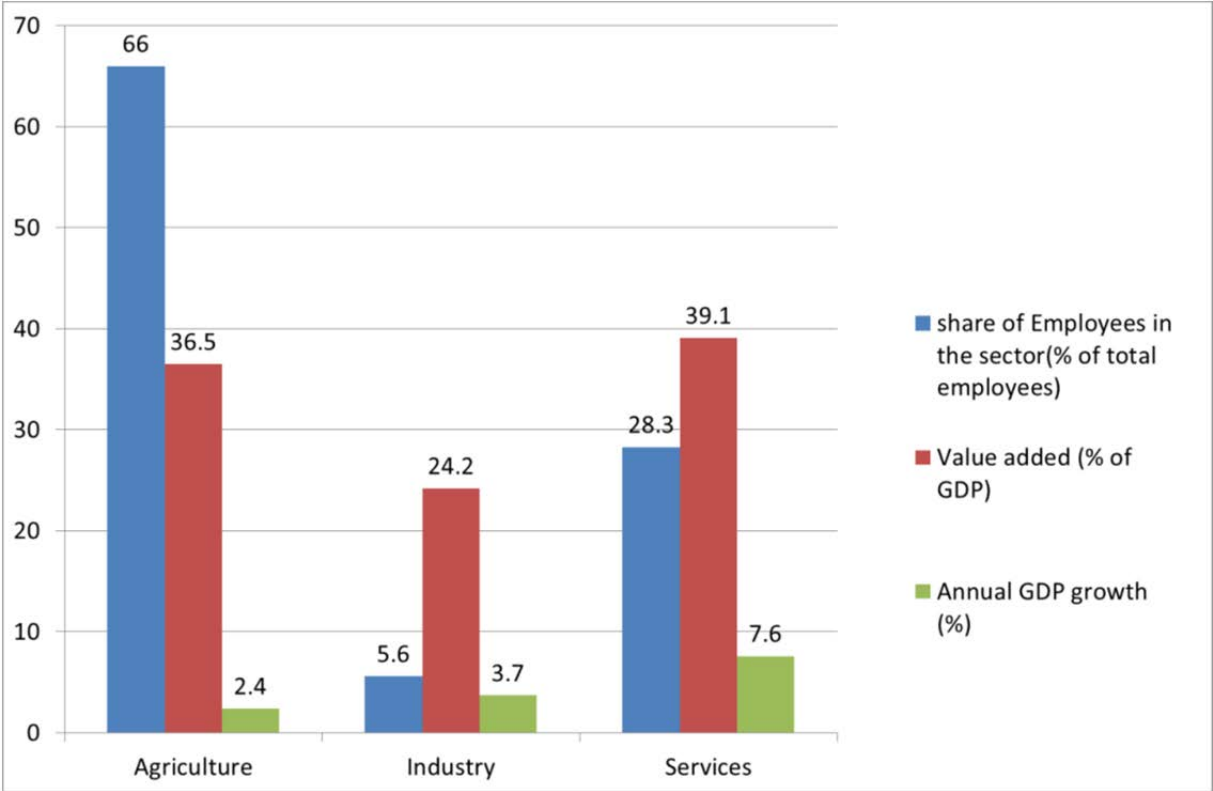


FIG. 9. Contribution of the main economy sectors to employment, added value (% of GDP) and annual increase in added value in Mali for 2011.

Contribution of the main economy sectors to employment, added value (% of GDP) and annual increase in added value in Mali for 2011 are presented in Figure 9. The agricultural sector represents more than one third of the GDP and employs about two third of the total labour force. The industrial sector consists mainly of the construction/public works and the food processing. Services correspond to about 40% of the GDP. More than two thirds of the Malians live under the poverty line and the country still depends on international assistance.

2.7.3. Energy resources and sources

Mali has a significant potential in renewable energies, especially solar, hydroelectric and biomass/biofuels. It is estimated that currently about 3% of the installed capacity is in renewables, i.e. approximately 12 MW.

- Solar – average irradiation, available throughout the country, is 5-7 kW·h/m²/jour with sunshine duration of 7 to 10 hours;
- Biomass – Mali has:
 - In terms of fuel wood, approximately 33 million hectares of forest with approximately 520 million m³; The ecological diversity of Mali results in very contrasted forest situation between shrubby savannahs on the north with less than 10 m³/ha: striped bush on the south, which covers 25% territory with volumes reaching 20 to 40 m³/ha, to the forests zone close to Guinea border with biomass volume between 50 and 80 m³/ha, and sometimes more than 100 m³/ha in the forests galleries on the west. More than 350 thousands ha are surface with controlled exploitation. The forest surfaces are in perpetual regression. According to various studies, approximately 10 thousands ha are lost each year because of the anthropogenic activities and climatic change;
 - Several million tons of agricultural residues and vegetation wastes;
 - Annual production capacity of 2.4 million litres of alcohol (since 1997);
 - Approximately 2000 hectares of plantations of *Jatropha* for biofuels production;
- Wind – northern areas of Mali have wind speed from 2.5 to 7 m/s. This band can be exploited for pumping applications and electricity generation, but wind patterns are irregular;
- Hydro – 35 hydroelectric sites with medium to high capacity were identified throughout the territory with a total capacity of 1150 MW and expected annual generation of 4 TW·h. For now 4 sites are under exploitation, accounting for 25% of the total hydro potential, namely: Félou (0.6 MW; 3 GW·h/yr), Sotuba (5.2 MW; 40 GW·h/yr), Sélingué (44 MW; 200 GW·h/yr) and Manantali (200 MW; 800 GW·h/yr). Following sites were identified:
 - Sites under development: Taoussa (25 MW; 100 GW·h); Sotuba II (6 MW; 30.40 GW·h), Markala (10 MW; 45 GW·h), Félou (60 MW; 320 GW·h) and Kénié (42 MW; 188 GW·h);
 - Sites at the stage of the feasibility study: Gouina (140 MW; 560 GW·h);
 - Sites at the stage of prefeasibility: Labezanga (14.84 MW; 67 GW·h); Gourbassi (13 MW; 104 GW·h); Moussala (30 MW; 160 GW·h); Galougo (285 MW; 1520 GW·h); Badoumbé, Dioumbéla, Boudofara, Maréla and Bindougou;

- Sites at the stage of exploration: Toubani (35 MW; 134 GW·h); Baoulé II (30 MW; 124 GW·h); Bakoye II (45 MW; 193 GW·h); Salambougou (10 MW; 40 GW·h); Kourouba and Banifing;
- Sites of micro hydroelectric power stations (feasibility studies): Farako (50 kW); Kéniéba (180-250 kW); Nimbougou (8-12 kW); Papara (50-60 kW);
- Hydrocarbons – no discovery of any hydrocarbon reserves until now. However, Mali has five sedimentary basins of total 750 000 km², all located in the northern half of the country:
 - Oil shale – oil shale resource is evaluated to 870 million tons with low content (17.85 litres of oil per ton). Their profitability strongly depends on the oil prices.

2.7.4. Energy sector

In 2010 the structure of the energy balance was:

- Share of biomass in final consumption has decreased slightly from 76.2% in 2009 to 75.8%. The main reason for decrease is increase in LPG use (from 9 410 tons in 2009 to 10 164 tons in 2010); Share of other energy forms in final consumption is 20% for oil products and 4% for electricity;
- Final energy consumption is dominated by households (68%), followed by transport (22%) and industry (3%). Other sectors share the remaining 7%;
- Specific final energy consumption per capita has increased from 0.190 toe/capita in 2009 to 0.192 toe/capita in 2010;
- Electricity access rate in urban areas has increased from 53% in 2009 to 55.3% in 2010;
- Electricity access rate in rural areas has also increased from 4.6% in 2009 to 5.6% in 2010, but remains at very low levels.

The institutional responsibilities for the energy sector are divided up as follows:

- Energy is in the overall domain of the Ministry of Energy and Water (Ministère de l’Energie et de l’Eau);
- Centralised service is under National Direction for Energy (Direction Nationale de l’Energie – DNE);
- Decentralised service is under National Centre for Solar and other Renewable Energies (Centre National de l’Energie Solaire et des Energies Renouvelables – CNESOLER);
- There are two public agencies:
 - Mali Agency for development of Domestic Energy and Rural Electrification (Agence Malienne pour le Développement de l’Energie Domestique et de l’Electrification Rurale – AMADER);
 - National Agency for Development of Biofuels (Agence Nationale de Développement des Biocarburants – ANADEB);

- Regulatory body – Commission for Electricity and Water Regulation (Commission de Régulation de l'Electricité et de l'Eau);
- Three categories of private operators:
 - Operators with a concession of public service: EDM SA, SOPAM SA, Albatros Energie;
 - Operators with a licence for public service – several;
 - Auto producers – several;
- Law N° 00-019/P RM from 15 March 2000 on organisation of the electricity market;
- Decision on tax exemption for import of renewable energy equipment from 1996.

2.7.5. Electricity system

The electricity sector in Mali is characterised by:

- Average annual increase of demand by 10% in period 2002-2012;
- Low national electricity access rate of 31.7% in 2012;
- High level of system losses of 20%.

2.7.5.1. Generation

National electricity generation in 2010 reached 91 ktoe including auto producers. Electricity is generated in thermal and hydro power stations. The total installed power connected to the national network in 2011 reached 327.27 MW and 67.4 MW connected to the isolated centres.

Hydro production from Manantali plant is shared with Mauritania and Senegal. Mali has 52% share. In 2010 hydro covered 57.3% of total generation (rest was thermal). Total installed capacity in hydro power plants is 156 MW. Hydro plant Felou (62.3 MW) was completed in 2014.

Total installed capacity in thermal plants is 147 MW (of which 30 MW are auto producers). It is expected that the new project of Albatros Energy at plant Kayes will be commissioned in 2015 (additional 92 MW).

2.7.5.2. Transmission

The main characteristics of the transmission network are:

- 225 kV lines with total length of 871 km (after interconnection with Cote d'Ivoire was completed in 2012);
- 150 kV lines with total length of 360 km;
- 66 kV lines with total length of 68.5 km;
- 63 kV line with length of 107 km;
- 30 kV lines with total length of 75 km.

Transmission losses are around 4%. There are different on-going rehabilitation projects to reduce losses to 3%.

2.7.5.3. Distribution

The total length of the distribution network in 2011 was 5239 km (1562 km on medium and 3676 km on low voltage). Total number of medium to low transformer stations is 2197 (with total transformation power of 479.2 MVA). In the long term (in the next 15 years) it is planned to extend the network length by 60%.

2.7.5.4. Sub regional considerations

At sub regional development level, the following projects are of particular interest to Mali:

- Interconnection between Mali and Cote d'Ivoire was already realised with the current transfer capacity of 80 MW and plans to increase it to 200 MW;
- Interconnection between Mali and Ghana via Burkina Faso is expected to be established in 2014. It will require construction of 445 km of lines in Mali;
- Interconnection between Mali and Guinea. Feasibility and environmental study are finished and the project has been approved under the WAPP development plan. Project will see the construction of 920 km long 225 kV transmission link and seven transformer stations with the expected commissioning in 2017.

2.7.5.5. Electricity demand

Peak load has increased from 399 MW in 2008 to 470 MW in 2011. Further increase with average annual rate of 6% is expected to continue until 2020 and peak load is expected to almost double to 800 MW.

2.7.5.6. Regulatory framework for electricity

The regulatory framework of electricity sector is established through three types of instruments:

- Legislation defining sector activities:
 - Organisation of the sector (Law 00-019/P RM from 15 March 2000 and Decision n°00-184/P RM from 14 April 2000 with details on application of the law);
 - Regulation of the sector (Law n° 00-21/P RM and Decision n°00-21/P RM with details on application of the law from 15 March 2000);
- Legislation defining free competition;
- Legislation defining cooperation.

Next to the above mentioned regulation, there are financial laws and guidelines that define four possible sources of funding: (i) financial systems – banks and financial institutions, different credit lines; (ii) Fund for Rural Energy created by AMADER; (iii) Clean Development Mechanisms (CDM) for financing projects to reduce GHG emissions; (iv) Complementary Mechanisms.

2.8. SENEGAL

2.8.1. Geography and demography

Senegal has a land area of 197 000 km², with a population of about 12.7 million inhabitants. The country's climate is tropical with dry and rainy season.

2.8.2. Economy

Senegal is the fourth largest economy in the West Africa (after Nigeria, Côte d'Ivoire and Ghana). Still it is one of the Least Developed Countries (LDCs). Country's economy depends mainly on trade with Europe (France, Italy) and India.

Compared to other African countries, Senegal is very poor in natural resources. Its main revenue comes from fishing and tourism. But given its geographical location and political stability, Senegal is one of the most industrialized African countries with the presence of multinationals industries (mainly French and USA based owners).

The agricultural sector employs about 70% of the total population. However, the share of the primary sector in the Gross Domestic Product (GDP) continues to decrease. The decrease in rainfall and the crisis of the groundnut sector, the main cash crop of the country, have reduced the contribution of agriculture to less than 20% of GDP. Despite the degradation of fishery and recent increase of energy costs, fishing, however, remains a key sector of economy. Much of the wealth produced is concentrated in services and construction, mainly in Dakar and its outskirts.

Remittances from the Senegalese diaspora (emigration in Europe and the United States) now represent a significant income. Senegalese emigration generates cash remuneration that at least equals the aid from the international cooperation (37 USD per capita per year).

In 2009, the GDP was 22.92 billions USD (PPP) or 1900 USD/capita. The contribution of the agricultural sector to the GDP was 18%, industry contributed 19.2% and services 62.2%. The share of Senegalese living below the poverty line was estimated at 54% in 2005 [36].

2.8.3. Energy sector

The energy balance of the country in 2009 showed that biomass and petroleum products still account for 95%, renewable (including hydropower) for 0.6%, and mineral coal for 4% of the total primary energy supply. Final energy consumption per capita was 0.206 toe in 2009, i.e. below the African average (0.500 toe), and the global average (more than 1.2 toe). Access to commercial energy forms is still low. The main source of energy is biomass.

The high level of energy dependence on foreign imports is a heavy burden on public finances because of the economic choices of the Government to provide local user with affordable prices by subsidizing oil sector. In 2012, the funding support of the Treasury was expected to rise up to 400 million USD, in which 240 million USD were to be allocated as compensation for SENELEC income.

2.8.3.1. Hydrocarbons sub sector

For exploration purposes, Senegal was divided into 18 blocks; six blocks were awarded (3 off-shore and 3 on-shore) and are the subject to contracts for research and production sharing. Gas potential is estimated to 357 million m³ of recoverable proven reserves and

705 million m³ probable reserves in place. The daily production capacity of gas is currently around 180 000 m³.

The crude oil processing capacity of African Refinery Company (Société Africaine de Raffinage) is 1.2 million tons/year (against national demand of more than 1.8 million tons and sub regional market of nearly 2 million tons)

Generally, import complements the production of the African Refinery Company. In recent years the company operated under its normal capacity, due to financial issues.

The overall storage capacity is insufficient to meet the ever increasing demand and maintain security stocks (set in Senegal to equivalent of 50 day consumption).

Distribution is the segment in which the effects of liberalization (a key objective of the 1998 reform) are strongly visible, with the introduction of new independent companies sharing the market with previews leading companies. Just in twelve years, these independents companies succeeded to install many points of distribution, and they actually own 200 distribution stations over a total of 450 in the whole country.

2.8.3.2. Domestic fuel sub sector

The country committed significant programs to improve the sustainable supply of fuel wood for domestic purposes. In this policy the concept of participatory development was implemented with significant results: hundred thousand hectares of biomass identified and definition and implementation of management plans with a strong involvement of local participation has been put in place.

2.8.3.3. Renewable energies sub sector

Despite the advantages (high solar irradiation throughout the country with averages from southeast to northwest between 1850 and 2250 kW·h/m²/year and average wind speed of 6 m/s – measured at 50 m height on the coastal strip north of the country), the sub sector of renewable energy remains embryonic as shown by the PV installed capacity of about 2 MW – a mere 0.4% of total electricity generation capacity and almost no wind power plants.

2.8.4. Energy policy

2.8.4.1. Sector vision

The overall policy target is to provide energy at the lowest possible cost and ensuring universal access to modern energy services. In 2017, Senegal aims to achieve the electricity access of 50% in rural, 95% in urban and 70% at national level.

2.8.4.2. Strategic objectives

The new energy policy, which takes into account the national and international context has the following strategic objectives:

- Ensure sufficient supply of energy services in a cost efficient and sustainable way;
- Increase energy diversification to reduce vulnerability to risks (including exogenous factors, e.g. world oil prices);
- Promote development of renewable energy;

- Improve access to modern energy services, giving priority to disadvantaged regions and vulnerable customers;
- Promote energy efficiency.

The government's strategy is to have an emerging economy ensuring sustainable development and solidarity in its output sharing. The program *Yoonu Yokute* promoted by the Head of State has set a development goal reaching a Human Development Index between 0.75 and 0.80 by 2035-2040. To achieve this objective, the average economic growth rate rose is expected to be 7%/yr over the next 5 years and 11.5% on average over the next thirty years.

In the energy sector, the program aims at addressing the challenge of energy deficit and rehabilitation of the network to provide electricity service quality and quantity.

2.8.5. Electricity system

Plant availability has steadily declined in recent years, from an average of 73% over the period 2005-2009 to 69.2% in 2010 and 56.1% in 2011. This caused deficit in supply, which consequently increased from 153 GW·h in 2010 to 253 GW·h in 2011. Sales have increased by 80% between 2005 and 2010, from 1777 GW·h to 2056 GW·h.

The main problem is the low access to electricity in rural areas. In 2012, access was 24%, meaning that three out of four households in rural areas in 2012 did not have access to electricity. With 54% of national electricity access in 2012, Senegal aims to achieve 70% by 2017.

The electricity sub sector is dominated by SENELEC, a vertically integrated company, which has the monopoly of purchase and wholesale. SENELEC still faces difficulties to satisfy the growing electricity demand. The lack of capacity due to investment delays and decrease in the availability of production equipment are the main reasons behind this situation. In terms of capacity, the deficit varies between 35 and 50 MW. Other reasons, such as insufficient fuel supply for power plants and saturation of the distribution network, justify the common blackouts whose impact on economy is estimated at 1.4% loss on GDP growth. Reforms and other initiatives have not produced the desired results. Dealing with the worsening energy crisis, the outgoing Government has established an Emergency Plan for Restructuring and Recovery of Energy Sector which has mobilized 134 million USD from technical and financial partners (AFD, World Bank, IDB, BOAD, and state). This money was used to finance investment of up to 240 million USD, and complement financing from the Special Fund for Support of Energy (fiscal and budgetary resources associated to a levy on oil prices).

The state succeeded to benefit from the support of development partners with the defined strategy and mobilize significant funding to support private sector in the implementation of Rural Electrification Priority Programs.

2.8.5.1. New policy vision

The new policy vision for electricity sector of Senegal is to have electricity available in quantity and quality, at competitive prices and produced from a variety of sources, including coal, gas, hydro, wind and solar. The government has therefore decided, to improve rehabilitation, development and operation of the system (generation, transmission and distribution) and also restructure the (financial and organisational changes). This should create favourable environment for independent producers and specific provisions for improving SENELEC management through performance contracts.

2.8.5.2. Objectives and strategic directions of the electricity sub sector

The main objectives of the government are securing electricity supply, expanding access to electricity and improving the effectiveness of the sub sector. Strategic guidelines adopted by the government are:

- Diversification of electricity generation;
- Promotion of rural and peri-urban electricity access;
- Rehabilitation and strengthening of transmission and distribution infrastructure;
- Encouraging and sustaining the participation of private investors and operators;
- Demand side management;
- Improving the sub sector governance;
- Implementation of institutional reforms and regulatory framework;
- Implementation of operational and financial restructuring of SENELEC;
- Regional and sub regional cooperation.

The government intends to diversify energy sources for electricity generation and give emphasis to the least expensive options (hydro, coal, gas) and renewable energies to improve energy security of the country.

Delays of the first initiatives of coal based independent producers have impacted and delayed solution of difficulties at SENELEC. With this experience, the state favours the option of bilateral cooperation for the realization of coal based plants with leading operators at international level, with technical and financial capacity to conduct large scale projects in the shortest time possible.

Regarding the use of natural gas in electricity generation the government will:

- Support the exploration of Senegalese sedimentary basin;
- Examine the possibilities of importing gas by pipeline from neighbouring countries;
- Explore opportunities to purchase electricity from power plants using natural gas;
- Conduct a study for the use of LNG purchased from the international market.

The government intends to work within the framework of the OMVS and OMVG to advance hydropower projects seeking ways to overcome the constraints and accelerate their implementation.

The government intends to develop the potential of renewable energy through projects approved by the Accreditation Committee set up by the Ministry of Energy and other mechanisms.

With regard to the transmission and distribution, the government has been able to mobilize significant funding for network rehabilitation and construction so that bottlenecks are removed and the quality of service is improved.

At demand side, measures for energy savings and efficiency will be implemented to contribute to reduction of deficit. The first distribution of energy saving lamps is implemented with funding from the West African Development Bank (BOAD) and the European Investment Bank (EIB). The project plans distribution of 3 million low consumption bulbs, corresponding to a reduction of the power demand equivalent to a plant of 70 MW. Other measures are also being studied including prepayment and smart meters. The Government promotes private sector involvement in electricity generation.

2.9. SIERRA LEONE

2.9.1. Demography

According to 2010 revision of the World Population Prospects, the total Sierra Leone population was 5.868 million in 2010. The share of population below age of 15 in 2010 was 43%, 55.1% was between 15 and 65 years, while 1.9% was 65 years or older. The population growth rate is estimated to 2.277% (2012). Urban population forms 38% of total population (2012). Estimated rate of urbanization for period 2010-2015 is 3.3%/year.

Sierra Leone is one of the poorest countries in the world with comparatively high income inequality. About 70% of the population lives below the poverty line and 26% in extreme poverty. Sierra Leone had been at the bottom of the UN Human Development Index for years but is climbing since 2010. In 2011, Sierra Leone ranked 180 out of 187 countries. Sierra Leone has vast natural resources, however, the poorly diversified economy, underdeveloped infrastructure, weak education system, lack of markets and weak capacity to manage these resources in a sustainable way, leave the economy's full potential still untapped.

2.9.2. Economy

Since the end of the civil war in 2002, the economy has been gradually recovering with a GDP growth rates between 4 and 7%. In 2009 GDP reached 1.9 billion USD. Agriculture share in GDP is 58.5%, followed by trade, tourism and other services with 29.0%, while mining and construction share is 6.2%.

Sierra Leone's economic development has always been hampered by an overdependence on mineral exploitation as the main export activity. For a long time diamonds and gold industry was used as the main generator of foreign currency earnings. On the other side, agriculture, commodity products, industrial development and sustainable investments have been neglected.

Mineral exports remain Sierra Leone's principal source of foreign currency. Although the resource base is large, the country has struggled to manage its exploitation and export. Annual production estimates range between 70 and 250 million USD. Only a fraction of that passes through formal export channels.

Sierra Leone continues to rely on significant amounts of foreign assistance, principally from multilateral donors (e.g. 60% of its health care budget comes from foreign aid). The largest bilateral donors are United Kingdom and the European Union, and the list includes also the United States, Italy, and Germany.

2.9.3. Energy resources and sources

Total estimated hydroelectric potential is 1513 MW. The country has seven major rivers and tributaries with an estimated hydro potential of 1200 MW (sites with hydropower potentials larger than 5 MW). All potential sites have large flow variations between the wet and dry season. Therefore, only two rivers are attractive in terms of possible annual inflow regulation. Yiben I and II, Bekongor III, Kambatibo, and Betmai III are the most promising sites in terms of average generation cost.

There are many locations suitable for small to medium hydro power plants (range between 1 and 100 MW). Large number of sites is suitable for pico to mini hydro systems (5 kW to 1 MW). Those locations could be of interest for private investors and for Public Private

Partnerships (PPP). Other plans in the hydropower include the extension of Bumbuna plant by 275 MW, and increase of total power at Bekongor plant to 200 MW.

Biomass resources include fuel wood, animal dung, charcoal, straws, water hyacinths etc. Fuel wood is derived from forest and mangroves. Over 40% of the wood produced is converted to charcoal.

Potential of biomass from the forest waste is estimated to 656 400 tons annually, enough to generate about 2 706 GW·h of electricity. Other feed stocks include rice husks and straw. The main issue with wider use of biomass in electricity generation is very high deforestation rate. This is mainly caused by a high reliance of rural zones (62 % of the total population) on the traditional biomass.

In terms of biofuels, a project is under consideration to construct a biomass fuelled power plant and sugarcane ethanol refinery. The annual ethanol refinery capacity should be 90 million litres, and will be powered by the biomass plant. Plant will also sell electricity to the grid. Ethanol production started in 2009. The by product, molasses/bagasse that could be used for the production of electricity is estimated to be enough to supply about 20 MW.

The known coal resource is mainly lignite and is estimated at 2 million tons. The high sulphur content and its quantity made recovery uneconomic.

Prospecting for oil is ongoing and there are indications of oil off shore. The estimated deposits would determine the viability of its exploration. No study has yet been conducted into the geothermal potential of Sierra Leone, and there are no current uses of this source in the country.

Average daily solar radiation is estimated at 4.15.2 kW·h/m². Existing capacity of solar PV is estimated to 25 kW.

The existing wind speed data indicates average speed of 35 m/s. In some areas, preliminary investigations suggested wind speeds of up to 12 m/s. The Ministry of Energy is encouraging studies of the potential sites. Currently wind is not used to produce electricity.

2.9.4. Energy sector

Total primary energy supply in 2008 was 2721 ktoe. The main energy forms used in Sierra Leone are biomass (75% in TPES) and hydrocarbon fuels (23%). The share of electricity is only 2%.

Fuel wood and charcoal are the main energy commodities used in households (mainly for cooking). About 40% of wood is used for charcoal production. The country is self-sufficient in terms of its biomass supply, but deforestation problems are increasingly visible.

The only oil refinery in Freetown (Sierra Leone Petroleum Refining Company Limited) has not been operational for a number of years. Therefore, all petroleum products are imported. In 2009 petroleum products import was about 1.8 million barrels.

2.9.4.1. Energy policy

The Ministry of Energy is responsible for the electricity and water management. Ministry is in charge of energy policy development, planning and coordination.

The Ministry of Agriculture and Food Security (MAFS) is responsible for biomass issues, especially use of fuel wood. Petroleum distribution and trade is handled by the Ministry of Trade and Industry (MTI). The Ministry of Finance (MF) controls import and storage of petroleum products. Presidential Petroleum Commission is responsible for oil exploration and extraction. The Ministry of Mineral Resources (MMR) deals with the extraction of minerals.

In 2004 the government conducted a study to formulate national energy policy. The study was funded by the United Nations Economic Commission for Africa (UNECA). Following an analysis of the existing situation, energy demand and supply assessment, a document entitled *The Energy Policy for Sierra Leone* was drafted. The main policy goal in electricity sector is to increase access to 35 % by 2015. No specific targets for renewables were considered. However, the following policy statements relate to the promotion of renewables:

- Organisation of institutions to deal with renewable energy;
- Consideration of different supporting schemes (e.g. tax reductions and subvention for imported renewable energy equipment);
- Promotion of in country manufacturing of renewable energy equipment (e.g. industrial investment programs);
- Development of a long term financing mechanisms for renewables;
- Standardisation of equipment to ensure level playing (technical performance) field among manufacturers and importers;
- Promotion of use of solar water heating systems in public buildings (e.g. hospitals and medical centres);
- Promotion of solar cookers in rural areas (e.g. remove fear to use barrier);
- Promotion and encouragement of energy service companies to facilitate the financing of renewables solutions;

In April 2010, the government started work on the National Energy Policy Implementation Strategy. This document should incorporate all plans and actions necessary for the fulfilment of goals defined in the National Energy Policy.

The main axes of the new energy sector strategy are: public and private investments, regional integration and restructuring/reforms of the sector. Institutional reforms are targeting to improve financial situation of the NPA. There are plans to reduce operational costs, adjust tariff system to take into account real generation costs, and increase collection rate.

Restructuring of the sector aims to separate generation, transmission, and distribution into different entities. A new generation company would run the existing generating assets and promote private generation projects (as independent power producers). The NPA would remain in charge of transmission, distribution, trade and supply.

There are plans to extend hydroelectric generation on the Seli River with a new facility at Yiben. Together with capacity increase at Bumbuna site, additional 200 MW of power would be available. Current peak load is estimated to 400 MW, but large part of customers are not connected to the distribution grid. In 2009 the electrification rate was 15%. Second Poverty Reduction Strategy from 2009-2011 states that the key development objective and tool to

fight poverty is to increase access to reliable power supply throughout the country, and promote low carbon intensive solutions (e.g. hydropower).

2.9.4.2. Regional Cooperation

Sierra Leone sees regional cooperation, political and economic integration as the main tools to manage and reduce sub regional volatility and limit the spread of instability across the borders. Sierra Leone is a member of the ECOWAS and the African Union. The NPA is member of the West African Power Pool (WAPP). Presently, the national electric system is not connected to other countries. An interconnection project Guinea – Sierra Leone – Liberia – Cote d'Ivoire is under consideration and would link four countries via a 225 kV transmission line.

Relatively high hydro potential in Sierra Leone (estimated at 1.2 GW) could be developed in cooperation with neighbouring systems. Through WAPP, national utilities will be able to balance for large seasonal variations in hydroelectric generation.

2.9.5. Electricity system

2.9.5.1. Generation

For years, national electricity supply is not enough to meet ever increasing demand. Electricity generation is based on expensive imported oil products. In the west, electricity is produced on two sites: Kingtom and Blackhall Road, oil fired thermal plants. In the Bo and Kenema regions, electricity supply is integrated with mining activities, from thermal plants and a hydropower plant.

There are three hydro power plants, but only two are in operation. In the western zone, the Guma plant (2.4 MW), was installed in 1967, but it is out of service since 1982. BKPS consortium operates a runof-river plant located in the eastern province and provides 6 MW. The plant is connected to a local grid linking thermal power plants in Bo and Kenema. The Bumbuna Falls plant was commissioned in 2009. It supplies 50 MW during wet season, and 18 MW during dry months. The plant supplies electricity to Freetown through a 161 kV line.

Majority of electricity demand (~90%) is concentrated in four largest cities: the capital city of Freetown consumes 82% of electricity, followed by Kenema and Bo (each 3%), and Makeni (2%). Although the completion of the Bumbuna hydro power plants in 2009 substantially increased generation, electricity demand in the range of 300-500 MW is still difficult to meet. Due to an increased power flows, the distribution networks cannot intake all of the domestic generation. High fuels costs, poor maintenance and financial problems of the NPA make situation worse.

Participation of the private investments into electricity business has been limited due to non existing legal and regulatory framework. Uncertainties for investors, for both, grid and off grid projects remain high and many procedures are unclear or missing. Administration bottlenecks increase costs of doing business (e.g. construction permits, property rights and registration). NPA tariffs for households are not enough to cover the production cost, and about 20% of electricity supplied is not billed or collected.

Current state of the electricity sector is a serious obstacle for the economic growth, especially in industry and service sectors (high generation and operation costs). Construction of the Bumbuna plant had positive effects as overall generation costs decreased, but high fuel prices (usually more expensive than in neighbouring countries) are still hurting normal operation of

the NPA. Due to a difficult situation the NPA is unable to attract private investments into electricity sector, and there is a two stage process to restructure it:

- NPA stays vertically integrated company, but private producers are allowed to enter market. Market will be regulated by an independent regulatory agency;
- NPA is restructured (unbundled) as a limited liability company.

Possible privatization of the NPA is considered, but it is not decided yet. The National Commission for Privatization took control over the NPA in November 2010.

2.9.5.2. Future Projects

In the recent years there have been several project proposals (from private investors) to improve electricity supply in the coming years:

- Addax Bio energy project
 - A project to grow sugar cane and produce ethanol and electricity. Final commissioning for the project was expected to take place in 2013. The African Development Bank (AfDB) co financed the Addax Bio energy project with €25 million in funding.
- In 2006 and 2007, several foreign investors approached the government with various project offers. Some of private investors signed Memorandum of Understanding (MoU) with the government, but until today none of the projects was realized:
 - ENERGEON Inc., USA, biomass plant of 100–500 MW capacity (feedstock like tree branches, agricultural residues, municipal solid waste);
 - Alternative Use PLC, Waste to Energy project;
 - NAANOVO Energy Inc – 5.0 MW solar PV;
 - Cinergex Solutions Ltd. – Biomass (Waste to Energy) project.

3. ELECTRICITY SYSTEM DEVELOPMENT

3.1. APPROACH AND METHODOLOGY

Understanding and assessing the future options of electricity supply at the lowest costs to the West African sub region¹³ was the main objective of this study. The study also examines the utilization of energy resources and investment needs and opportunities in the region, so that by 2030, the population has universal access to electricity.

The principal approach used in the study is scenario analysis supported by a mathematical model of the national and regional electricity systems. According to the Intergovernmental Panel on Climate Change , "Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future outcomes and to assess the associated uncertainties. Any scenario necessarily includes subjective elements and is open to various interpretations". A scenario is not a prediction of the one future to come but an internally consistent description of a future state or trajectory that is as comprehensive as needed for the purposes of the analysis.

A scenario approach was chosen because the future is inherently uncertain, and there is a need to analyse and understand the implications of different potential development paths, rather than to predict the future and/or irrevocably stick to solutions that are less robust and flexible and more sensitive to uncertainties.

The electricity supply analyses were carried out by applying IAEA's energy system assessment tool and modelling framework MESSAGE¹⁴. It is a flexible and tool specifically designed for complex energy system analyses including cogeneration or multiple input/multiple output technologies. For exogenously given energy/electricity demand and user defined constraints that reflect policy choices and assumption, the MESSAGE model provides the lowest cost energy supply and electricity system development strategies.

The time horizon covered by the study is from 2010 until 2030. Shorter planning periods are more appropriate under stable and well defined conditions (and for operational purposes), and that is not the case in fields such as energy system development, where large changes and possible discontinuities have to be taken into consideration. Energy/electricity technologies have lifetimes spanning from several years (e.g. end user equipment and PV systems) to several decades (e.g. power plants, transmission and distribution networks and dams). Many of the technologies that will enter into operation in the next decade will stay in operation well beyond the end of the planning horizon, while at the same time new and improved technologies will emerge and start competing for their market share. Equally important, the planning, preparation and construction lead times are substantial and some of the energy/electricity project decisions and implementations require 10-15 years before the project goes live (e.g. power plants, multi-purpose hydro projects, transmission lines and interconnections). The uncertainty of a long term availability of locally available energy resources may create a "lock-in" situation that, in the worst case, may turn these capacities into stranded assets at potentially considerable costs.

¹³ The focus is on West African countries without Cabo Verde.

¹⁴ Model for Energy Supply Strategy Alternatives and their General Environmental Impact.

3.2. ELECTRICITY DEMAND ANALYSIS

One of the objectives of regional renewable energy sources (RES) and energy efficiency (EE) policies is to reach universal access to modern energy services by 2030. In this study, the focus is on reaching electricity access and usage levels close to the targets of universal access. Therefore, two electricity demand scenarios were defined and analysed:

- The Reference scenario;
- The Universal access scenario.

3.2.1. Development assumptions

Electricity demand for the study was developed based on the expected/projected development of several influencing factors. The main factors influencing future energy/electricity demand are economic activities in the country (e.g. overall GDP level and its structure, development of certain energy intensive sectors), expected changes in population and lifestyle (e.g. urbanization, electrification, number of dwellings, fuel switching, changes in mobility) and technological development and choices (e.g. equipment and appliances improvements, new solutions, decrease in investment costs). There are also many interrelations between above mentioned factors.

Continued population growth over the planning horizon and the expansion of different service sectors are the key determinants of future electricity demand. Other drivers include general economic development and new construction due to an additional boost from the investments made into different industrial and tourism branches.

3.2.1.1. Population

According to the UN Population division data and forecasts [37], the total population in the West African sub region in 2010 stood at 300.8 million, representing less than 30% of the total African population.

Nigeria is the most populated country, with 158.4 million people in 2010, or almost 53% of the West African population. The smallest country is Cabo Verde (0.5 million), while in the continental part it is Guinea Bissau with 1.5 million inhabitants.

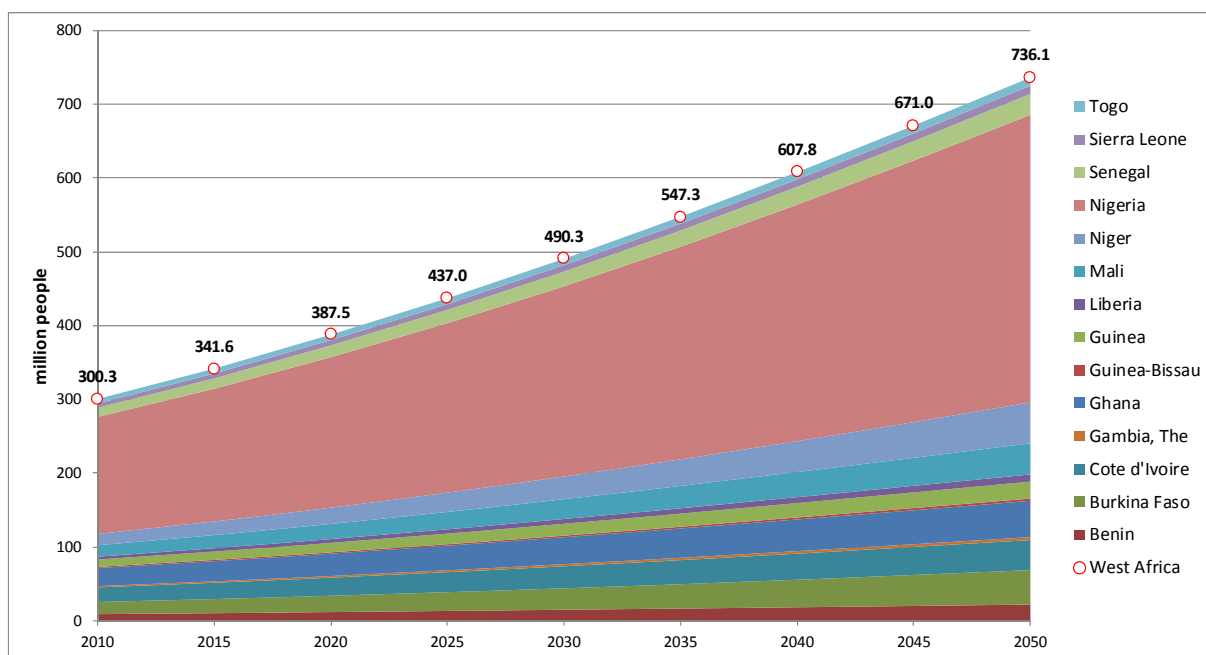


FIG. 10. Expected population in West Africa until 2050. (Data Source: [37])

By 2030 the total population is expected to increase to 490.9 million at an average annual rate of 2.48% (see Figure 10). Nigeria will still dominate with 52.5% of total region population living there. Shares of other countries are not expected to change significantly; with a higher population growth countries like Burkina Faso, Mali and Niger will slightly increasing their share, while the share of Ghana and Cote d'Ivoire will tend to decrease.

The overall increase is expected to continue also beyond 2030. By 2050, the West African population is expected to double and reach 736.8 million people or almost 34% of the total African population.

3.2.1.2. Urbanisation

The African continent has seen unprecedented changes over the past 60 years in terms of demographic development and urbanization. In 1950, less than 10% (i.e. only 6.8 million) of the West African population has lived in urban areas, while in 2010 the urban population represented 44.3% (i.e. 133.4 million) of the total population.

This trend is expected to continue in the future: by 2020 urban and rural areas will have approximately the same number of inhabitants; by 2030, 55.4% (i.e. 272.2 million) of people will live in large cities and urban areas, and by 2050 this share will further increase to 65.7% (i.e. 484.6 million), as illustrated by Figure 11.

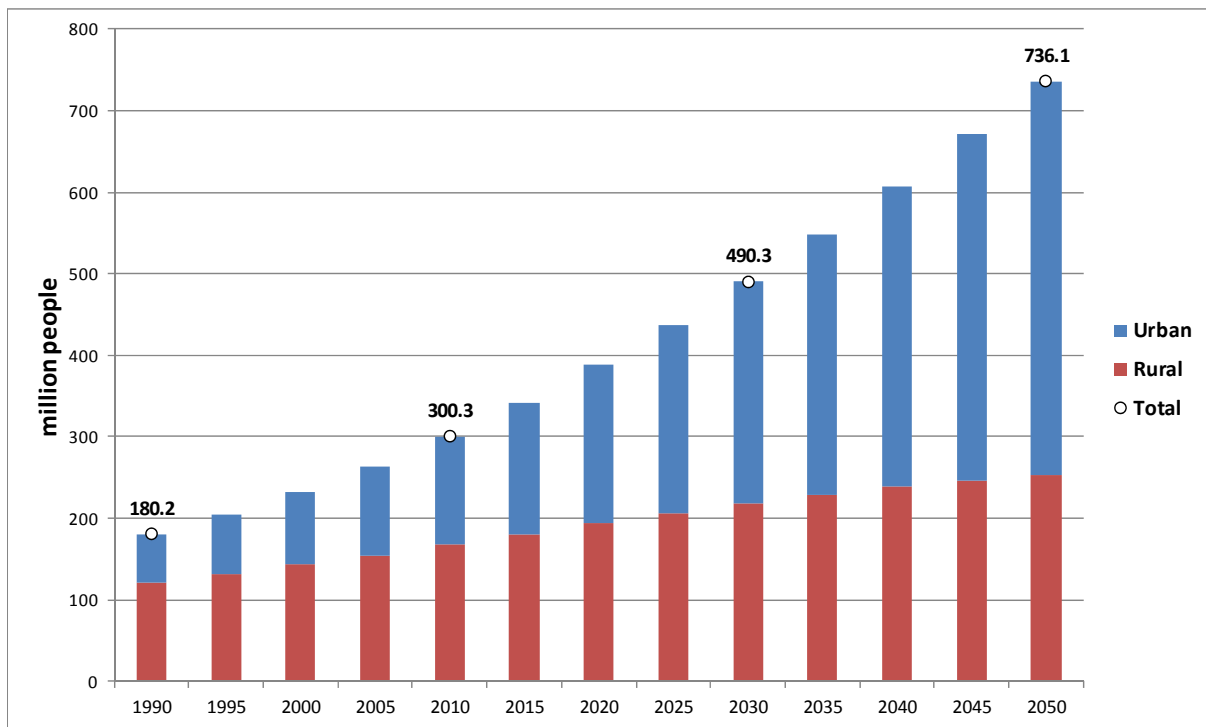


FIG. 11. Expected urbanization in West Africa until 2050. (Data Source: [37])

Changes in the lifestyle and increased concentration of the population in larger cities will have a big influence on energy use patterns and will foster a shift to other forms of energy and technological solutions, assuming that the supplying infrastructure will adequately support such shifts. This will put additional requirements on governments and decision makers to create and implement appropriate solutions to timely deliver affordable and sustainable energy services for the benefit of citizens and overall social and economic development. Energy can effectively support and drive the development of a country, but if needs and changes are not recognized and correctly estimated in time, some short lived solutions could produce additional development hurdles.

3.2.1.3. Gross domestic product

The economies of the West African countries are mainly relying on agricultural production, mining and oil, and exports consist of a limited range of agricultural commodities [38] and oil (Nigeria is the only net oil exporter in the region).

Reliance on internationally traded commodities leaves West African countries vulnerable to the external shocks of international market price fluctuations. Volatility of prices of imported oil products often coincide with exported commodity price shocks. There are very few manufactured goods exported to other markets. Trade between countries in the sub region remains marginal, about 10% of total trade. This fact reflects non complementarity of the national economies.

Regional development in the past has seen many ups and downs due to unstable political conditions. Economic growth in West Africa increased significantly during the 2000s (compared to the 1990s). Improvement in per capita growth rates is estimated at 2 percentage points. Part of this improvement, about 1.1 points, is attributable to changed structural policies, while 0.9 points is due to improved infrastructure. ICT revolution and infrastructure

played positive role. On the opposite side, lacking power infrastructure slowed the growth [39].

The main assumption of the present study is that in the next 20 years, the West African sub region will see a steady development of national economies, supported by regional cooperation and political stability. According to the World Bank development indicators [40], the total regional GDP in 2010 reached 134.8 billion USD₂₀₀₀. It is expected that by 2030, the regional GDP will more than triple to 425.6 billion USD₂₀₀₀, i.e. GDP should increase at average annual rate of 5.8%. GDP per capita is also expected to increase from 2010 level of 460 USD₂₀₀₀ to 870 USD₂₀₀₀ in 2030 as shown by Figure 12 and Figure 13.

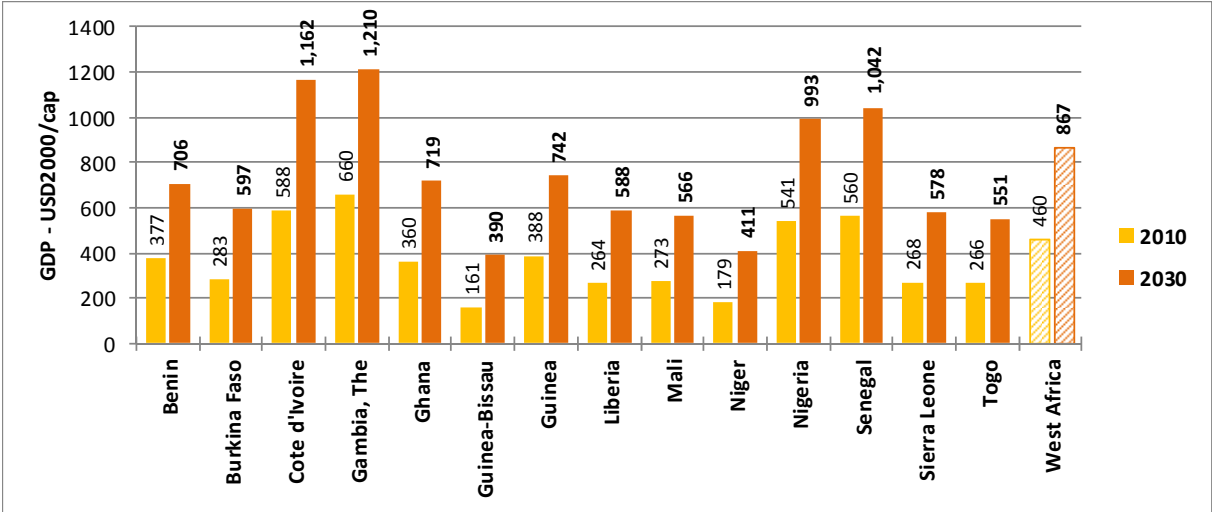


FIG. 12. Projected increase of GDP per capita for West Africa until 2030.

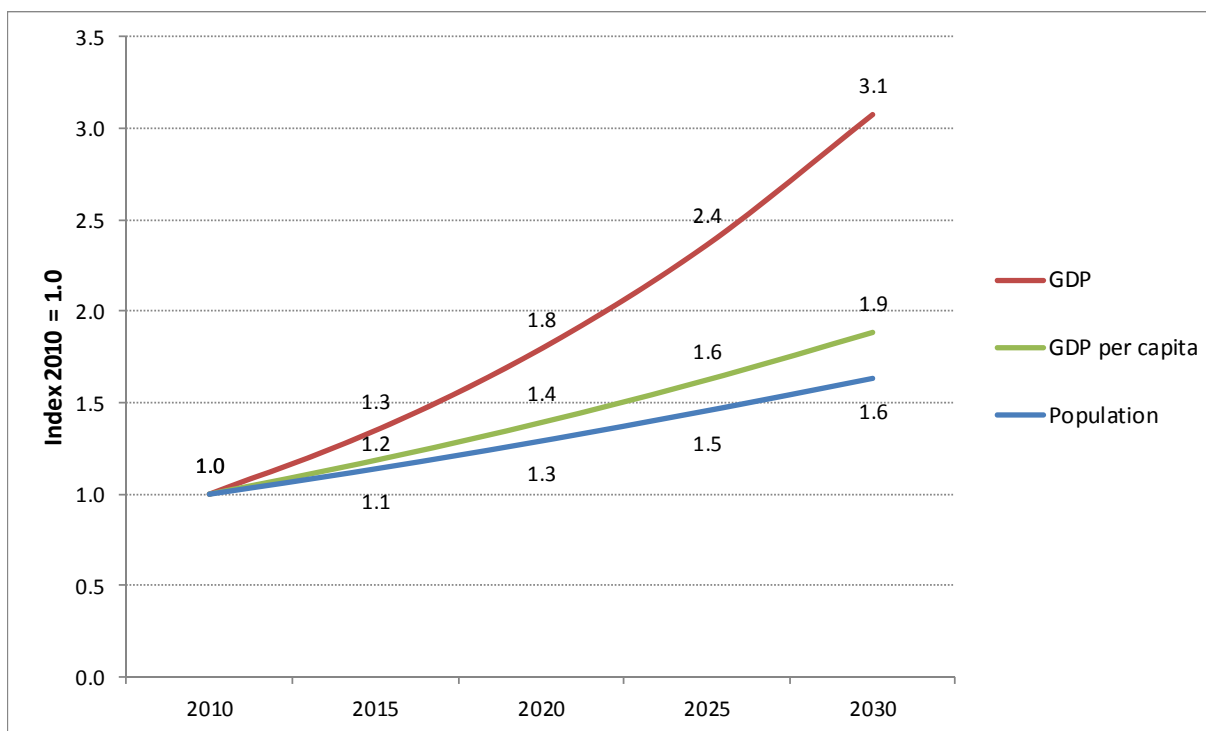


FIG. 13. Assumed population, GDP per capita and GDP trends in West Africa until 2030. (Data Source:[37])

3.2.2. Reference scenario

The reference demand scenario (Reference scenario) assumes development of the region in line with historical trends, primarily driven by population growth, higher urbanization levels and economic development as outlined above. The final electricity demand is expected to increase substantially over the next two decades as presented in Table 6 and Figure 14.

TABLE 6. FINAL ELECTRICITY DEMAND IN WEST AFRICA UNTIL 2030 ACCORDING TO Reference scenario.

TW·h	2010	2015	2020	2025	2030
Benin	0.870	1.328	2.014	3.036	4.548
Burkina Faso	0.773	1.224	1.935	3.036	4.733
Cabo Verde	0.267	0.386	0.556	0.800	1.142
Cote d'Ivoire	4.262	6.415	9.636	14.393	21.358
Gambia	0.214	0.326	0.494	0.741	1.103
Ghana	7.124	10.346	14.895	21.275	30.183
Guinea Bissau	0.062	0.097	0.150	0.232	0.359
Guinea	0.901	1.394	2.145	3.280	4.986
Liberia	0.312	0.495	0.781	1.224	1.909
Mali	0.951	1.533	2.458	3.914	6.200
Niger	0.833	1.426	2.441	4.155	7.026
Nigeria	20.876	32.951	51.965	81.465	127.116
Senegal	2.364	3.518	5.193	7.606	11.066
Sierra Leone	0.135	0.218	0.349	0.555	0.878
Togo	0.676	0.998	1.464	2.132	3.080
West Africa	40.6	62.7	96.5	147.8	225.7

Under the Reference scenario, sub regional electricity access by 2030 will reach 67%, but significant disparities between and within countries will remain. In many countries, a large part of the population will not have access to electricity (e.g. in several countries electricity access in 2030 will range between 42% and 60%), and rural areas will continue to rely on biomass.

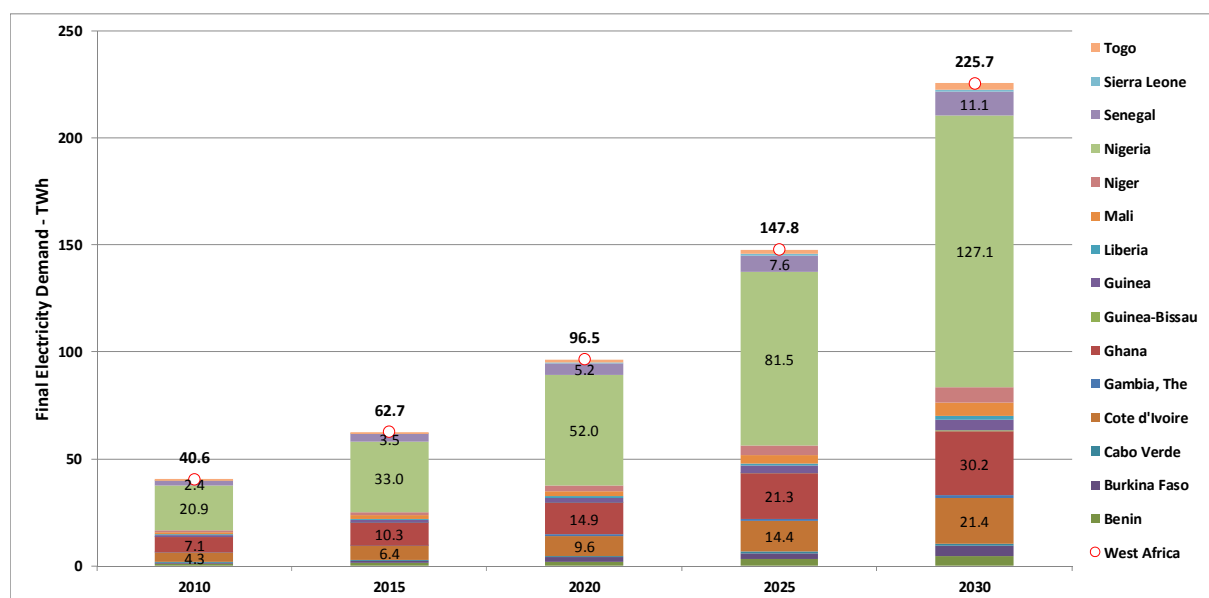


FIG. 14. Final electricity demand in West Africa until 2030 – Reference scenario.

The final electricity demand is expected to increase by more than five times between 2010 and 2030, i.e. it will increase from 40.6 TW·h to 225.7 TW·h or at average annual rate of 9% for the whole region. At country level, average annual rates of increase vary between 7.5%

and 11.3%. Higher increase rates are expected in countries with very low levels of current electricity consumption, like Niger, Burkina Faso, Mali, Sierra Leone, Liberia and Guinea Bissau. Electricity consumption in the largest system – Nigeria, is also expected to increase at a rate of 9.5%/yr, i.e. it will increase by more than six times during twenty years.

The average electricity to GDP elasticity is expected to be at 1.55, ranging from 1.33 for Ghana to 1.68 for Nigeria and Sierra Leone.

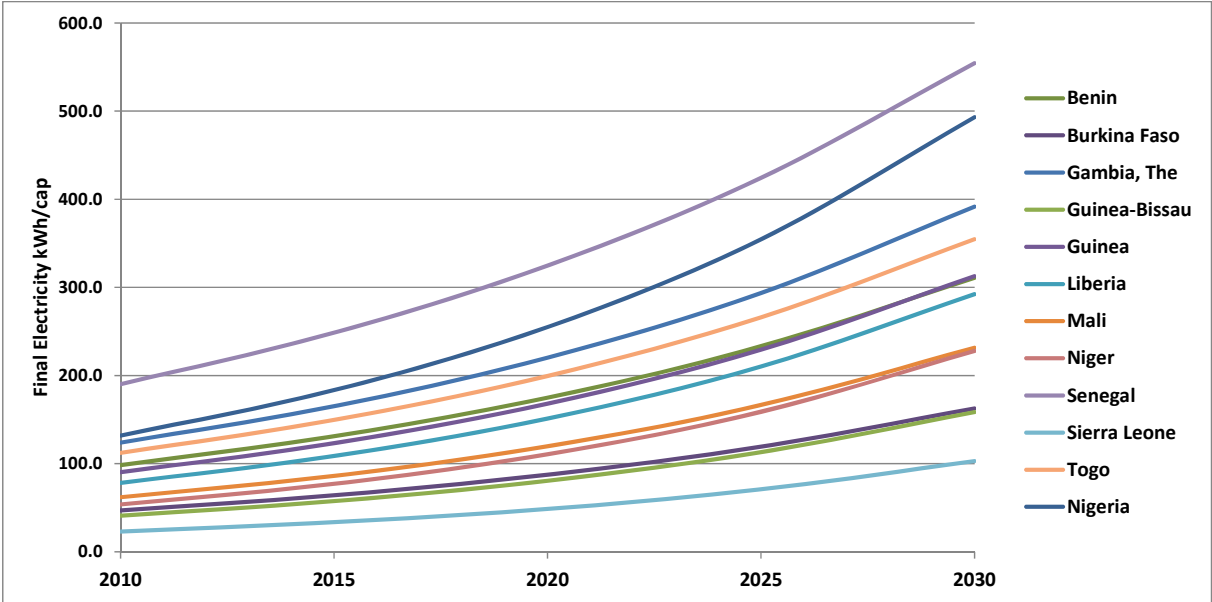


FIG. 15. Final electricity demand per capita in West Africa until 2030 – Reference scenario.

The specific final electric consumption per capita is expected to increase from 135 kW·h in 2010 to 460 kW·h in 2030, i.e. it will increase by factor of 3.4. Compared to some historical values, e.g. the increase in the period 1990-2010 by a factor of 1.2, it is visible that the next two decades will be much more dynamic and much more action at the supply side has to be taken to deliver sufficient electricity to the final users. Still, under the Reference scenario, the disparity in electricity use among countries remains high (see Figure 15 and Figure 16). Although more and more electrification projects will improve the situation in rural and peri-urban areas, the disparity in electricity access and use between cities and villages will remain.

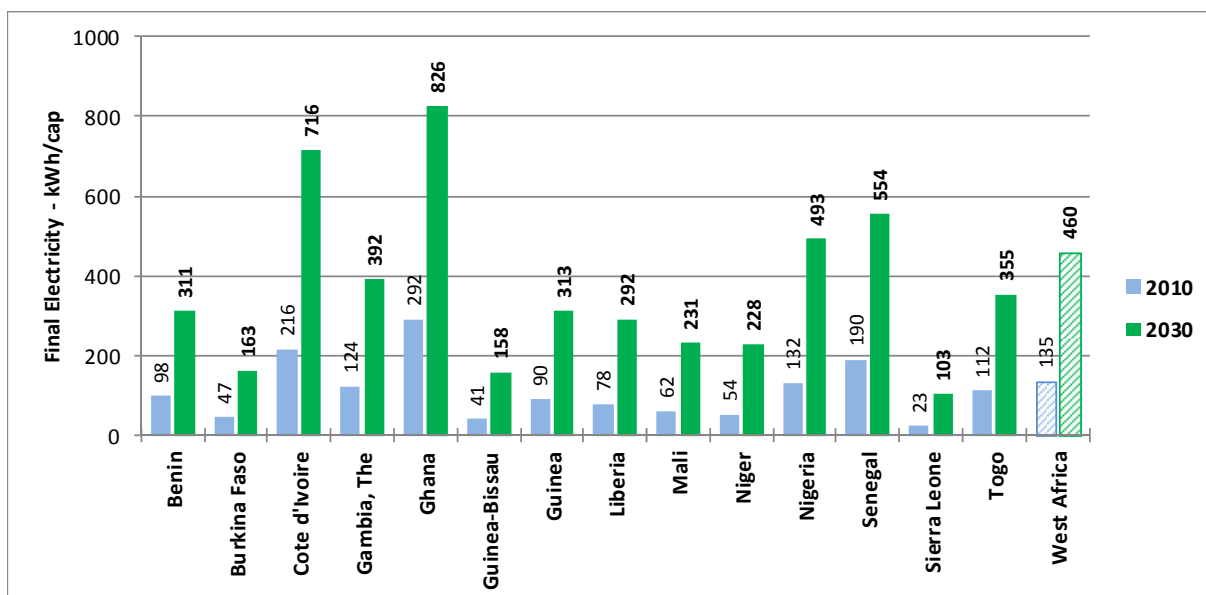


FIG. 16. Country by country comparison of final electricity demand per capita in West Africa in 2010 and 2030 – Reference scenario.

3.2.3. Universal access scenario

The universal electricity access scenario (Universal access scenario)¹⁵ assumes additional policy efforts and field actions to speed up the electrification programmes, both in urban and rural areas, so that by 2030/2035, practically all population in West Africa enjoys affordable, reliable and sustainable electricity supply. Universal access scenario seeks to bring electricity to all and reduce disparities within and among countries, bringing the whole sub region to a joint development path.

Reaching universal electricity access requires substantial policy and field actions. Electricity systems will have to develop more rapidly so that the current deficiencies in electricity supply are eliminated. Increased access to electricity by households will be an additional driver for the development of some services and smaller industries, leading to further economic development¹⁶. These policy actions will result in an increase of overall electricity use as presented in Table 7 and Figure 17.

¹⁵ Universal Access for different countries in the study is considered as achieved if more than 90% of the population has access to electricity.

¹⁶ For the time being and in this analysis, positive effects of additional economic activities were not assessed and a conservative approach was taken, so that the same GDP levels were used to project demand under the Universal access scenario.

TABLE 7. FINAL ELECTRICITY DEMAND IN WEST AFRICA UNTIL 2030 ACCORDING TO Universal access scenario.

TW·h	2010	2015	2020	2025	2030
Benin	0.870	1.481	2.507	4.216	7.046
Burkina Faso	0.773	1.570	3.184	6.409	12.818
Cabo Verde	0.267	0.386	0.556	0.800	1.142
Cote d'Ivoire	4.262	6.611	10.235	15.756	24.095
Gambia	0.214	0.346	0.555	0.884	1.396
Ghana	7.124	10.884	16.484	24.769	36.966
Guinea Bissau	0.062	0.124	0.248	0.494	0.980
Guinea	0.901	1.549	2.651	4.507	7.616
Liberia	0.312	0.557	0.988	1.744	3.062
Mali	0.951	1.819	3.460	6.539	12.288
Niger	0.833	1.690	3.428	6.914	13.856
Nigeria	20.876	33.505	53.729	85.648	135.893
Senegal	2.364	3.590	5.409	8.084	12.003
Sierra Leone	0.135	0.397	0.840	1.750	3.600
Togo	0.676	1.082	1.719	2.712	4.245
West Africa	40.6	65.6	106.0	171.2	277.0

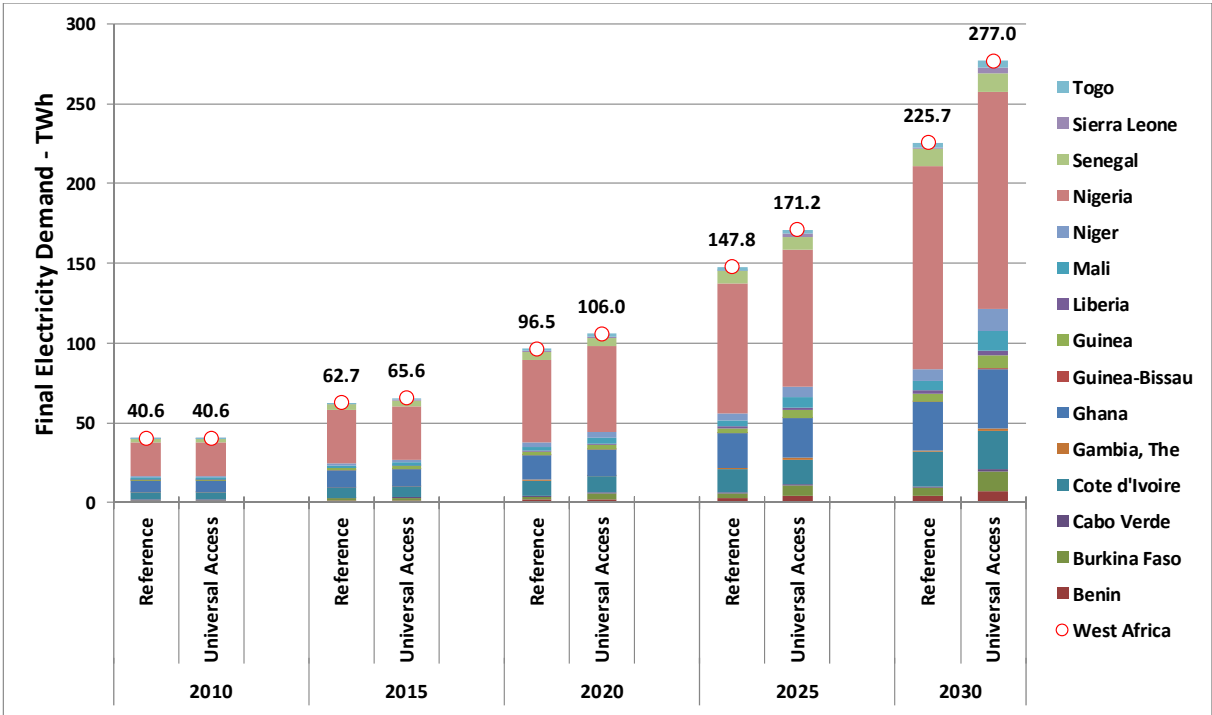


FIG. 17. Comparison of final electricity demand in West Africa for Reference scenario and Universal access scenario.

Although additional policy efforts should already be noticeable by 2015 (i.e. an increase in overall final electricity consumption by 4.7% compared to the Reference scenario), changes should become clearly visible after 2020 as presented by Figure 17. In 2020, the overall

demand in Universal access scenario should be 15.8% higher compared to the Reference scenario, while for 2030, the increase should reach 22.7%.

In terms of electricity demand per capita (see Figure 18), the Universal access scenario seeks to equalize disparity among countries and bring countries (especially the least developed countries) to a common development path. This can be achieved only by a full integration of the sub region and the development and implementation of energy and electricity strategies on regional level.

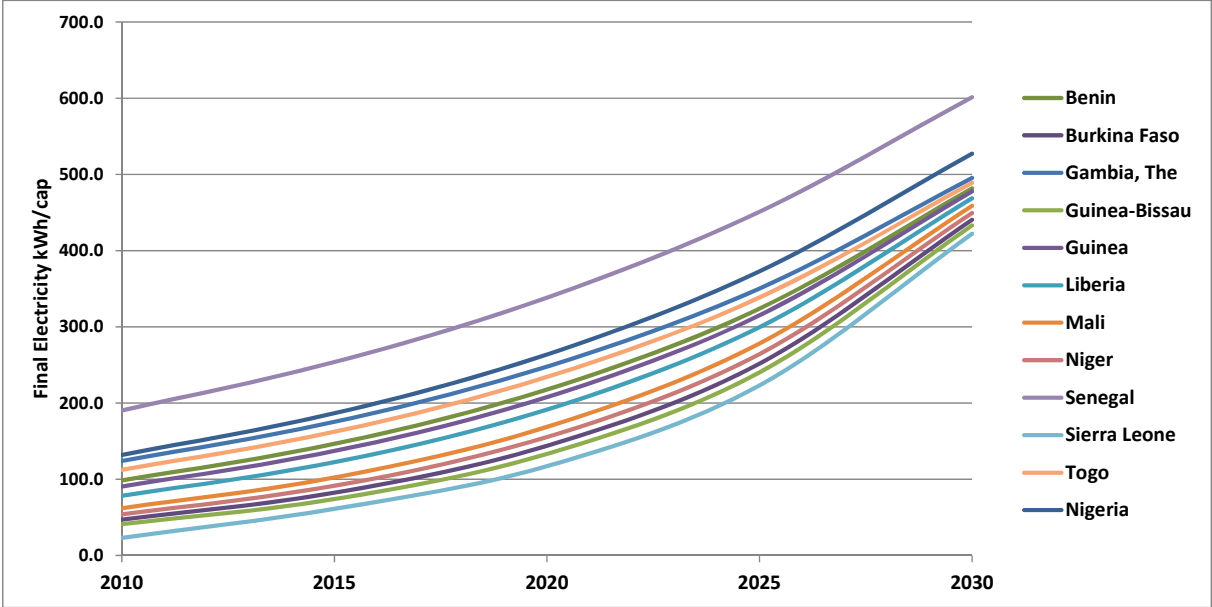


FIG. 18. Final electricity demand per capita in West Africa until 2030 and decreasing disparity under the Universal access scenario.

Expected changes in electricity access between the Reference scenario and the Universal access scenario are presented by Figure 19. Under the Reference scenario, overall regional electricity access is expected to increase from the current level of 38% to about 67% by 2030. If the objectives of Universal access scenario demand scenarios are met, this rate could reach around 93%, i.e. be close to the objective of the universal electricity access. Some countries will most probably reach the universal access target even under the Reference scenario – e.g. Ghana and Cote d'Ivoire.

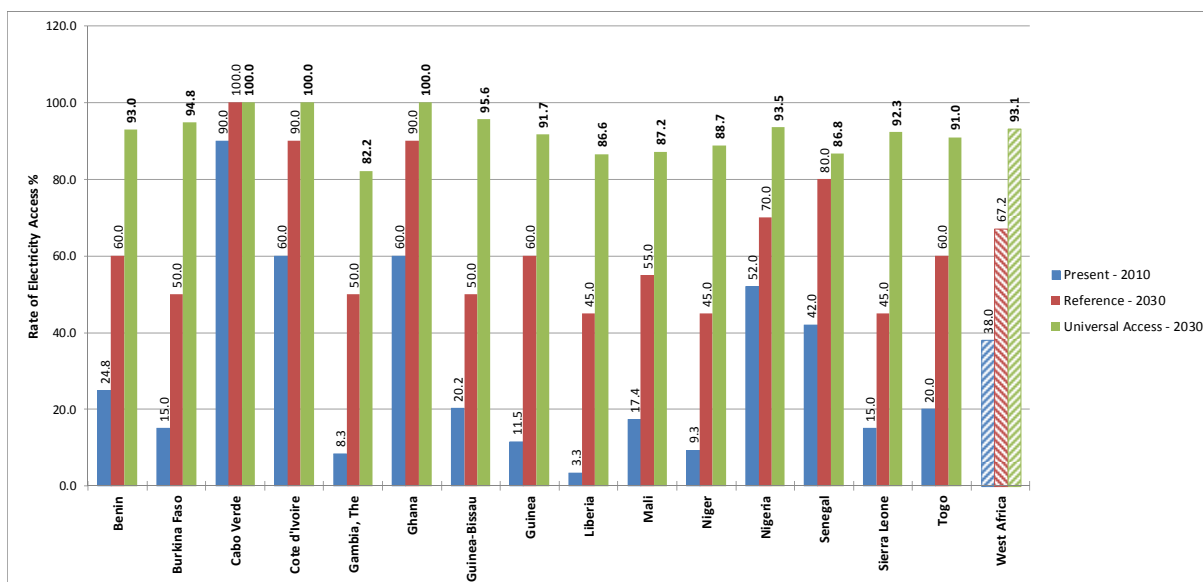


FIG. 19. Comparison of expected electricity access rates between Reference scenario and Universal access scenario by 2030.

It is evident from the above analysis that reaching universal electricity access requires substantial policy and field actions. Electricity systems will have to develop at a much faster rate, so that the current deficiencies in electricity supply are eliminated.

3.3. ELECTRICITY SUPPLY OPTIONS AND STRATEGIES

3.3.1. Electricity generation options

3.3.1.1. Coal

Local coal reserves for electricity generation are available in Nigeria and Niger. Coal import is possible for all countries with the direct sea access. For other countries, it was assumed that coal transportation infrastructure (e.g. trains) would be too expensive to develop. Therefore for those countries coal is not an option for future electricity generation.

3.3.1.2. Natural gas

Natural gas is locally available in Nigeria, Cote d'Ivoire and Ghana (without extracting domestic gas) and is already used for electricity generation. Nigerian gas is also exported through the West African Gas Pipeline to Ghana, Togo and Benin, and Cote d'Ivoire plans to connect to the pipeline. The operation of the pipeline was compromised by several technical issues and breakdowns which are expected to be rectified in the future. Senegal has some natural gas reserves, but plans to import gas from Mauritania from 2016 onwards. LNG import is possible in all coastal countries.

3.3.1.3. Oil

Although oil product prices are high and the conversion efficiency of oil based generation relatively low, it is expected that oil will remain an important option for electricity supply, at least until the point when the major regionally relevant projects (i.e. hydro, interconnections) are to be completed. Traditionally, heavy fuel oil (HFO), diesel (DDO), and light crude oil are used for electricity generation. The price difference between coastal and inland countries was taken into account (i.e. oil transportation cost to the inland areas).

3.3.1.4. Nuclear

Several West African countries expressed interest to explore the possible role and contribution of nuclear power to national electricity generation (e.g. Senegal, Ghana, Nigeria and Niger). These projects could also have a regional dimension. The study assumes that nuclear power projects in the region are possible at earliest beyond 2025/2030, due to the long lead times related to the development of the appropriate infrastructure.

3.3.1.5. Hydro

Only about 17% of the large hydro potential in the region is currently used. An additional generation capacity of up to 81 TW·h (or 18.7 GW) is identified across the region as presented in Table 8. The largest potential exists in Nigeria (43.7 TW·h or more than half of the total large hydro potential) and in Guinea (14.3 TW·h). Ghana is already using about 60% of the total potential.

TABLE 8. LARGE HYDRO POTENTIAL AVAILABLE FOR DEVELOPMENT (DATA SOURCE: [41])

Country	Projected power MW	Average generation GW·h	Dry year generation GW·h
Burkina Faso	60	192	146
Cote d'Ivoire	1072	4953	2916
Gambia	68	241	92
Ghana	661	2330	1010
Guinea	3346	14296	10974
Guinea Bissau	14	48	18
Liberia	967	4763	3633
Mali	434	2003	1342
Niger	279	1269	486
Nigeria	10142	43710	33220
Senegal	530	1988	1100
Sierra Leone	755	4168	3468
Togo/Benin	357	1004	722
West Africa	18685	80965	59127

Many small scale hydro locations have been identified (Source: WAPP) with the total expected output power of 5.9 GW. The largest part of this potential is located in Nigeria (estimated 3500 MW) and Liberia (1000 MW). Small hydro is assumed to supply rural demand.

3.3.1.6. Solar

The huge potential for solar energy, both CSP and PV, in West Africa is evident. The estimated annual electricity generation from CSP is 280 TW·h, and from PV an additional 1038 TW·h. Maps with solar DNI (Direct Normal Irradiance; relevant for estimation of CSP projects) and solar GHI (Global Horizontal Irradiance; relevant for estimation of PV projects) are given in Figure 20 and Figure 21, respectively.

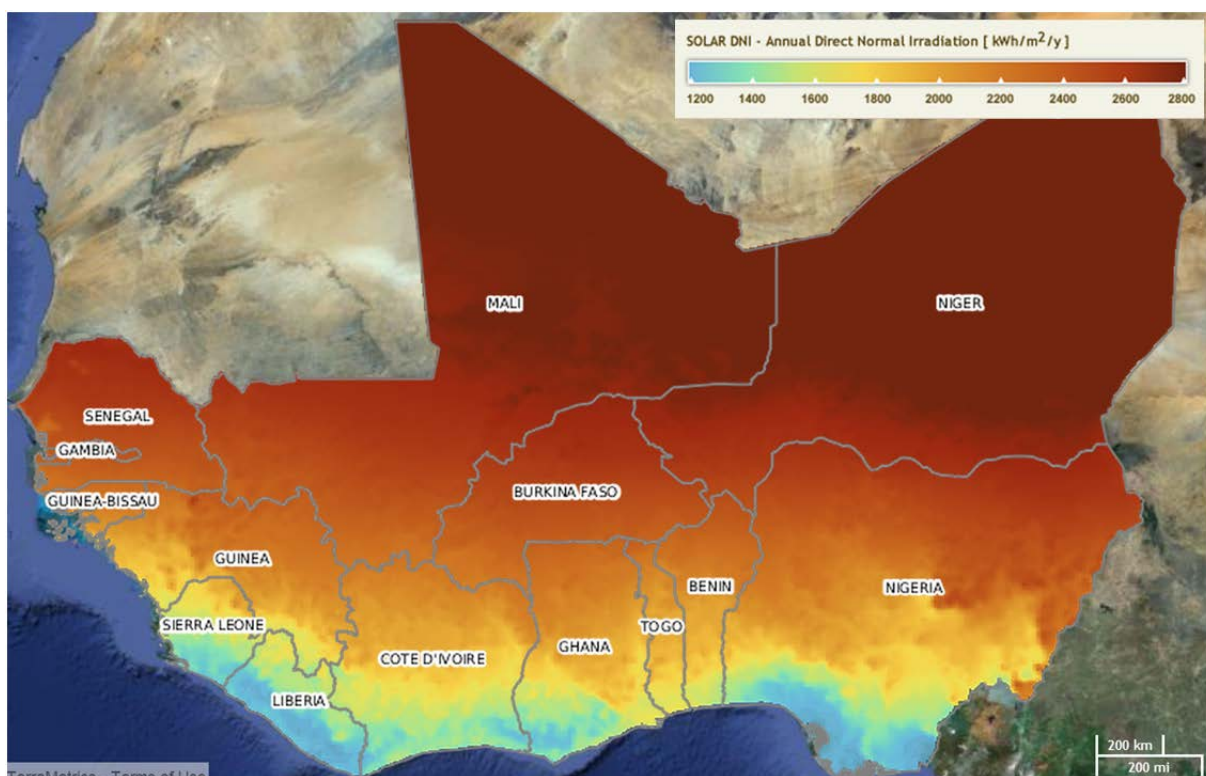


FIG. 20. Solar potential in West Africa – annual direct normal irradiation. (Reproduced courtesy of ECREEE ECOWREX [42])

Most of the prosperous locations for CSP projects are found in Nigeria, Niger and Mali (together 80% of the estimated CSP potential). For CSP, two options were considered:

- Solar CSP without storage – medium to large scale CSP projects connected upstream of transmission and supplying electricity only during the day;
- Solar CSP with storage – medium to large scale CSP projects with thermal storage and being able to supply electricity during the day and in the evening.

The potential of PV technologies is more evenly spread across the region (compared to CSP), with the most promising locations in Nigeria, Niger, Cote d'Ivoire, Burkina Faso, Senegal and Ghana.

The following types of PV installations were considered:

- Utility size PVs or PV fields managed by the utility and connected upstream of transmission. Solar PV installations were assumed to produce electricity during the day (no storage option);
- Distributed or rooftop solar PV – to supply either urban residential, commercial and small industries, or rural residential and commercial. Solar PV installations were assumed to produce electricity during the day (no storage option);
- Distributed or rooftop solar PV with battery for extended use beyond daylight hours (1 2 additional hours).

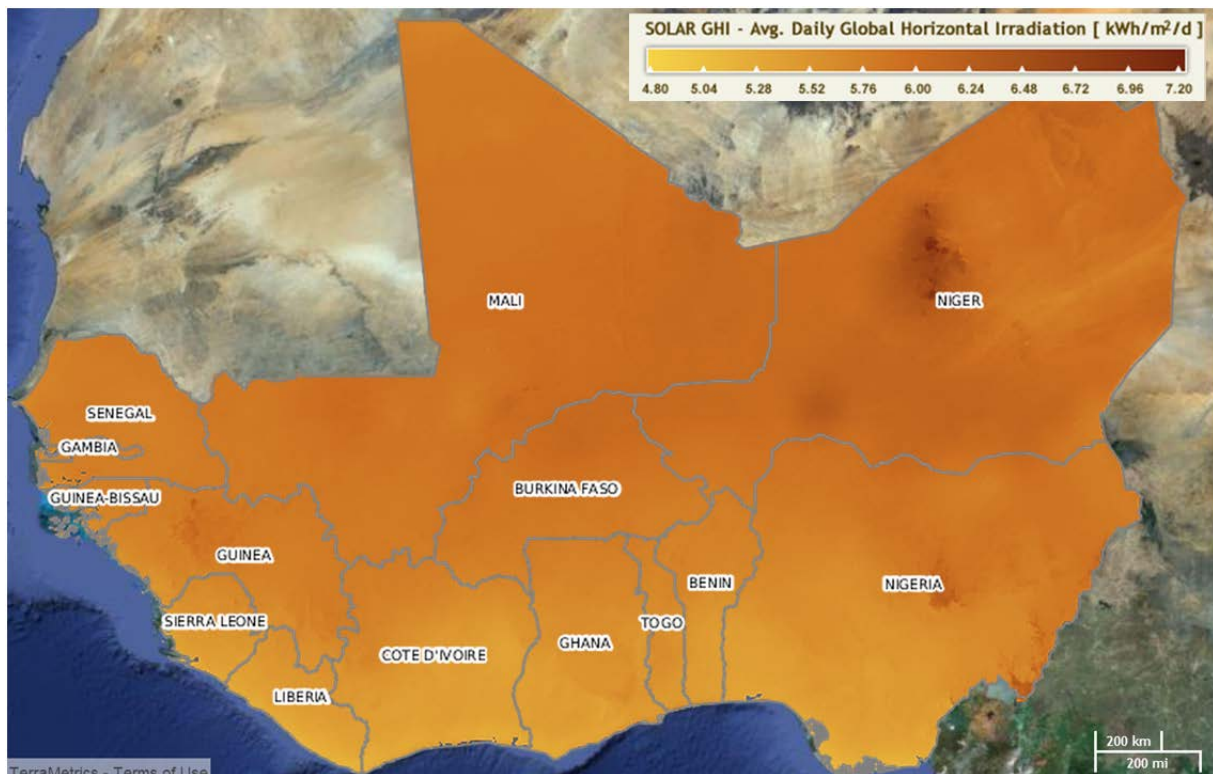


FIG. 21. Solar potential in West Africa – average daily global horizontal irradiation. (Reproduced courtesy of ECREEE ECOWREX [42])

3.3.1.7. Wind

Wind potential in the region is substantial as indicated in Table 9 and by Figure 22. The possible total wind capacity is estimated to 53.8 GW with an average annual production of 93.4 TW·h. Almost 90% of this potential is estimated to be in locations with a power factor of only ~20% (equivalent to ~1750 hours production at full capacity). The remaining locations were estimated to have a power factor of 30% (i.e. ~2700 hours production at full capacity). Only on shore locations were considered.

TABLE 9. ASSUMED UPPER LIMIT ON WIND POTENTIAL IN WEST AFRICA.
(DATA SOURCE: [41])

Area	Wind 25%, MW	Wind 30%, MW
Burkina	4742	29
Cote d'Ivoire	491	0
Gambia	197	5
Ghana	691	9
Guinea	2	0
Guinea Bissau	142	0
Mali	2195	0
Niger	16699	5015
Nigeria	14689	363
Senegal	6226	1243
Togo/Benin	552	0
Total	46627	6663
Liberia and Sierra Leone – no relevant wind potential		

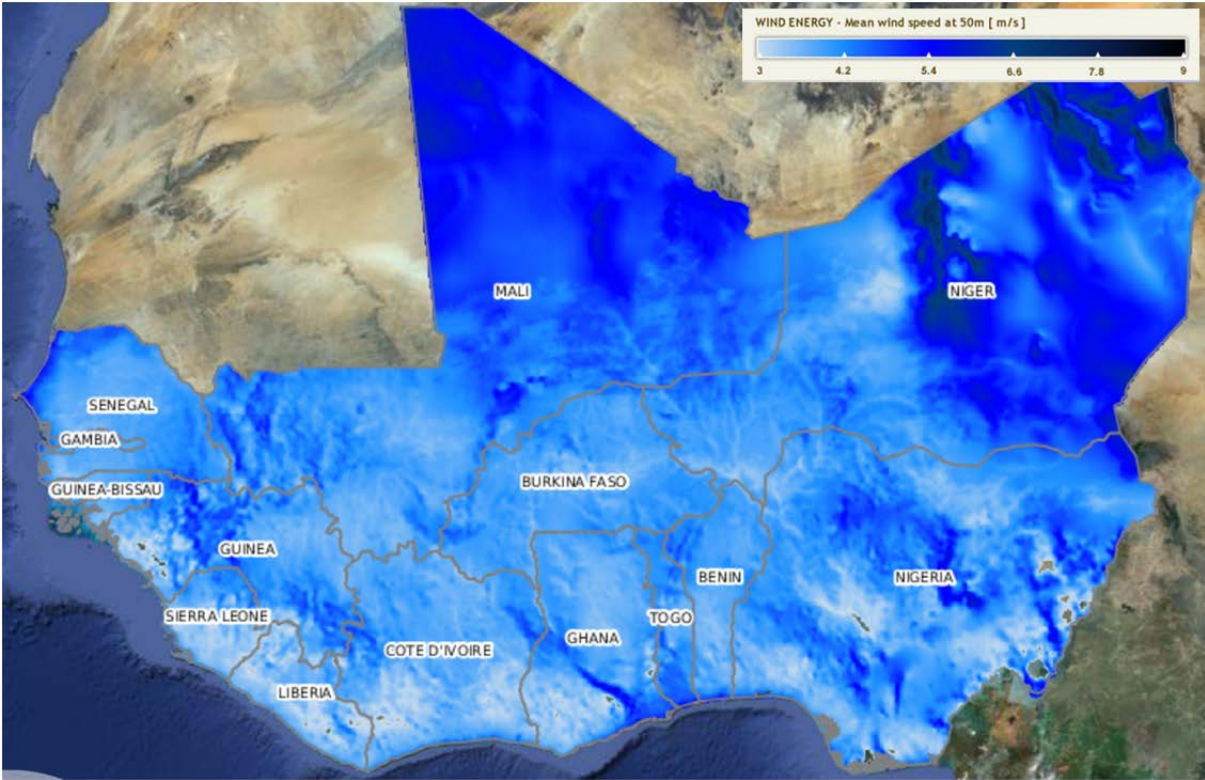


FIG. 22. Wind potential in West Africa – mean wind speed at 50 m. (Reproduced courtesy of ECREEE ECOWREX [42])

3.3.1.8. Biomass

Biomass was considered for electricity generation, but mainly in the form of industrial cogeneration (i.e. consumed on the site and exporting surpluses to the system). The total possible installed capacity was estimated to 7100 MW. Most of the potential exists in Nigeria

(2000 MW), Cote d'Ivoire (1350 MW) and Ghana (1000 MW). The technical potential is much higher, but there are no reliable data on the expected biomass cost. The biomass resource in the three inland countries (Mali, Burkina Faso and Niger) is assumed to be scarce, which is reflected in a higher price.

3.3.2. Interconnections

Existing interconnection lines in the WAPP are given in Table 10 and presented by Figure 23.

TABLE 10. EXISTING INTERCONNECTION LINES IN WEST AFRICA. (DATA SOURCE: [41])

Interconnection Line	Line capacity, MW
Ghana - Cote d'Ivoire	327
Ghana - Togo/Benin	310
Senegal - Mali	100
Cote d'Ivoire - Burkina	327
Nigeria - Togo/Benin	686
Nigeria - Niger	169
Ghana - Cote d'Ivoire	327

Current electricity trade is limited by the underdeveloped interconnecting infrastructure. The major energy exporters are respectively Nigeria, Ghana and Côte d'Ivoire, while major importers are Benin and Togo (almost half of the total imported volume of electricity in 2010 goes to these two countries). Other important importers are Mali, Niger and Burkina Faso. Senegal, Ghana and Cote d'Ivoire import minor quantities (Ghana and Cote d'Ivoire remain net electricity exporters).



FIG. 23. Transmission lines and gas pipeline in West Africa. (Reproduced courtesy of ECREEE ECOWREX [42])

The priority projects adopted by ECOWAS and being implemented by WAPP are [41]:

- Coastal interconnected system (Côte d'Ivoire, Ghana, Benin/Togo, Nigeria);
- Inter zonal Transmission Hub Subprogram (Burkina Faso, OMVS via Mali, Mali via Côte d'Ivoire, LSG via Côte d'Ivoire);
- North core Transmission Subprogram (Nigeria, Niger, Burkina Faso, Benin);
- OMVG/OMVS Power System Development Subprogram (The Gambia, Guinea, Guinea Bissau, Mali, Senegal);
- Côte d'Ivoire Liberia Sierra Leone Guinea Power System Re-development Subprogram (Côte d'Ivoire, Liberia, Sierra Leone, Guinea);
- WAPP Strategic Generation Subprogram (Emergency Power Supply Security Plan).

Above projects are illustrated by Figure 24.

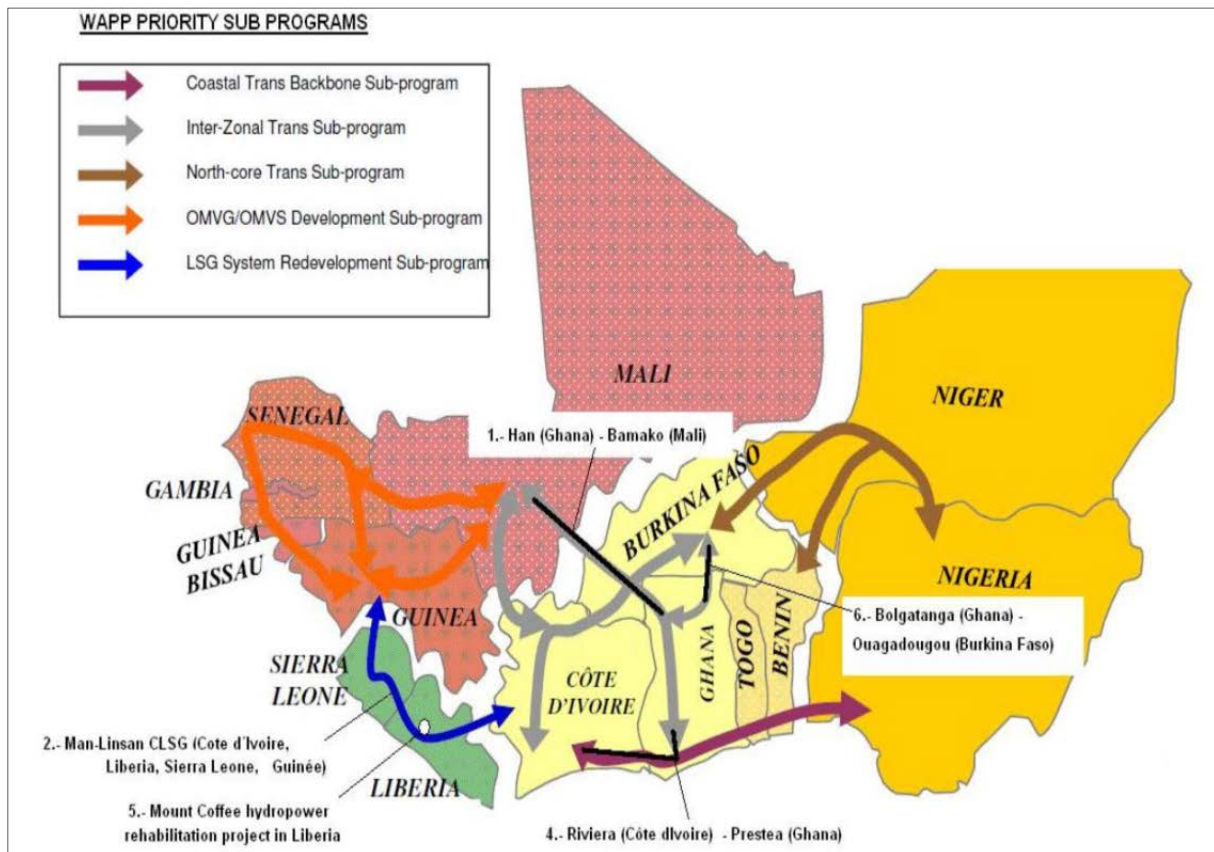


FIG. 24. ECOWAS/WAPP priority projects adopted for implementation. (Reproduced courtesy of ECOWAS/WAPP [41])

3.3.3. Modelling assumptions

The following assumptions were made for all electricity supply scenarios:

- The simulation and optimization model runs until 2050, while results are reported from 2010 until 2035;
- The monetary unit is USD₂₀₁₀;
- The discount rate is 10%;
- Seasonal and daily changes (e.g. hydro and solar availability, electricity demand patterns, etc.) were taken into account by dividing the year into three seasons. Each season has one day type which is divided into three or four parts, to take into account demand and other changes between night, day and peak times;
- Each national power system was modelled, including interconnections between them¹⁷.

3.3.3.1. Fuel prices

One scenario for the development of fuel prices was used in all cases. Fuel prices are presented in Table 11 and Figure 25.

¹⁷ Except the electricity systems of Benin and Togo, which were modeled together, as these countries are developing their systems through a single company (CEB).

TABLE 11. ASSUMED FUEL PRICES FOR ELECTRICITY GENERATION UNTIL 2030

Fuel prices in USD₂₀₁₀/GJ				
Fuel type	2010	2015	2020	2030
Diesel	22.0	24.2	26.4	29.7
Diesel inland	25.2	27.7	30.2	34.1
Heavy Fuel oil	12.9	14.2	15.5	17.4
Heavy Fuel Oil inland	16.3	17.9	19.5	22.0
Coal domestic	3.0	3.1	3.2	3.4
Coal import	4.6	4.6	5.0	5.3
Gas	8.5	9.0	9.5	11.0
Gas import	10.3	10.9	11.6	13.5
Biomass	1.5	1.5	1.5	1.5
Biomass scarce	3.6	3.6	3.6	3.6
Nuclear	1.0	1.0	1.0	1.0

Base year (i.e. 2010) fossil fuel prices are as in the WAPP Master Plan from 2011. Prices of oil products (diesel and heavy fuel oil), natural gas and coal were derived from an assumption of the OPEC oil price being USD 100/barrel. It was assumed that future prices of oil products will increase by 35% by 2030. Natural gas prices were assumed to escalate by 30% by 2030 (relative to 2010). The domestic coal in Niger and Nigeria was set at a lower price compared to the price in coastal countries. The domestic coal price was based on a study from 2004 [43]. For biomass two groups of countries were considered: biomass resources in the three landlocked countries (Mali, Burkina Faso and Niger) were assumed to be scarce and the price is therefore higher.

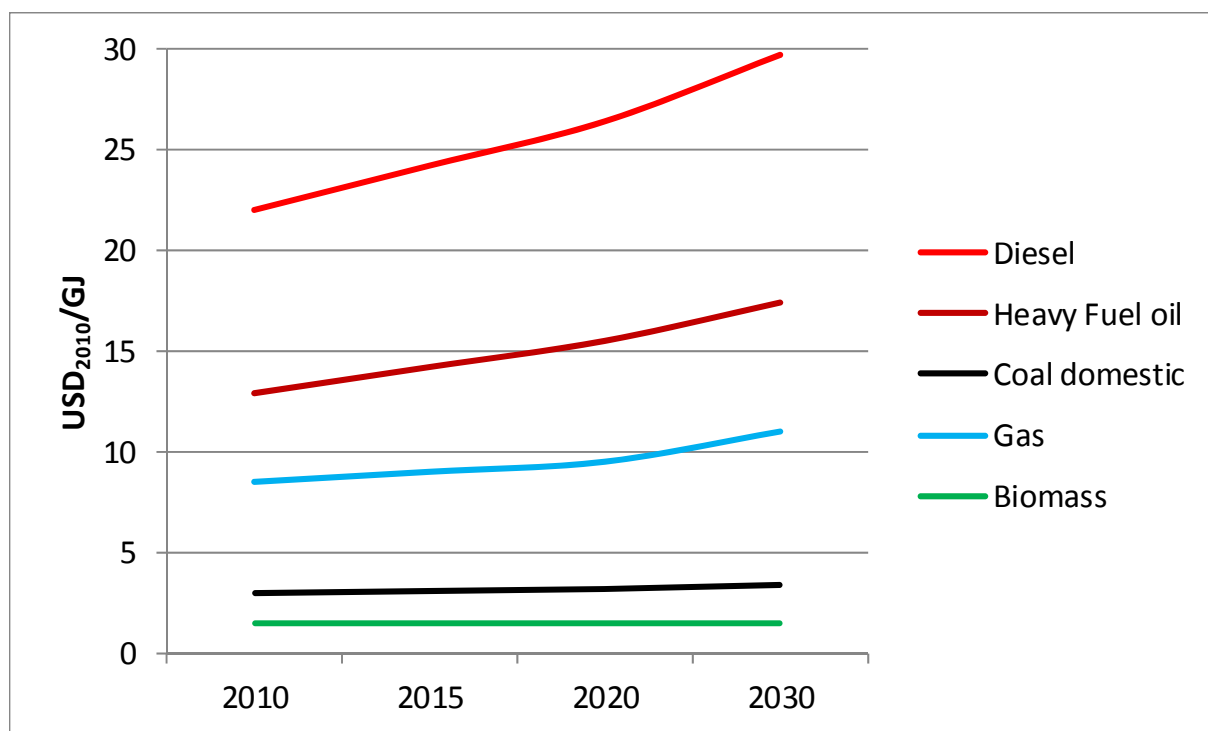


FIG. 25. Assumed fuel prices for electricity generation until 2030.

3.3.3.2. Candidate power plants

In the simulation/optimization model, demand is first met by existing plants and committed projects. The remainder of the demand is then met by site specific projects and/or generic power generation technologies. Certain technologies are assumed to provide electricity via the grid (i.e. centralized), while others are assumed to provide on-site electricity (i.e. decentralized or distributed). Main techno-economic characteristics of candidate power plants are presented in Table 12.

TABLE 12. CANDIDATE POWER PLANTS

Technology	Overnight cost USD₂₀₁₀/kW	O&M cost USD₂₀₁₀/ MW·h	Efficiency %	Load factor %	Life year
Diesel Centralized	1070	17.0	35%	80%	25
Diesel 100 kW system (industry)	659	55.4	35%	80%	20
Diesel/Gasoline 1 kW system (residential/commercial)	692	33.2	16%	30%	10
HFO	1350	15.0	35%	80%	25
OCGT	603	19.9	30%	85%	25
CCGT	1069	2.9	48%	85%	30
CCGT Associated Gas	1069	2.9	48%	85%	30
Supercritical coal	2403	14.3	37%	85%	30
Supercritical Domestic Coal	2403	14.3	37%	85%	30
Nuclear	5028	13.9	33	0.84	40
Hydro	2000	6.0	100%	50%	50
Small Hydro	4000	5.4	100%	50%	30
Biomass	3240	20.0	38%	50%	30
Bulk Wind (20% CF)	2000	17.4		20%	25
Bulk Wind (30% CF)	2000	14.3		30%	25
Solar PV (utility)	2000	20.1		25%	25
Solar PV (roof top)	2100	23.8		20%	20
Rooftop PV with 1h Battery	4258	19.0		23%	20
Rooftop PV with 2h Battery	6275	17.1		25%	20
Solar thermal no storage	3000	22.3		35%	25
Solar thermal with Storage	5400	18.9		50%	25
Solar thermal with gas co firing	2200	18.9	53%	85%	25

These costs are based on estimates of some projects underway or being considered in different countries in the region. For renewable energy, technological learning was assumed, resulting in the specific investment cost reductions as presented by Figure 26.

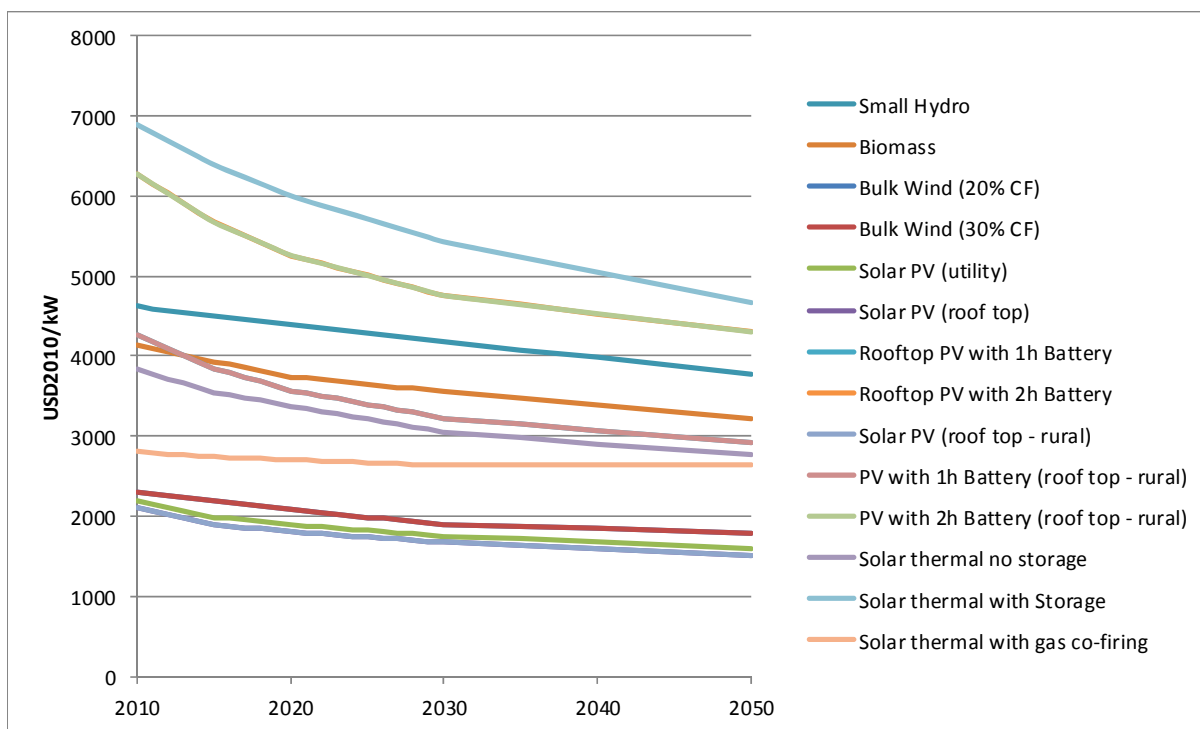


FIG. 26. Assumed technological learning for renewable technologies.

3.3.4. Electricity supply scenarios

Two main criteria were used to define three electricity supply scenarios that would meet the demand defined in the underlying electricity demand scenarios:

- The expected development of electricity demand;
- The level of sub regional cooperation.

In all three electricity supply scenarios, all technological options were considered in line with the availability of resources in each country. The existing efforts of each country concerning the supply options were also taken into account to define the earliest possible year of operation for some technologies (e.g. the availability of gas and the development of nuclear infrastructure).

The first two (Business as usual and Cooperation) are based on the Reference scenario demand scenario; the third, SE4ALL, is based on the Universal access scenario demand scenario.

Table 13 presents the assumptions and characteristics of the three supply scenarios.

TABLE 13. ELECTRICITY SUPPLY SCENARIOS

Electricity Supply Scenario	Business as usual (BaU)	Cooperation	SE4ALL
Underlying Demand Scenario	Reference scenario	Reference scenario	Universal access scenario
Characteristics of Electricity Supply	Continuation of high dependence on fossil fuels Free competition among all supply technologies	Free competition among all supply technologies	More emphasis on renewables Free competition among all supply technologies
Level of cooperation	Interconnections	Interconnections	Interconnections and cooperation

These three scenarios for meeting the electricity demand, Business as usual, Cooperation and SE4ALL, have the following detailed features:

3.3.4.1. Business as usual scenario

- Electricity consumption is in line with the demand scenario Reference scenario. Under this demand scenario overall electricity access should reach 67% by 2030, but disparities between countries will remain. Many countries will still have a large part of population left without access to electricity: electricity access will range from 42% and 60% for many countries, while only the most advanced like Ghana, Cote d'Ivoire and Senegal will have more than 80%.
- On the supply side, a continuation of the high dependence on fossil fuels and free competition among available technologies was assumed.
- From the point of view of sub regional cooperation, this scenario assumes that the current level of interconnection will remain stable, which directly limits potential benefits of joint utilization of the large electricity supply resources available in some countries (e.g. large hydro in Guinea, natural gas from Nigeria, etc.).

3.3.4.2. Cooperation scenario

- Electricity consumption is in line with the demand scenario Reference scenario (i.e. the same assumption as for scenario Business as usual).
- On the supply side, free competition between all options was assumed.
- Sub regional cooperation is active and there is a clear multilateral effort in the implementation of the interconnection projects and sub regional electricity supply options.
- Countries are becoming increasingly aware of the limited impacts of individual policies and of the benefits of cooperation. Energy exchanges between countries within sub region are expected to increase significantly, favouring the emergence of a sub-regional energy market and large scale energy projects.

3.3.4.3. SE4ALL scenario

- On the electricity demand side, the scenario assumes that additional effort will be made to bring electricity to most of the population in reaching the target of the universal access by 2030/2035. Disparity between countries will be reduced, so that by 2030 at sub regional level electricity access of about 93% is reached, meaning that most of the urban population will reach 100% electrification. By 2035 all population would have access to affordable electricity supply.
- The target of universal electricity access and reduction of disparities will be achieved by maximum integration and cooperation among countries on the sub regional level to create a harmonized regulatory and institutional framework for implementing energy supply strategies and plans. The objective is to create a competitive sub regional market. The scenario also assumes free movement of people, goods and services and better utilization of energy resources in the sub region.
- On the supply side, free competition between all technologies is assumed, with additional emphasis on renewables.
- A fourth scenario, of SE4ALL LES (Less Environmental Stress), is based on SE4ALL, with the only difference being reduced environmental stress.

Scenarios were subject to a sensitivity analysis for some of the assumptions (e.g. the availability of some electricity generation options, the discount rate and environmental impact considerations).

4. ANALYSIS OF ELECTRICITY SUPPLY SCENARIOS

4.1. BUSINESS AS USUAL SCENARIO

In the Business as usual scenario, Reference scenario electricity demand is assumed along with weak cooperation between countries in terms of electricity system integration and development of the sub regional market (i.e. only existing interconnections are considered). The Business as usual scenario also assumes continuing high dependence on fossil fuels and free competition among all supply technologies. This scenario demonstrates how the national system might evolve, if cooperation is missing. It also serves as a reference point to assess the possible benefits of cooperative strategies.

Under this scenario, overall electricity access reaches 67% by 2030, but disparities between countries remain. Many countries still have a large part of population left without access to electricity. On the supply side, cost competition between all available technologies was assumed at a national level. Investment in nuclear power was allowed in Ghana, Nigeria and Niger from 2030.

Installed capacity is presented in Table 14 and Figure 27.

TABLE 14. INSTALLED CAPACITY FOR SCENARIO Business as usual

Installed capacity, MW, scenario Business as usual	2010	2020	2030	2035
Coal	38	528	1 847	2 632
Oil	1 465	2 408	1 944	1 487
Gas	4 978	20 318	25 891	30 313
Nuclear	0	0	0	1 406
Hydro	3 430	10 054	18 383	19 659
Biomass	0	205	780	1 844
Solar PV	0	549	1 514	1 972
Solar Thermal	0	394	1 238	2 272
Wind	0	756	1 483	2 162
Oil Distributed	4 326	3 577	3 168	6 017
Biomass Distributed	0	0	0	0
Mini Hydro Distributed	0	863	3 697	4 596
Solar PV Distributed	0	55	201	585
Total Generation Capacity	14 237	39 705	60 146	74 944
Peak Load Centralized System	8 869	17 081	39 553	58 926
Interconnection Capacity	3 838	3 838	3 838	3 838

The scenario clearly shows that a substantial investment is needed to increase overall installed capacity from the current level of 14.2 GW to 60.1 GW in 2030 (four times increase) and further to 74.9 GW in 2035 (more than five times increase). The peak load will also increase, from 8.8 GW in 2010 to 39.5 GW in 2030.

As one of the main assumptions was that sub regional cooperation is missing, the interconnections capacity and opportunities for regional trade under this scenario remain unchanged, (i.e. the same as at the beginning of the planning horizon).

The evolution and the structure of generation capacity over the study period are illustrated by Figure 27. While at the beginning fossil fuel plants dominate (i.e. mainly oil/diesel and gas units), in 2035 hydro power plants reach 24.2 GW (out of which 4.8 GW on small distributed sites).

Still, fossil fuel based units keep a majority share of 54% – dominated by natural gas (40.4% of total installed capacity). Oil units are still present, both as centralized and decentralized option. Often these units are used as back up or to provide supply when intermittent sources are not available. Coal installations are increased, but their share remains relatively low at 3.5% of the total installation of 2.6 GW.

Other RES (without hydro; i.e. wind, solar and biomass, centralized and distributed) reach 8.8 GW in 2035 or 11.8% of total installations. The share of all RES (i.e. including large and small hydro) reaches 44.1% of total installed capacity.

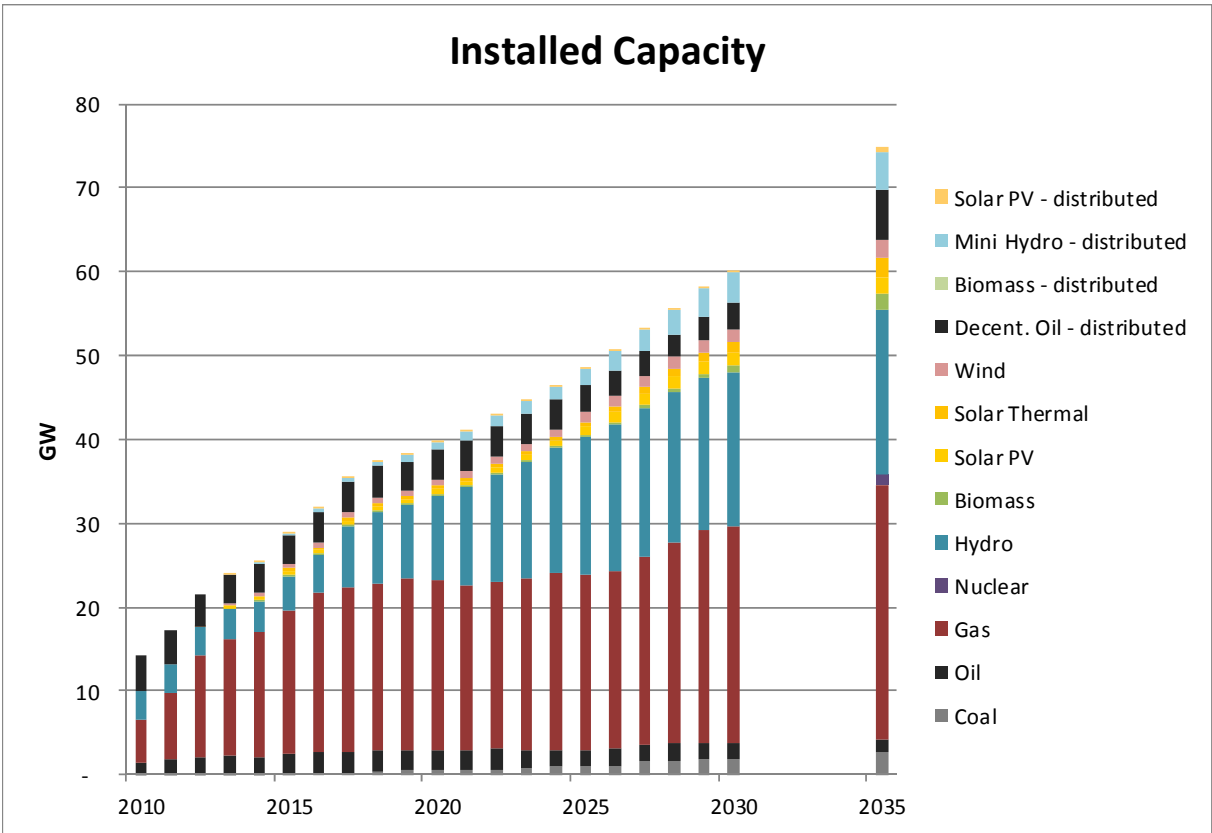


FIG. 27. Installed capacity for scenario Business as usual.

Nuclear power proves to be a competitive option beyond 2030 reaching 1.4 GW in 2035.

The total generation capacity increases rapidly until 2016 due to a number of already committed projects, especially gas based units in Cote d'Ivoire and Ghana. After 2015 a substantial development of hydro potential is visible, while further development of the natural gas units picks up after 2025.

Final electricity consumption in this scenario is expected to increase by almost nine times between 2010 and 2035.

Electricity generation is presented in Table 15 and Figure 28. The composition of electricity generation mirrors the description of new power plant constructions. Large scale hydro power

generation, as one of the cheapest and locally available options, is expected to increase by a factor of five, from 16.7 TW·h in 2010 to 88.1 TW·h in 2035. Hydro projects are expected to be completed in rapid succession during the period 2017-2025. If small and distributed hydro power is included, the total share of hydro in generation mix could reach 106.9 TW·h or 28.7% of total generation by 2035 (i.e. a decrease from 33.8% share in the base year).

The share of other RES in generation will increase from a negligible share at present to 29.9 TW·h or 8.1% of total generation by 2035. Therefore, the share of all RES in total generation will increase slightly from 33.8% in 2010 to 36.8% in 2035. Among other RES options (i.e. without hydro), the largest share in 2035 will come from solar thermal (10.1 TW·h) followed by biomass (8.5 TW·h), wind (5.7 TW·h) and solar PV (5.5 TW·h).

TABLE 15. ELECTRICITY GENERATION FOR SCENARIO Business as usual

Electricity generation, GW·h, scenario Business as usual	2010	2020	2030	2035
Coal	282	3 941	13 488	19 605
Oil	3 413	3 527	3 793	4 853
Gas	27 029	46 927	112 780	197 816
Nuclear	0	0	0	10 355
Hydro	16 726	44 255	82 636	88 119
Biomass	0	1 298	3 819	8 481
Solar PV	0	1 201	3 313	4 347
Solar Thermal	0	1 237	4 581	10 150
Wind	0	1 920	4 099	5 745
Oil Distributed	2 085	1 225	1 249	2 593
Biomass Distributed	0	0	0	0
Mini Hydro Distributed	0	3 183	13 923	18 830
Solar PV Distributed	0	96	406	1 175
Total Generation	49 535	108 811	244 088	372 068
Final Electricity Consumption	40 353	95 919	224 548	341 690

Natural gas generation will also increase rapidly, (i.e. more than six fold), from 27.0 TW·h in 2010 to 197.8 TW·h in 2035. However, the relative share of gas fired generation will remain roughly the same at the end of the planning horizon – 53.2%.

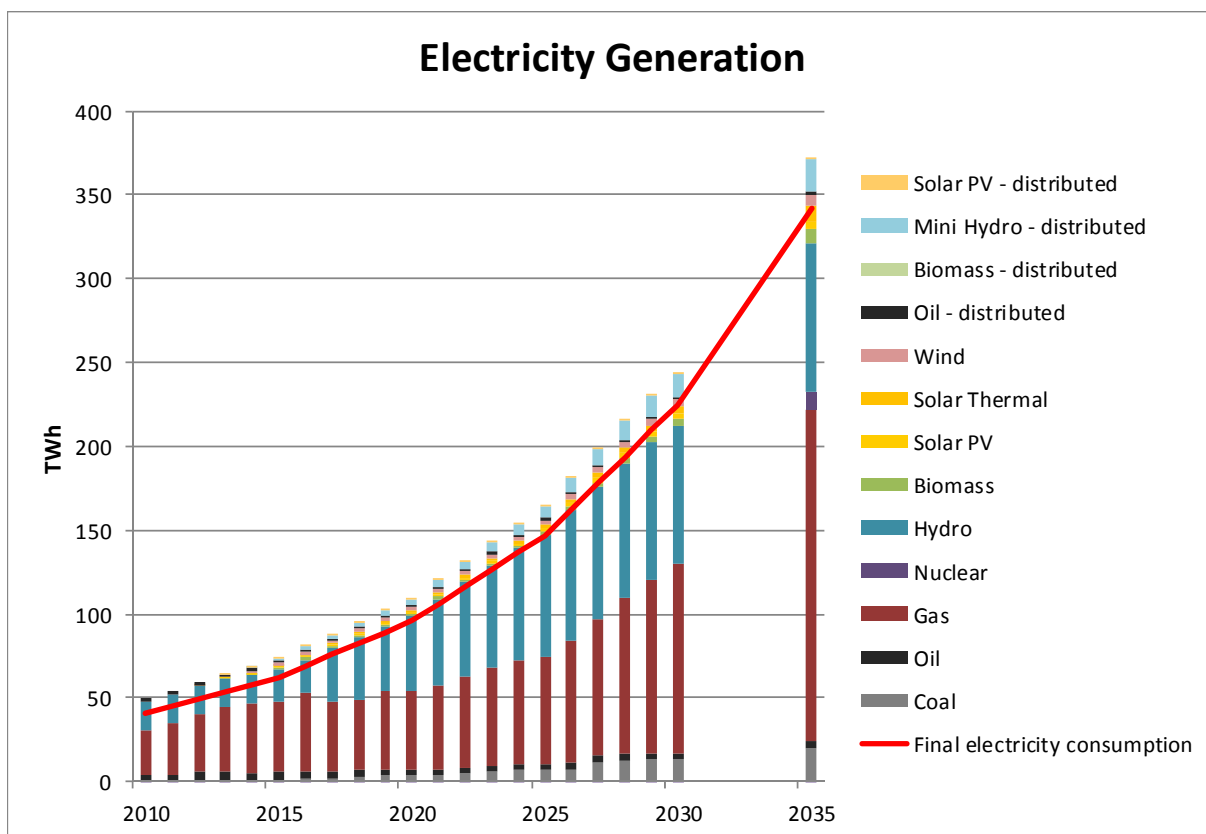


FIG. 28. Electricity generation for scenario Business as usual.

Coal is expected to increase its share from the current 0.6% to 5.3% or 19.6 TW·h in 2035. Oil generation will also increase in absolute terms, from 5.5 TW·h in 2010 to 7.4 TW·h in 2035, but its relative contribution is expected to fall from 11.1% in 2010 to only 2.0% in 2035. Structure of electricity generation is presented in Figure 29.

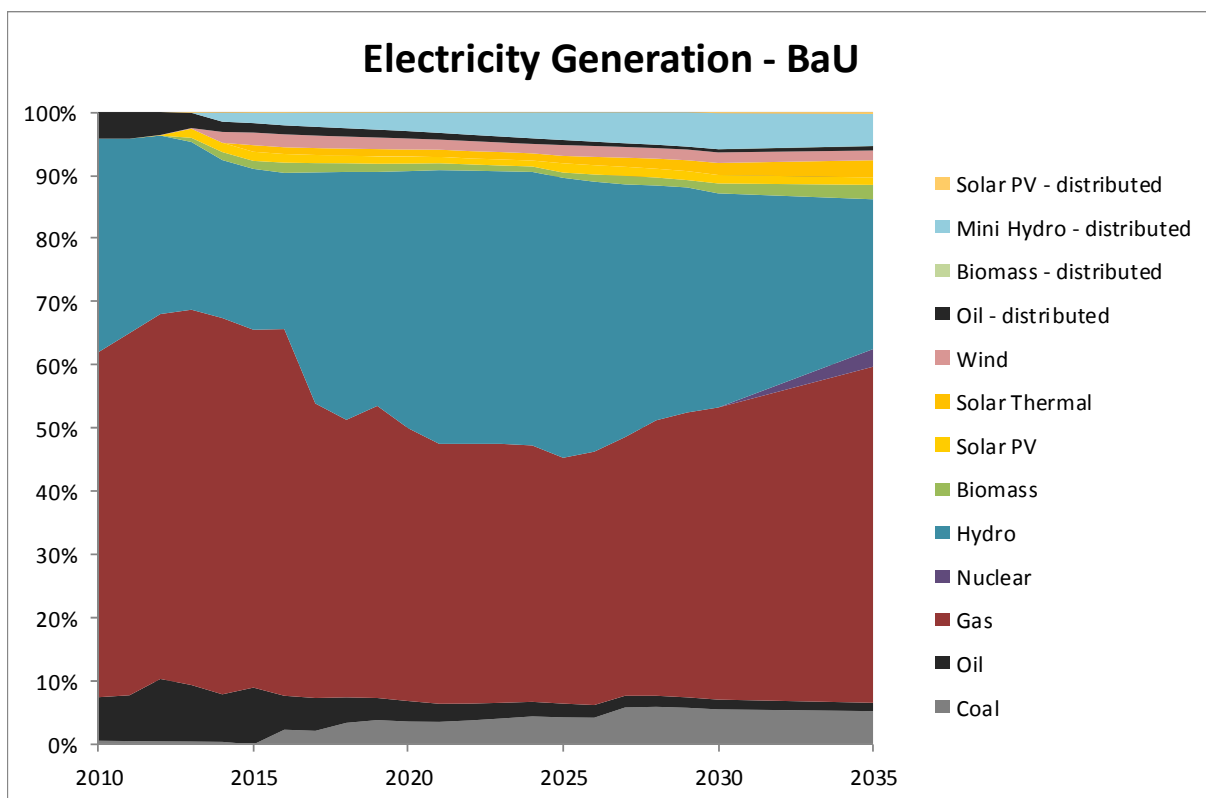


FIG. 29. Structure of electricity generation for scenario Business as usual.

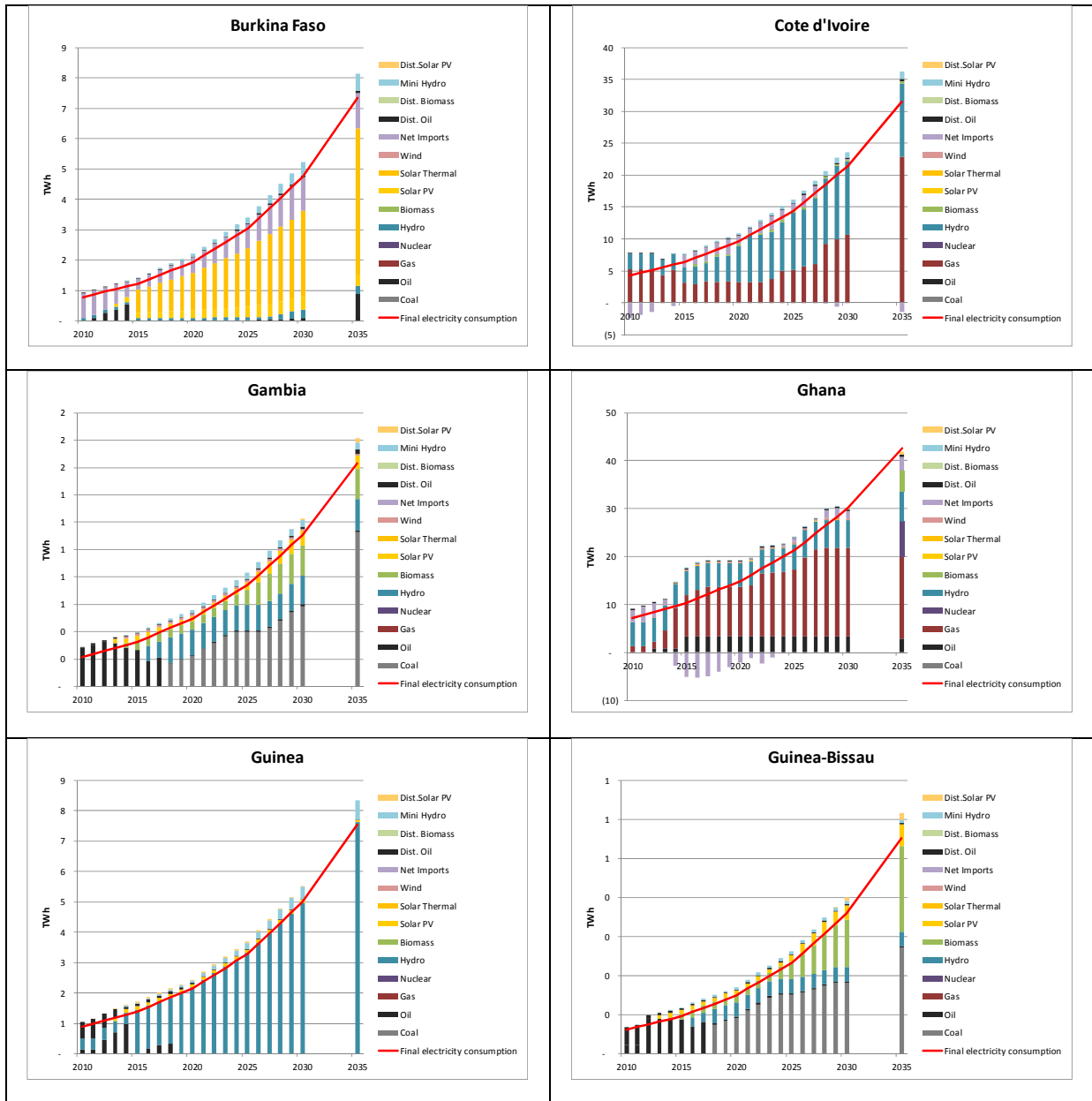
Fossil fuel based generation share is decreasing at the beginning of the period, leaving room to hydro and other renewables. After 2025, when large scale hydro potential will be close to its saturation point, fossil based generation will start to increase its share.

Figure 30 provides overview of expected changes in the electricity generation patterns across countries. Due to the assumption of limited sub regional trade (i.e. limited to the capacity of the existing interconnections), most of the countries are forced to use locally available electricity generation options.

- Countries like Burkina Faso, Togo, Benin and Niger are expected to continue to import electricity in line with the assumed limitations (i.e. using existing interconnections only). In Burkina Faso, the use of solar thermal and PV proves to be the preferable local generation option.
- Cote d'Ivoire relies on domestic hydro and natural gas. At the beginning of the period surplus electricity is exported, but after 2015 there is an economic benefit from electricity import. Gambia and Guinea Bissau could see a complete change in the generation structure, diverting from oil based supply to diversified production from coal, hydro, solar and biomass plants.
- In the midterm Ghana is expected to export some of the hydro and gas based generation. Share of gas is expected to increase over time, and by 2035 the introduction of a nuclear power plant proves to be competitive. Nuclear power is also competitive in Niger (smaller unit size).
- For Guinea, Liberia and Sierra Leone the most competitive option is to develop local hydro resources and divert from today's predominantly oil based generation.

- After developing its own hydro potential, Mali is expected to orient towards solar technologies and import.
- Imported coal is used in Gambia, Guinea Bissau, Senegal and Togo/Benin, while only Niger uses domestic coal.

The largest system in the sub region, Nigeria, relies completely on hydro and gas generation with some export to neighbouring countries (Togo/Benin, Niger).



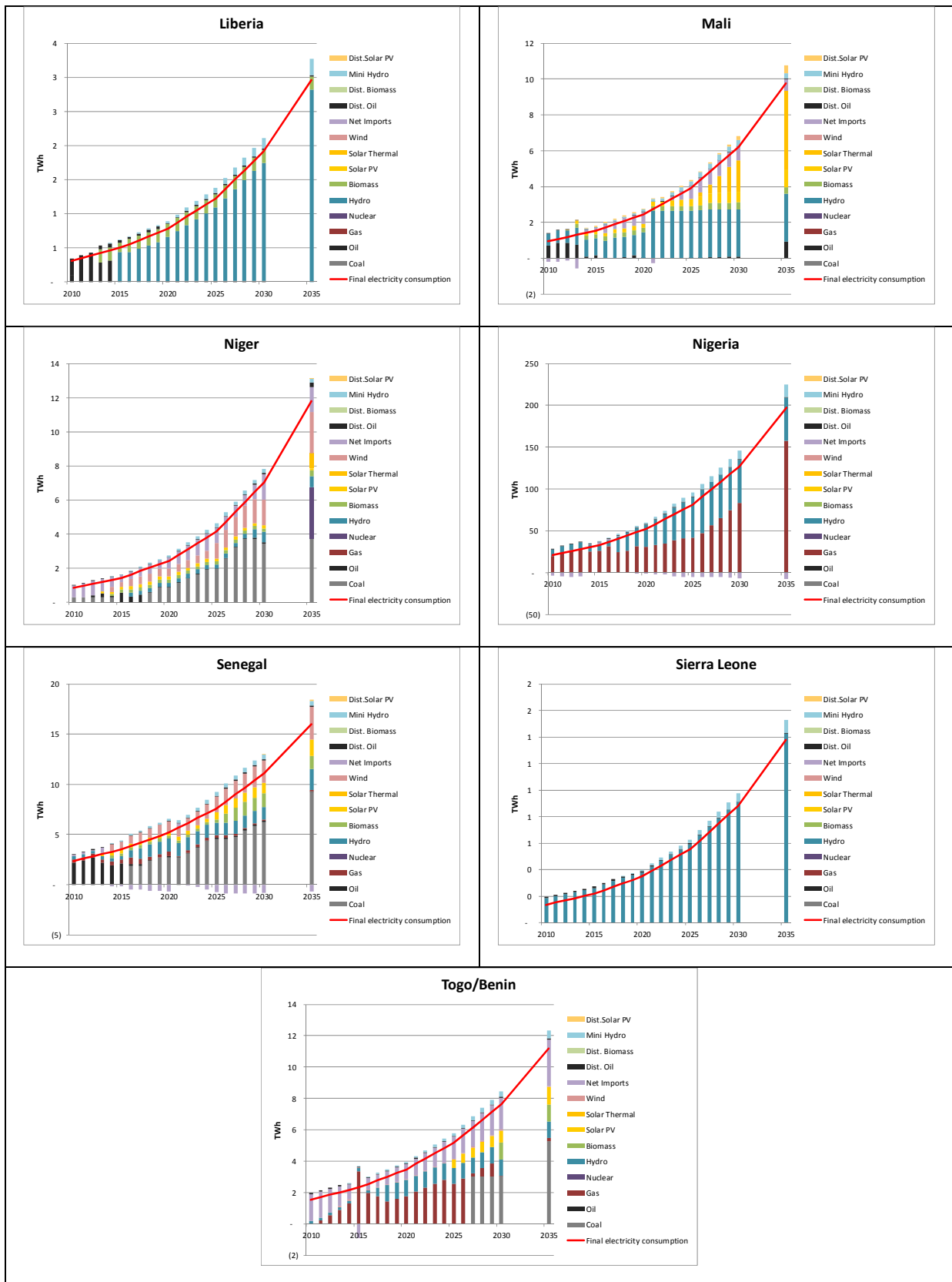


FIG. 30. Electricity generation by country for scenario Business as usual.

The structure of annual costs for this scenario is given by Figure 31 (excluding annualized investment costs for the existing units). Annual costs are expected to increase for about six

times until 2035 – to 33.72 billion USD. At the end of the period more than 60% of the annual costs will be fuel costs.

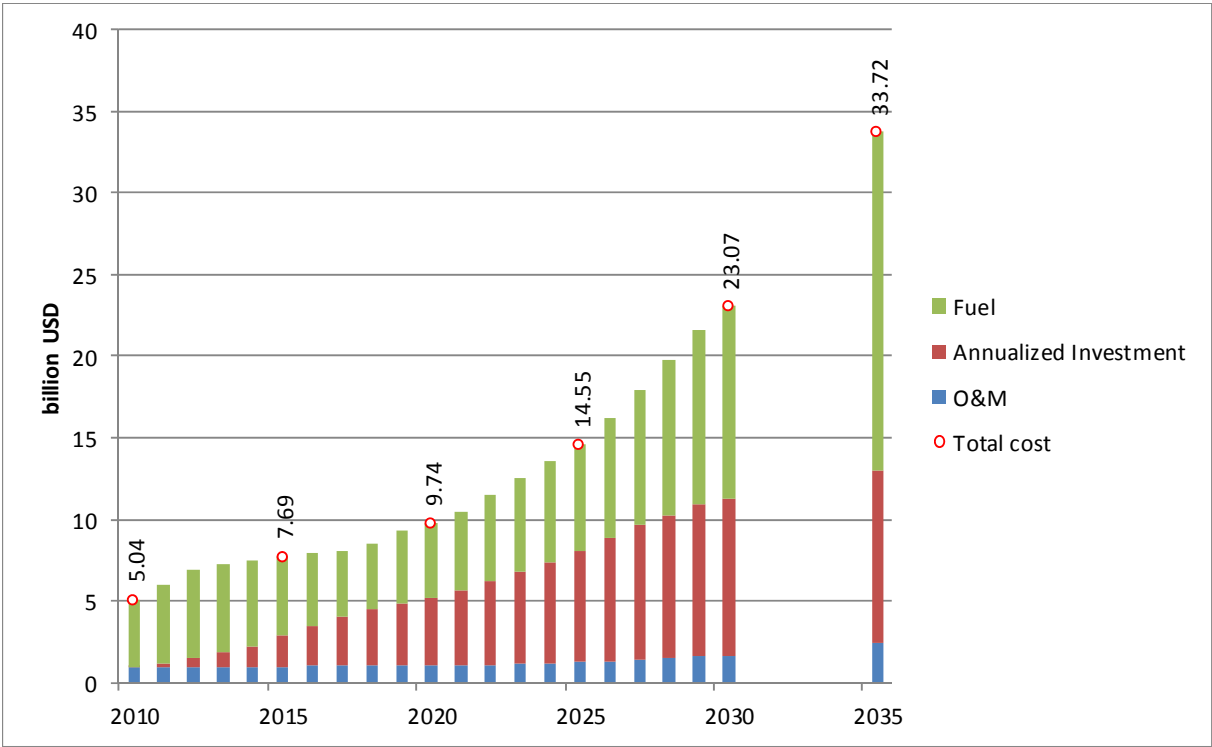


FIG. 31. Structure of annualized electricity generation costs for scenario Business as usual.

The total investment in generation (centralised and distributed) and transmission/distribution (local and interconnections) during the period 2010-2035 is expected to reach 254.1 billion USD (see Table 16).

TABLE 16. INVESTMENTS INTO GENERATION AND TRANSMISSION ASSETS FOR SCENARIO Business as usual

billion USD			
Period	Generation Investment	Transmission Investment	Total
2010-2014	11.4	7.3	18.7
2015-2019	20.2	10.6	30.9
2020-2024	21.9	18.8	40.7
2025-2029	26.4	31.3	57.6
2030-2035	54.4	51.8	106.2
Total	134.3	119.8	254.1

4.2. COOPERATION SCENARIO

The Cooperation electricity supply scenario assumes electricity demand as in the Reference scenario, plus active cooperation between countries in terms of electricity system integration and development of the sub regional market. The scenario also assumes free competition among all supply technologies. Active cooperation is translated into timely implementation of already committed interconnection lines, while planned or uncommitted projects under consideration are constructed according to economic benefits of electricity trade opportunities.

Under this scenario, overall electricity access is assumed to be the same as under the Business as usual scenario, (i.e. to reach 67% by 2030). The option to construct nuclear power projects was allowed in Ghana, Nigeria and Niger from 2030 onwards.

Although disparities between areas and countries will remain, the results of this scenario demonstrate how national systems could evolve if cooperation is effective, allowing construction of large scale regional projects for the benefit of all countries in the sub region. Ultimately this would lead to increased affordability of electricity (due to expected decrease of electricity supply costs in the sub region) and reduced environmental stress (due to better use and allocation of available resources).

Installed capacity is presented in Table 17.

TABLE 17. INSTALLED CAPACITY FOR SCENARIO Cooperation

Installed capacity, MW, scenario Cooperation	2010	2020	2030	2035
Coal	38	382	1 284	1 999
Oil	1 465	2 401	1 937	1 280
Gas	4 978	19 897	27 115	32 028
Nuclear	0	0	0	1 229
Hydro	3 430	10 979	20 682	22 150
Biomass	0	268	806	1 889
Solar PV	0	370	1 519	1 950
Solar Thermal	0	503	1 431	2 116
Wind	0	706	1 491	2 192
Oil Distributed	4 323	3 505	3 124	4 761
Biomass Distributed	0	0	0	0
Mini Hydro Distributed	0	856	3 670	4 604
Solar PV Distributed	0	0	53	194
Total Generation Capacity	14 233	39 865	63 113	76 391
Peak Load Centralized System	8 870	17 271	40 375	60 197
Interconnection Capacity	3 838	14 444	17 873	21 629

Under this scenario, the total installed capacity is expected to increase from the current level of 14.2 GW to 63.1 GW in 2030 and further to 76.4 GW in 2035. The increase in installed power is slightly higher compared to the Business as usual scenario, because under the Cooperation scenario, more hydro power plants are constructed and these have lower plant factors compared to the gas and coal units (as used in the Business as usual scenario). The regional cooperation results in lower average generation costs as shown in Figure 32.

The peak load for the centralized power system is also expected to increase – to 40.4 GW in 2030 compared to 39.5 GW under the Business as usual scenario. This increase is explained by the fact that more demand will be met by centralized units (as a more cost effective way compared to the decentralized options).

As one of the assumptions under the Cooperation scenario was that the sub regional collaboration is active, the interconnection capacity and opportunities for the regional trade under this scenario are substantially increased. The capacity of interconnecting lines increase from 3.8 GW to 17.8 GW in 2030 and to 21.6 GW in 2035. From a trade volume of 7 TW·h/yr, electricity exchanges increase ten times to reach 71.5 TW·h by 2035.

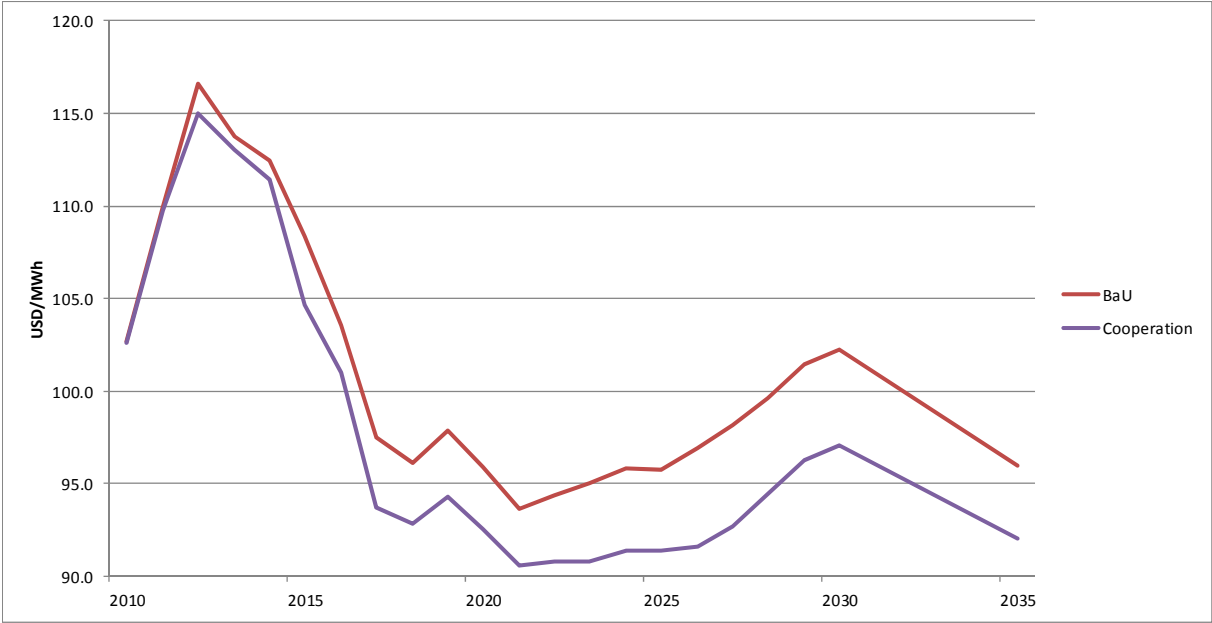


FIG. 32. Average generation costs – comparison between Cooperation and Business as usual scenarios.

The structure of generation capacity in 2035 is given by Figure 33. While at the beginning the structure is dominated by fossil fuel based plants (i.e. mainly oil/diesel and gas units), in 2035 hydro power plants reach 26.7 GW (out of which 4.8 GW is small/distributed).

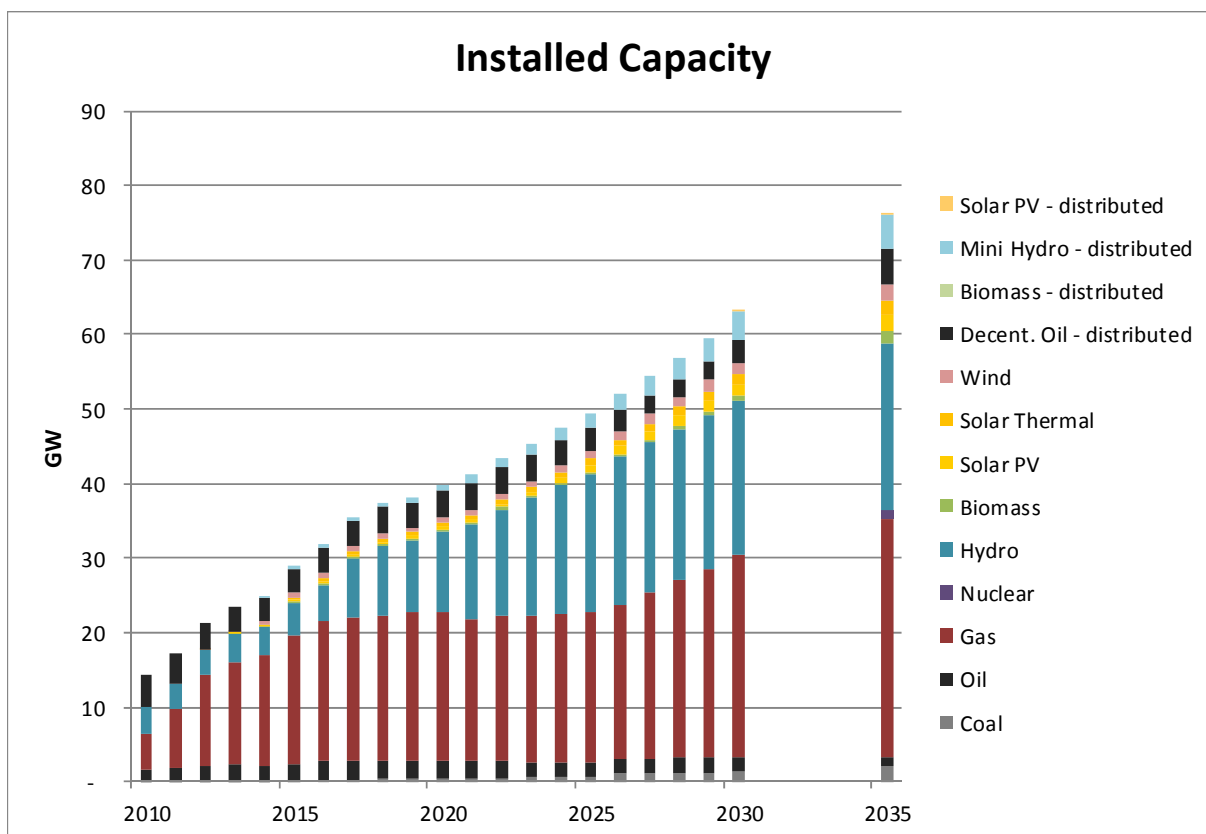


FIG. 33. Installed capacity for scenario Cooperation.

Similarly to the Business as usual scenario, fossil fuel based units keeps a majority share of 54% – dominated by natural gas (40.4% of total installed capacity). Oil units are still in place as centralized, as well as decentralized plants, but their installed capacity decreases to 6 GW in 2035, compared to 7.5 GW reached under the Business as usual scenario. This drop reflects a reduction in decentralized generation. Coal installations are increased, but their share remains relatively low at 2.6% of the total installation or 2.0 GW (i.e. lower compared to the Business as usual scenario).

Other RES (without hydro; i.e. wind, solar and biomass, centralized and distributed) reach 8.8 GW in 2035 or 10.9% of total installations. The share of all RES (i.e. including large and small hydro) reaches 45.9% of total installed power.

Nuclear power proves to be a competitive option beyond 2030, reaching 1.2 GW in 2035. This is lower than in the Business as usual scenario, as other generation sources take a larger share of the market.

In order to meet the rapidly increasing electricity demand, the generation mix changes substantially supported by trade opportunities as presented in Table 18 and Figure 34. Hydro generation is expected to increase by a factor of seven, from 16.7 TW·h in 2010 to 118.5 TW·h or 31.7% of total generation in 2035 (large and small scale hydro). This is an increase over the Business as usual scenario. Hydro projects are expected to develop rapidly during the 2017/2025 period.

The share of other RES in generation will increase from the current negligible level to 28.7 TW·h or 7.7% of total generation by 2035. Therefore, the share of all RES in total generation is expected to increase from 33.8% in 2010 to 39.3% in 2035. This represents an

overall increase compared to the Business as usual scenario. Among other RES options (i.e. excluding hydro), the most used in 2035 will be solar thermal (9.1 TW·h), followed by biomass (9.0 TW·h), wind (5.8 TW·h) and solar PV (4.8 TW·h).

TABLE 18. ELECTRICITY GENERATION FOR SCENARIO Cooperation

Electricity generation, GW·h, scenario Cooperation	2010	2020	2030	2035
Coal	282	2 855	9 568	14 892
Oil	3 414	3 473	3 429	3 015
Gas	27 030	43 566	111 415	198 163
Nuclear	0	0	0	9 053
Hydro	16 726	48 871	93 451	99 688
Biomass	0	1 914	4 275	9 020
Solar PV	0	809	3 325	4 405
Solar Thermal	0	1 580	4 644	9 161
Wind	0	1 789	4 120	5 783
Oil Distributed	2 084	1 185	1 207	2 148
Biomass Distributed	0	0	0	0
Mini Hydro Distributed	0	3 178	13 898	18 851
Solar PV Distributed	0	0	104	384
Total Generation	49 535	109 220	249 437	374 562
Final Electricity Consumption	40 353	95 919	224 548	341 690

Natural gas generation is also expected to see a rapid development and increases from 27.0 TW·h in 2010 to 198.1 TW·h in 2035. The relative contribution of gas based generation should remain similar at the end of the planning horizon (i.e. 52.9%). Coal is expected to increase its share from the current 0.6% to 4.0% or 14.9 TW·h in 2035. Oil generation will decrease, from 5.5 TW·h in 2010 to 5.1 TW·h in 2035, and the relative contribution drops to only 1.4% in 2035.

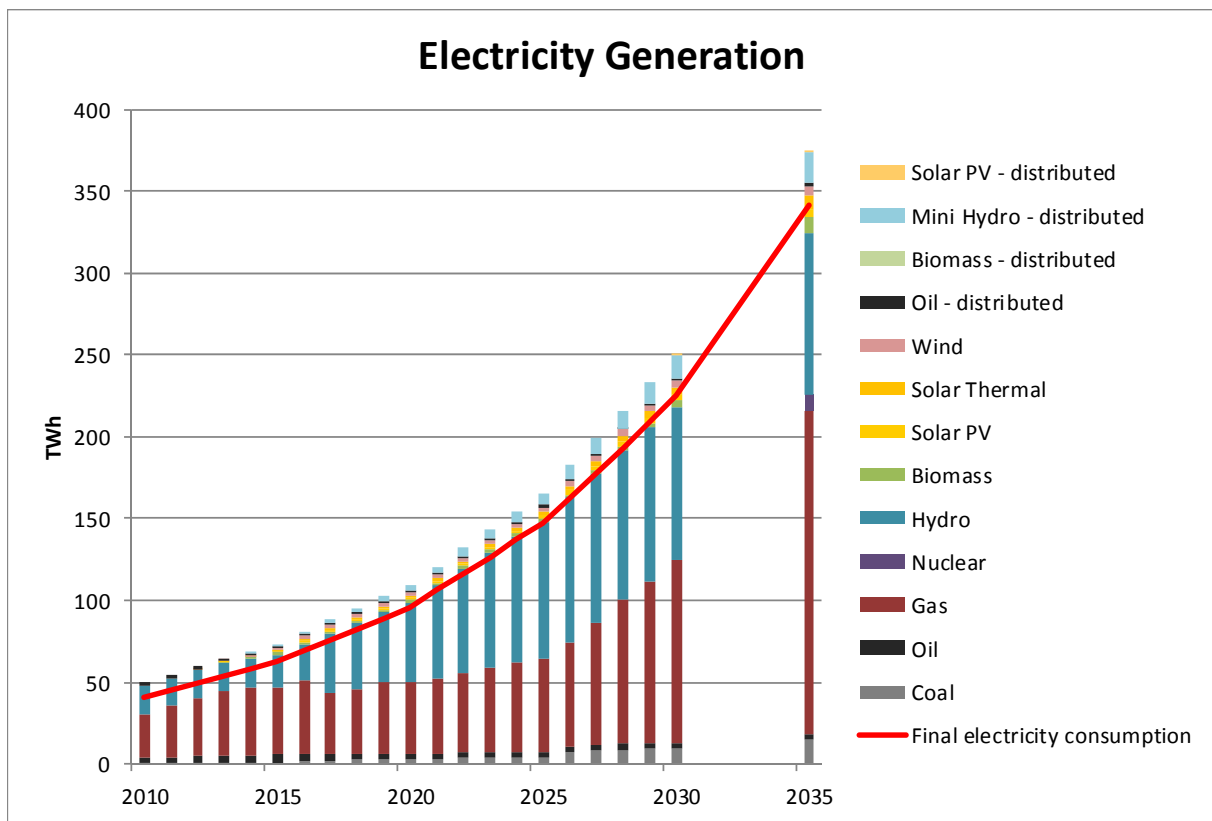
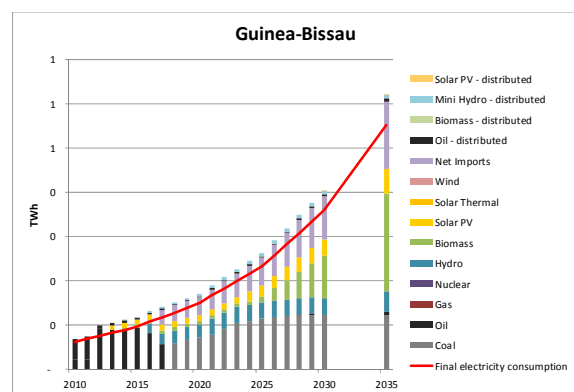
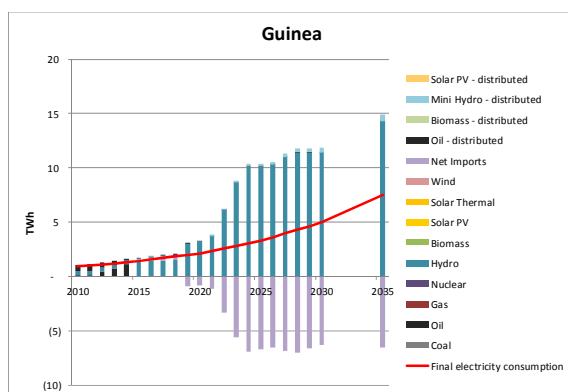
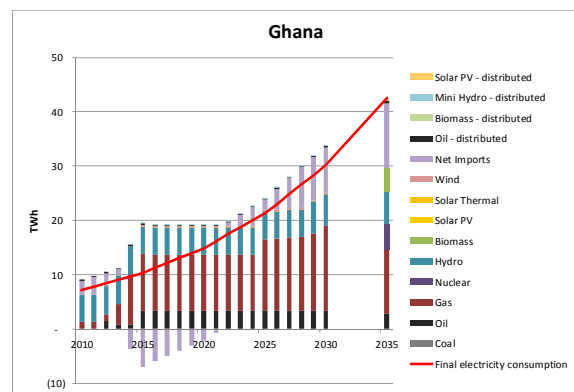
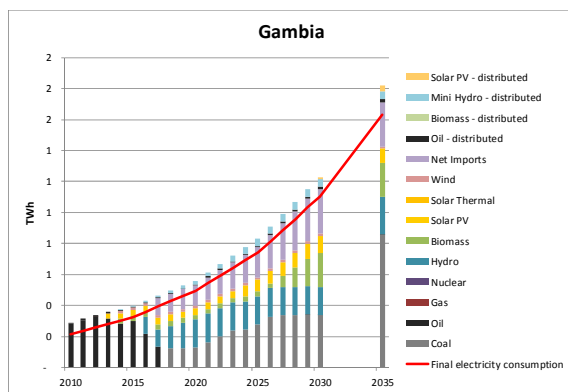
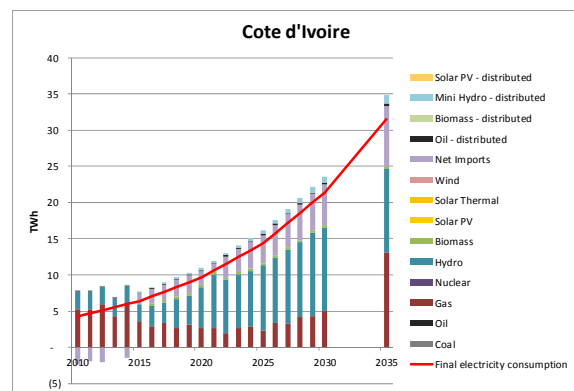
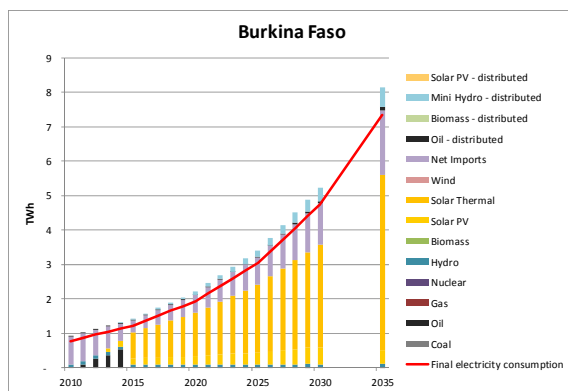


FIG. 34. Electricity generation for scenario Cooperation.

Figure 35 gives an overview of expected changes in the electricity generation patterns across countries. Due to the assumption of active development of sub regional market (construction of additional interconnection lines), some countries become net electricity exporters, while all countries benefit from a lower generation costs.

- The largest changes are visible in Guinea, Liberia and Sierra Leone. Local hydro potential available in these countries could make a large impact on the sub regional market and lead to increased electricity trade. Nigeria is also expected to increase its net exports under this scenario.
- Countries like Burkina Faso, Togo, Benin and Niger are expected to continue to import electricity. In Burkina Faso, the use of solar thermal and PV proves to be preferable local generation option.
- Cote d'Ivoire relies on domestic hydro and natural gas. At the beginning of the period surplus electricity is exported, but after 2015 there is an economic benefit from electricity import.
- Similar to the Business as usual scenario, Gambia and Guinea Bissau could see complete change in their generation structure, diverting from oil based supply to diversified production from coal, hydro, solar and biomass plants.
- In the midterm Ghana is expected to export some of its hydro and gas based generation, but from 2022 it will become net importer. The share of gas is expected to increase over time, while by 2035 the introduction of nuclear proves to be competitive. The nuclear option is also competitive in Niger (for a smaller unit size).

- For Guinea, Liberia and Sierra Leone the most competitive option is to develop local hydro resources and divert from today's predominantly oil based generation. Hydro generation is used to supply domestic demand and surrounding countries.
- After developing its own hydro potential, Mali is expected to orient towards import (from 2020) and development of solar technologies (strong after 2025).
- Imported coal is used in Gambia, Guinea Bissau, Senegal and Togo/Benin, while only Niger uses domestic coal, but as pointed above, total share of coal is relatively low.
- The largest system in the sub region, Nigeria, relies completely on hydro and gas generation with increasing export to neighbouring countries (Togo/Benin, Niger) towards 2035.



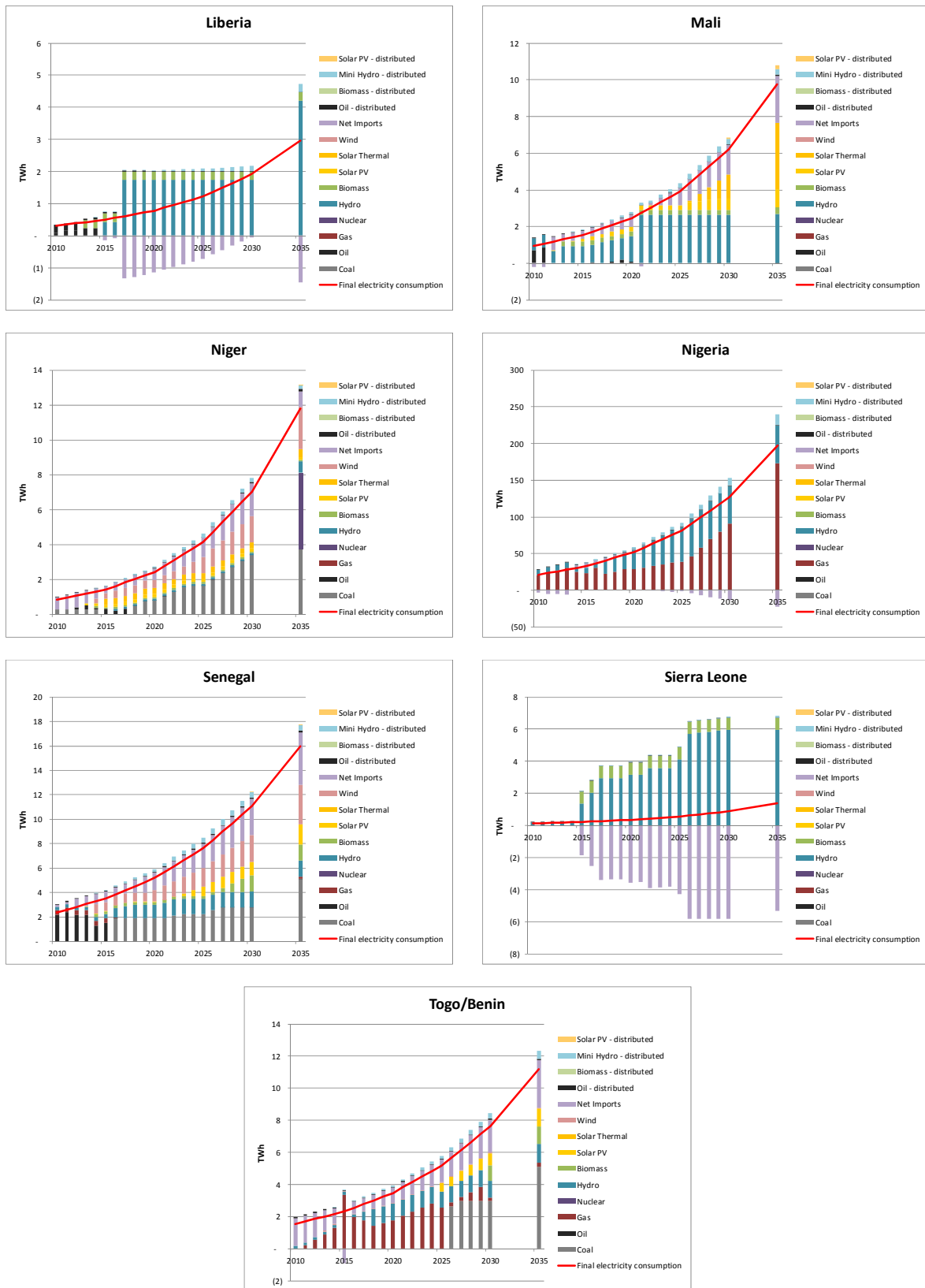


FIG. 35. Electricity generation by country for scenario Cooperation.

The structure of annualized electricity generation costs for scenario is given by Figure 36 (excluding annualized investment costs for the existing generation units). Annual generation costs are expected to increase for about six times until 2035 – to 32.58 billion USD. At the

end of the period, more than 60% of the annual generation costs will be fuel costs. The overall generation cost will be lower than under the Business as usual scenario.

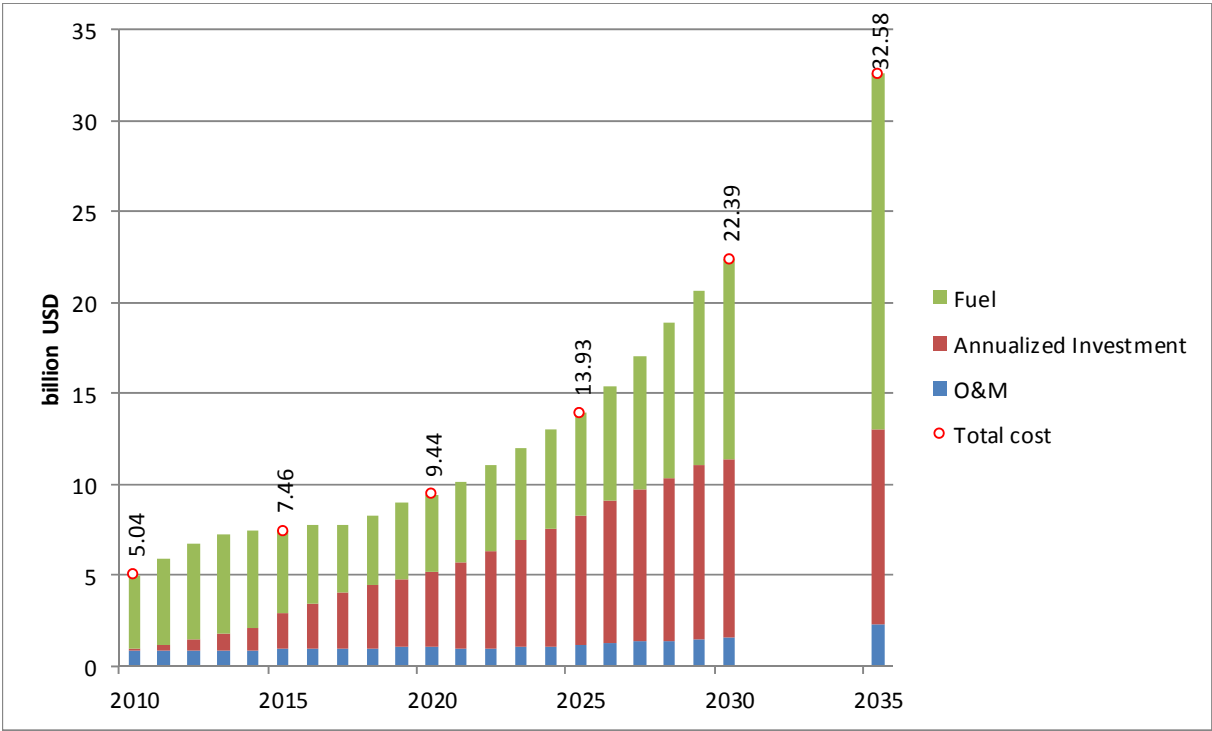


FIG. 36. Structure of annualized electricity generation costs for scenario Cooperation.

The total investment in generation (centralized and distributed) and transmission/distribution assets (local and interconnections) during the 2012035 period is expected to reach 261.4 billion USD, (i.e. higher than in the Business as usual scenario), but due to fuel cost savings the resulting average generation costs are lower (see Table 19).

TABLE 19. INVESTMENTS INTO GENERATION AND TRANSMISSION ASSETS FOR SCENARIO Cooperation

billion USD			
Period	Generation Investment	Transmission Investment	Total
2010-2014	10.8	7.9	18.7
2015-2019	21.6	12.2	33.8
2020-2024	24.7	18.9	43.6
2025-2029	25.6	31.8	57.4
2030-2035	53.8	54.1	107.9
Total	136.5	124.8	261.4

4.3. SE4ALL SCENARIO

The scenario SE4ALL assumes that additional efforts will be made to increase electricity access, so that most of the population in West Africa has electricity access by 2030/2035. Disparities in electricity consumption between countries will be reduced, and by 2030 electricity access at sub regional level should be close to 95%. Urban population should reach 100% electrification. By 2035 the entire population has access to affordable electricity supply. This scenario puts more emphasis on renewables energies, with free competition among supply options.

The target of universal electricity access and reduction in disparities will be achieved by a full and committed integration and cooperation of countries in the sub region to create harmonized regulatory and institutional framework for the implementation of energy supply strategies and plans. In this context, the emphasis is on economic aspects, and the objective is to build a competitive sub regional market. The free movement of people, goods and services and freedom of establishment contribute in addition.

Installed capacity is presented in Table 20.

TABLE 20. INSTALLED CAPACITY FOR SCENARIO SE4ALL

Installed capacity, MW, scenario SE4ALL	2010	2020	2030	2035
Coal	38	447	1 737	4 823
Oil	1 465	2 407	1 947	2 569
Gas	4 978	20 507	30 780	37 373
Nuclear	0	0	229	2 000
Hydro	3 430	11 454	22 221	22 464
Biomass	0	293	1 073	2 293
Solar PV	0	584	2 666	5 115
Solar Thermal	0	1 016	4 039	7 540
Wind	0	799	2 103	3 472
Oil Distributed	4 326	3 839	4 399	8 007
Biomass Distributed	0	0	0	0
Mini Hydro Distributed	0	944	4 130	5 041
Solar PV Distributed	0	19	350	1 738
Total Generation Capacity	14 237	42 309	75 674	102 437
Peak Load Centralized System	8 869	19 096	48 314	78 129
Interconnection Capacity	3 838	14 824	20 828	22 178

Under the SE4ALL scenario, the total installed capacity is expected to increase from 14.2 GW in 2010 to 75.7 GW in 2030 and to 102.4 GW by 2035. This increase in installed power is substantially higher compared to the Business as usual and SE4ALL. Peak load at centralized power system is also expected to increase – to 78.1 GW in 2030 compared to 40.4 GW in the SE4ALL scenario.

The scenario SE4ALL assumes active sub regional collaboration. Due to increased electricity demand, the development of interconnection capacity has to be faster, especially during the 2020-2030 period. The total capacity of cross border interconnection lines increases to 22.1 GW in 2035.

The traded volume increases to 67.5 TW·h in 2030, and then decreases to 53.4 TW·h by 2035. This trend is explained by the fact that increased national electricity consumption leaves less space for economic trade between systems. Less expensive supply options are exhausted earlier to supply local demand, and at later stage more and more costly generation options have to be deployed and used. This is reflected in the average generation costs given below.

The average generation cost in the SE4ALL scenario is higher compared to the Cooperation scenario, but it stays below the Business as usual scenario until 2027, indicating that cooperation could result in bringing more affordable electricity to final users compared to individual strategies. After 2027, the average generation cost increases above the values of the Business as usual scenario, indicating that more and more expensive options have to be used to satisfy growing demand (see Figure 37).

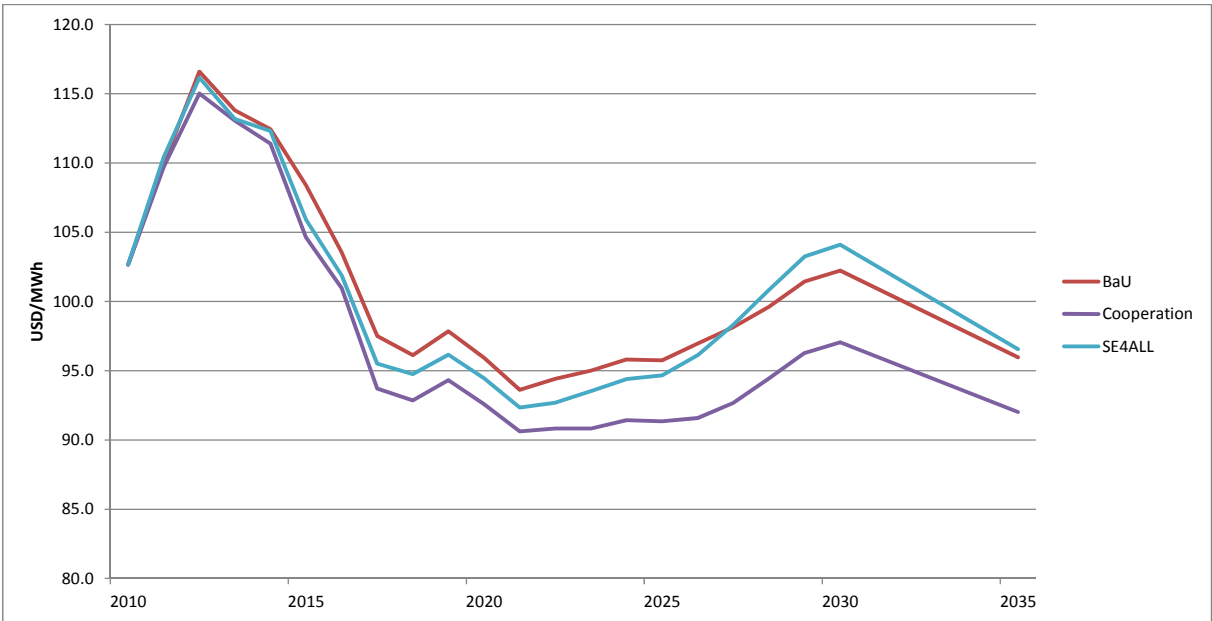


FIG. 37. Average generation costs – comparison between Business as usual, Cooperation and SE4ALL scenarios.

The structure of generation capacity in 2035 is given by Figure 38. While at the beginning the structure is dominated by fossil fuel based plants (i.e. mainly oil/diesel and gas units), in 2035 hydro power plants reach 27.5 GW (out of which 4.9 GW in small scale applications).

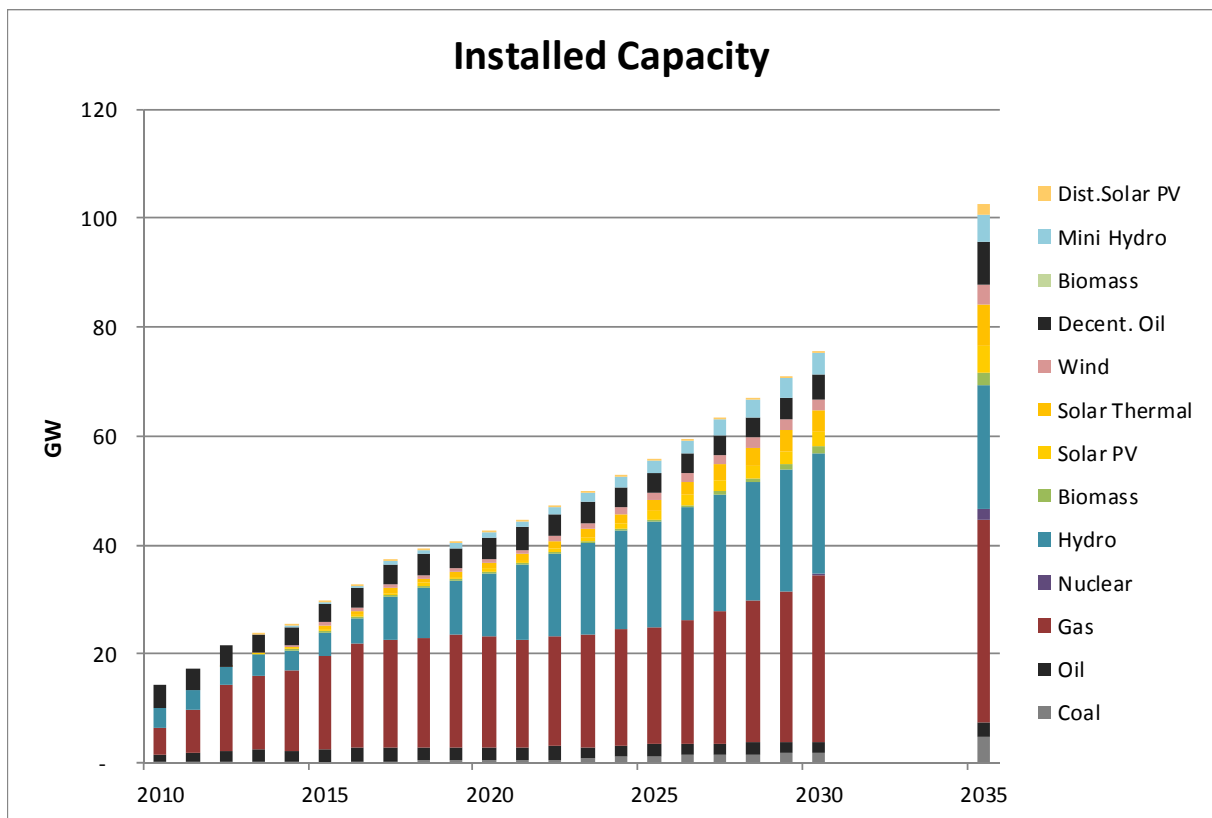


FIG. 38. Installed capacity for scenario SE4ALL.

Similarly to the other two scenarios, fossil fuel based generation units a majority share of 51% – dominated by natural gas (36.5% of total installed capacity). Oil units are still present as centralized and decentralized option, and their installed power increases to 10.6 GW in 2035 (higher than in two other scenarios). This increase comes from the decentralized part. Coal installations are increased, and their share reaches 4.7% of the total installation or 4.8 GW (i.e. higher compared to two other scenarios).

Other RES (without hydro; i.e. wind, solar and biomass, centralized and distributed) reach 20.1 GW in 2035 or 19.7% of total installation, and the share of all RES (i.e. including large and small hydro) reaches 46.5% of total installed capacity.

Nuclear power proves to be a competitive option from 2030 onwards, reaching 2 GW by 2035.

Hydro generation is expected to increase from 16.7 TW·h in 2010 to 121.8 TW·h or 24.8% of total generation in 2035 (large and small scale hydro). The relative share of hydro will decrease, as most of the assumed potential will be used up. The share of other RES will increase from the current negligible level to 68.0 TW·h or 13.8% of total generation by 2035. Therefore, the share of all RES in total generation is expected to increase from 33.8% in 2010 to 38.3% in 2035. Among other RES options (i.e. excluding hydro), the most used in 2035 will be solar thermal (32.9 TW·h), followed by solar PV (15.0 TW·h), biomass (10.9 TW·h) and wind (9.2 TW·h). Electricity generation is given in Table 21 and Figure 39.

TABLE 21. ELECTRICITY GENERATION FOR SCENARIO SE4ALL

Electricity generation, GW·h, scenario SE4ALL	2010	2020	2030	2035
Coal	282	3 337	12 939	35 915
Oil	3 413	3 542	3 755	7 723
Gas	27 029	48 708	132 333	240 114
Nuclear	0	0	1 689	14 729
Hydro	16 726	50 934	100 061	100 945
Biomass	0	2 025	5 443	10 900
Solar PV	0	1 279	5 834	11 432
Solar Thermal	0	3 191	15 394	32 939
Wind	0	2 035	5 728	9 199
Oil Distributed	2 085	1 307	1 683	3 290
Biomass Distributed	0	0	0	0
Mini Hydro Distributed	0	3 487	15 640	20 883
Solar PV Distributed	0	34	729	3 627
Total Generation	49 534	119 878	301 229	491 696
Final Electricity Consumption	40 353	105 285	275 664	447 917

Natural gas generation is also expected to increase rapidly, i.e. from 27.0 TW·h in 2010 to 240.1 TW·h in 2035. The relative share of gas based generation will remain high until the end of the planning horizon – 48.8%.

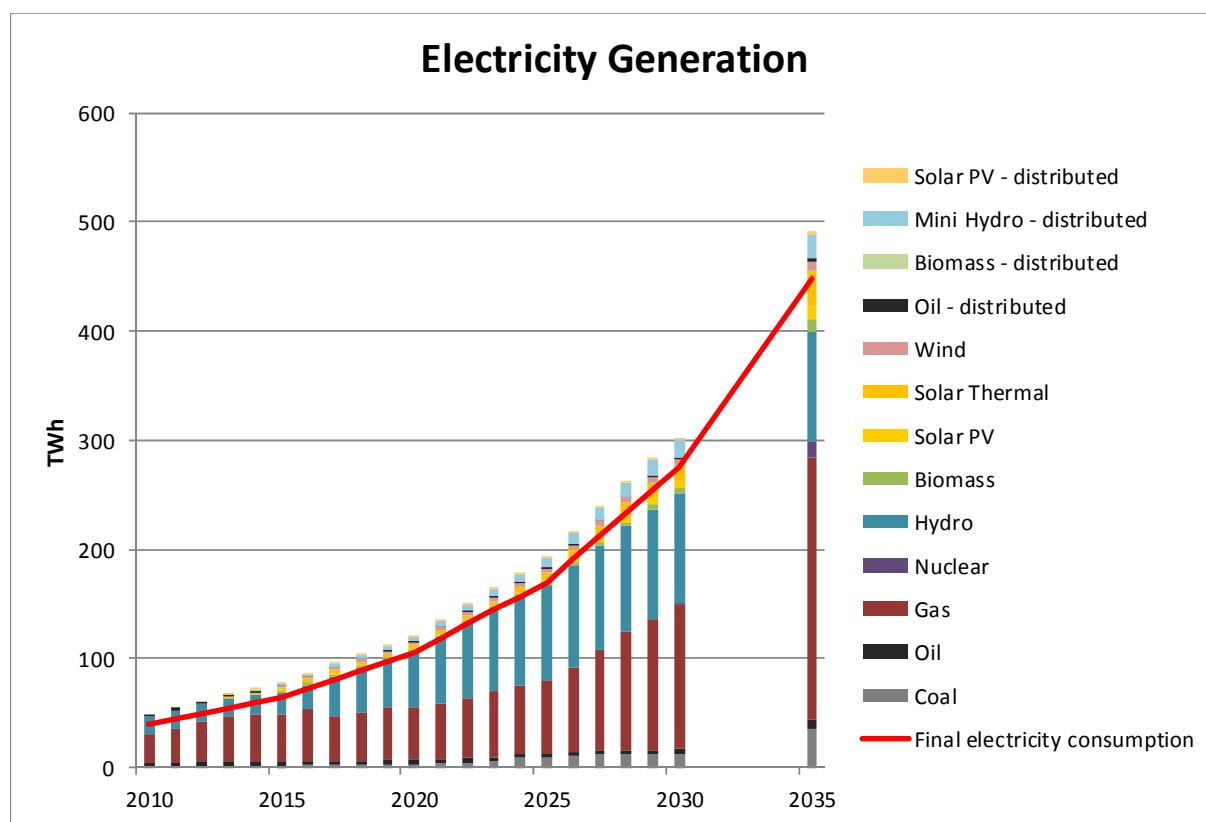


FIG. 39. Electricity generation for scenario SE4ALL.

Coal is expected to increase its share from the current 0.6% to 7.3% or 35.9 TW·h in 2035. Oil generation will double, from 5.5 TW·h in 2010 to 11.0 TW·h in 2035, but its relative contribution should decrease from 11.1 in 2010 to 2.2% in 2035.

An overall increase in use of fossil fuels (in order to supply higher demand) will lead to increased environmental stress, e.g. an increase in carbon dioxide emission as presented in Figure 40. Translated into numbers, cumulative carbon dioxide emission during 2010-2035 period under the SE4ALL scenario is 1244 Mton, an additional 84.7 Mton compared to the Business as usual scenario (7.5% increase) or 221.9 Mton more compared to the Cooperation scenario (21.7% increase). This leads to a conclusion that an increase of electricity access could put more pressure onto the environment.

In order to limit this pressure, a variation of the SE4ALL scenario was developed and analysed – with limited environmental stress (i.e. SE4ALL LES). Under this scenario, the same level of supply must be made available but with use of coal and gas resources¹⁸ limited to the levels achieved under the Business as usual scenario. In other words, the target was to reach the same electricity supply while avoiding a part of the emission and reducing environmental stress to a level similar to the Business as usual scenario. This approach requires higher investment into more expensive solutions, as presented below in a separate sub chapter and leads to a higher average generation costs.

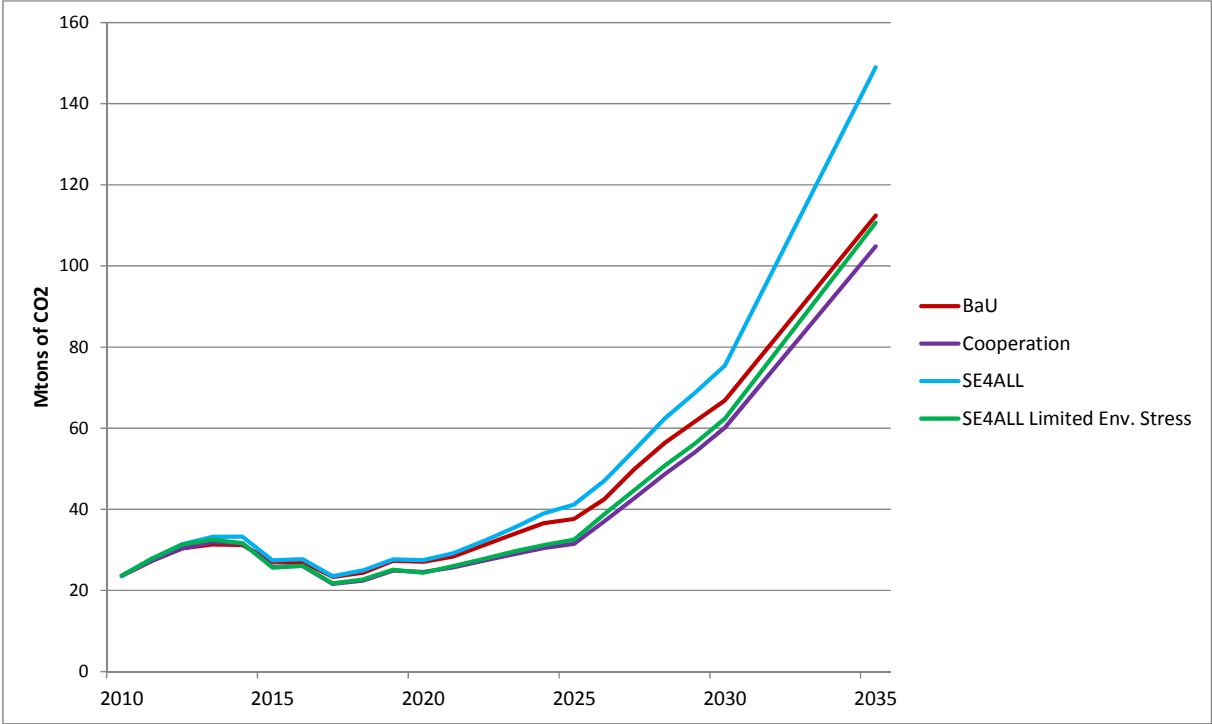
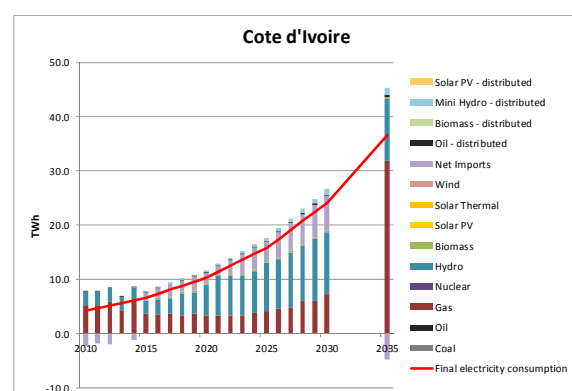
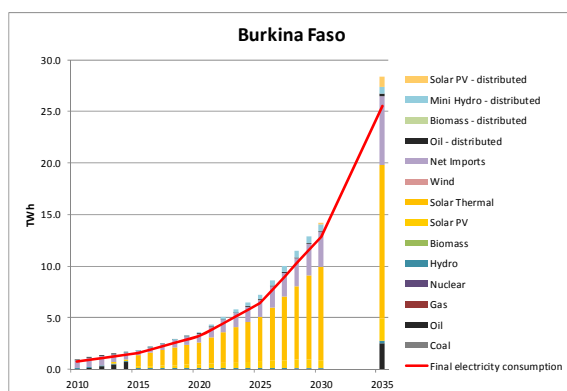


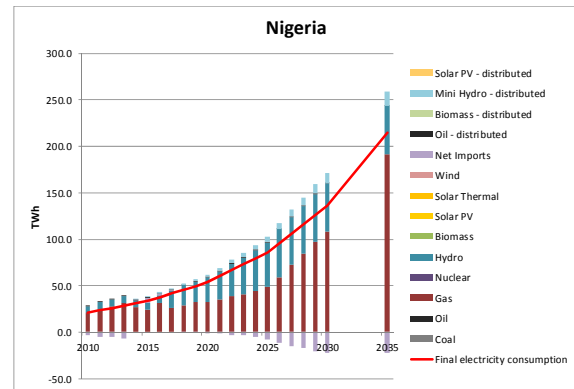
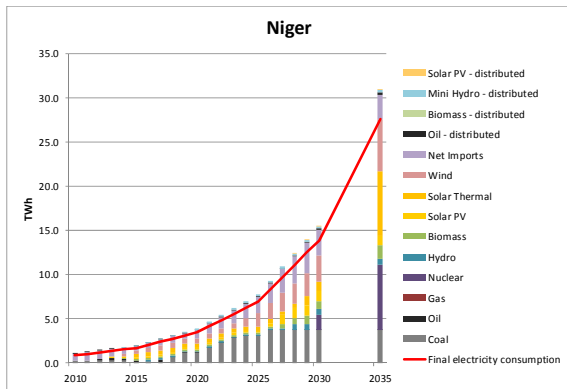
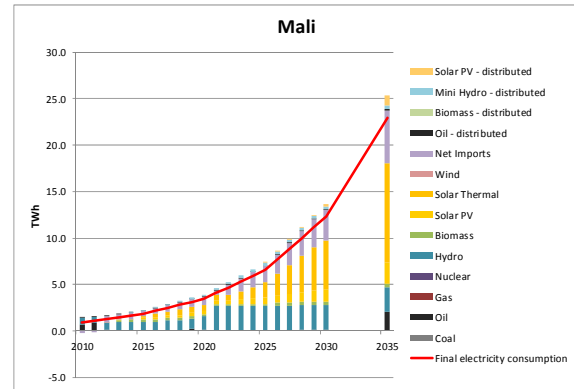
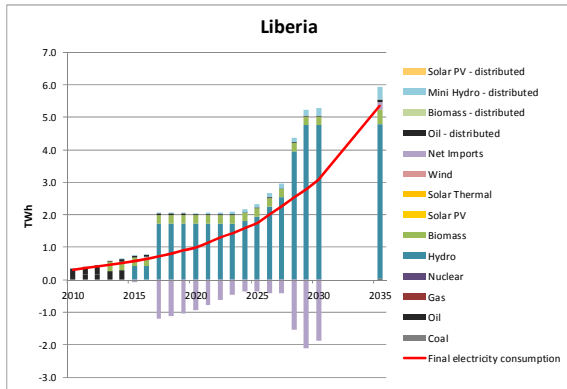
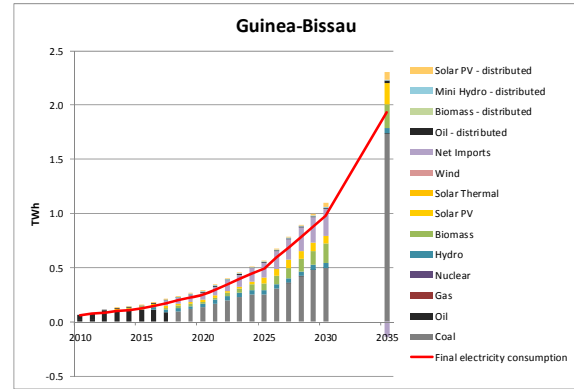
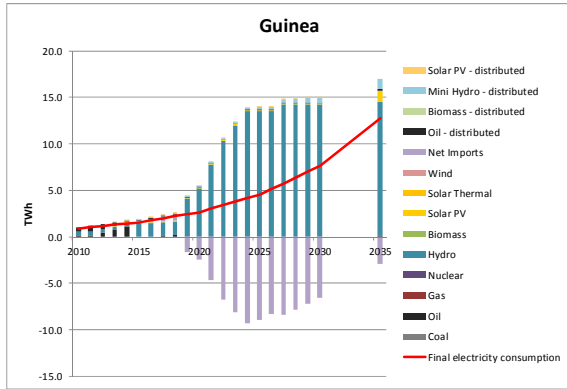
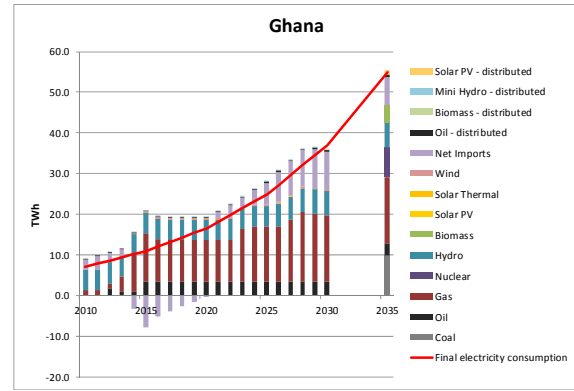
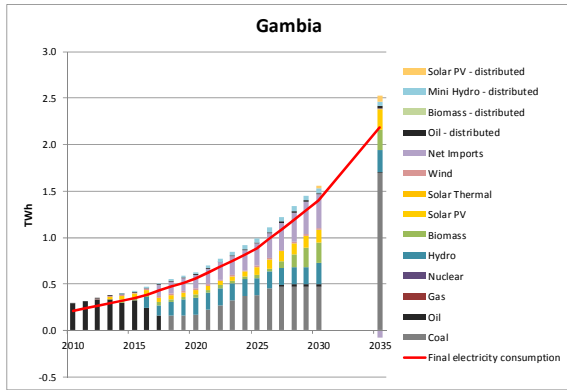
FIG. 40. Carbon dioxide emission under different electricity supply scenarios.

Expected changes in the electricity generation patterns across countries are similar to those of the scenario Cooperation (due to assumption of active development of sub regional markets, i.e. the construction of new interconnection lines). Some countries are becoming net electricity exporters as presented in Figure 41.

¹⁸ The use of oil was not limited.

- The largest changes are visible in Guinea, Liberia and Sierra Leone. The local hydro potential available in these countries could have a large impact on the sub regional market and lead to increased electricity trade. Nigeria is also expected to increase its net exports under this scenario.
- Countries like Burkina Faso, Togo, Benin and Niger are expected to continue to import electricity. For Burkina Faso the use of solar thermal and PV installation proves to be the preferable local generation option.
- Cote d'Ivoire relies on domestic hydro and natural gas. At the beginning of the period surplus electricity is exported, but after 2015 there is an economic benefit from electricity import.
- Similar to other scenarios, Gambia and Guinea Bissau could see a complete change in the generation structure, diverting from oil based supply to diversified production from coal, hydro, solar and biomass plants.
- In the mid term, Ghana is expected to export some of its hydro and gas based generation, but from 2022 onwards it will become a net importer. The share of gas is expected to increase over time, while by 2035 the introduction of nuclear power proves to be the most economical option. Nuclear power is also competitive in Niger from 2030 onwards (smaller unit sizes).
- For Guinea, Liberia and Sierra Leone the most competitive option is to develop local hydro resources and divert from today's predominantly oil based generation. Hydro generation is used to supply domestic demand and surrounding countries.
- After developing its own hydro potential, Mali is expected to orient towards import (from 2020) and development of solar technologies (strong after 2025).
- Imported coal is used in Gambia, Guinea Bissau, Senegal and Togo/Benin, while only Niger uses domestic coal. In this scenario, the use of coal increases in absolute and relative values, as more generation is needed to supply increasing consumption.
- The largest system in the sub region, Nigeria, relies completely on hydro and gas generation with increasing export to neighbouring countries (Togo/Benin, Niger) towards 2035.





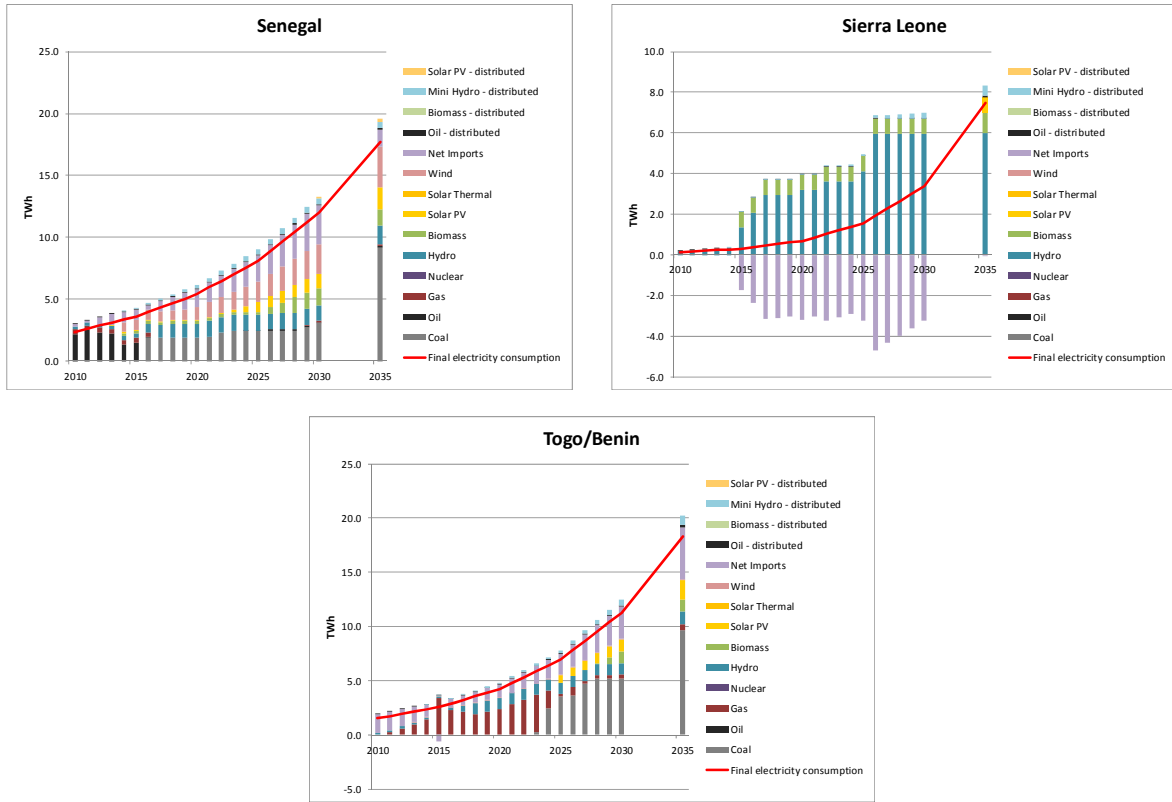


FIG. 41. Electricity generation by country for scenario SE4ALL.

The structure of annualized electricity generation costs for this scenario is given by Figure 42 (excluding annualized investment costs for the existing generation units). The annual generation costs are expected to increase about nine times until 2035 to 45.01 billion USD. At the end of the period, almost 60% of the annual generation costs will be fuel costs. The overall generation cost is higher compared to the two scenarios with Reference scenario electricity demand.

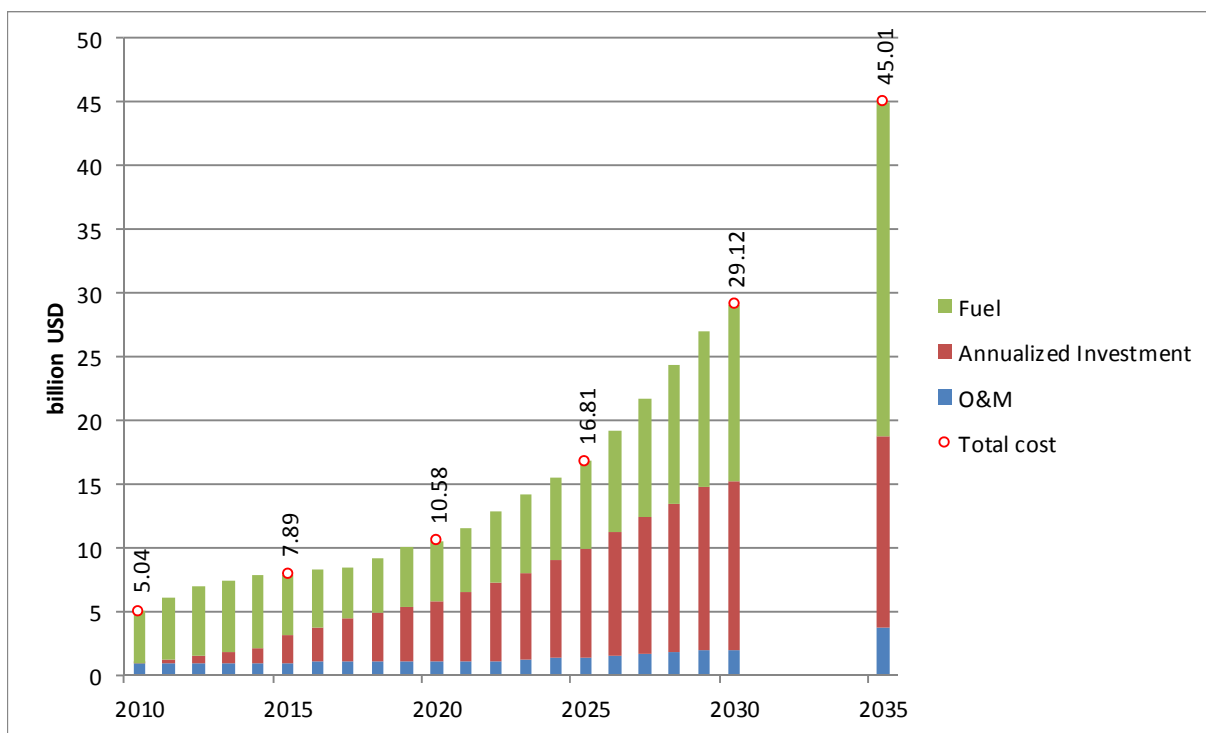


FIG. 42. Structure of electricity generation costs for scenario SE4ALL.

The total investment into generation (centralized and distributed) and transmission/distribution (local and interconnections) during 2010-2035 period is expected to reach 379.1 billion USD, which is an increase by almost 50% compared to the other two scenarios (see Table 22).

TABLE 22. INVESTMENTS INTO GENERATION AND TRANSMISSION ASSETS FOR SCENARIO SE4ALL

billion USD			
Period	Generation Investment	Transmission Investment	Total
2010-2014	11.1	9.0	20.1
2015-2019	25.6	13.9	39.5
2020-2024	31.7	23.6	55.3
2025-2029	44.1	40.8	84.9
2030-2035	102.0	77.2	179.2
Total	214.5	164.6	379.1

4.4. COMPARATIVE ANALYSIS OF SCENARIOS

This chapter presents a comparative analysis of the electricity supply scenarios discussed in the preceding three sub chapters: Business as usual (BaU), Cooperation and SE4ALL (including its dependant scenario, SE4ALL LES).

In terms of the installed capacity, the most visible change over the study period is a shift from a fossil fuel based generation portfolio in 2010 (76%) to a more balanced and diversified supply in 2035. The structure of installed capacity in 2030/2035 is similar for the Business as usual and Cooperation scenarios, while in the SE4ALL and SE4ALL LES scenarios, a higher penetration of other RES sources is expected (see Figure 43).

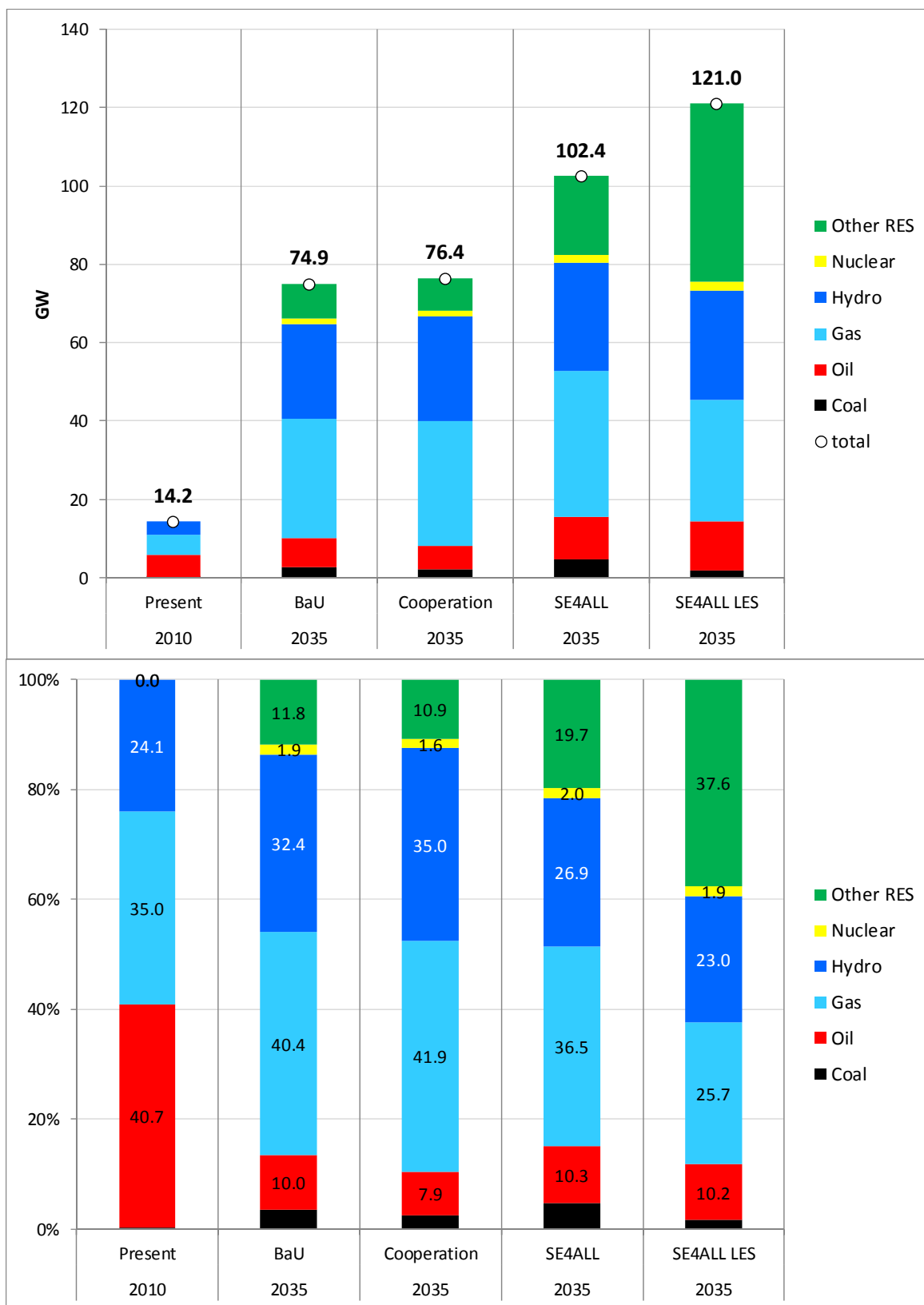


FIG. 43. Comparison of installed capacity across supply scenarios.

The share of RES technologies is expected to increase in all scenarios due to the rapid development of local hydro potential and the use of other RES options, primarily of solar thermal and solar PV. In three cases (Business as usual, Cooperation and SE4ALL), the share

of RES will almost double, from 24% in 2010 to 44 47% in 2035, while under the SE4ALL LES scenario, the total RES share goes to 60%.

At the same time, the share of fossil based generation assets will be reduced, and by 2035 it will represent slightly more than half of the total capacity (Business as usual, Cooperation and SE4ALL scenarios). Natural gas plants will play the most important role, while the use of coal proves to be competitive in some of the coastal countries and in Niger. Oil based generation will not disappear and in some cases will even increase in absolute numbers, but its relative contribution will be reduced significantly to 810%.

Nuclear power is an option open from 2030 onwards and was deployed in all scenarios. A variation of scenario assumptions showed that if nuclear option was excluded, more fossil based generation would be used; resulting in higher carbon dioxide emissions and in increased average generation costs.

Reaching the target of universal electricity access by 2030 or 2035 will require the installation of substantial additional generation capacities. The required installed capacity in 2030 in the SE4ALL scenario is 19.9% higher than in the Cooperation scenario. This difference increases in 2035 to 34.1%. If the same target of universal access is to be reached by keeping use of fossil fuels at the Business as usual scenario level, this difference increases further, showing the magnitude of additional actions and efforts needed to achieve the objective of sustainable energy development (see values for SE4ALL LES scenario in Table 23).

TABLE 23. COMPARISON OF INSTALLED CAPACITY ACROSS SCENARIOS

Total installed capacity, GW				
	Business as usual	Cooperation	SE4ALL	SE4ALL LES
2030	60.1	63.1	75.7	84.0
2035	74.9	76.4	102.4	121.0
Difference to Business as usual scenario, GW				
	Business as usual	Cooperation	SE4ALL	SE4ALL LES
2030		3.0	15.5	23.8
2035		1.4	27.5	46.1

Market shares in electricity generation are also expected to change, and the power systems become more diversified as presented in Figure 44. The share of fossil fuels is expected to decrease (66% in 2010). The largest drop occurs in the SE4ALL and SE4ALL LES scenarios in which penetration of other RES options (i.e. without hydro) is the highest. In all cases, the contribution of all RES sources to generation increase from 34% in 2010 to at least 37% (Business as usual) and up to 52% (SE4ALL LES).

Natural gas will remain the most important fossil fuel resource in all scenarios. Its contribution to overall supply is estimated between 39% and 54%. Oil based generation will still be present, but its share will drop to 1 3% of total supply. Coal could be deployed in several coastal countries (import) and in Niger. Nuclear power reaches a market share of 2 3%.

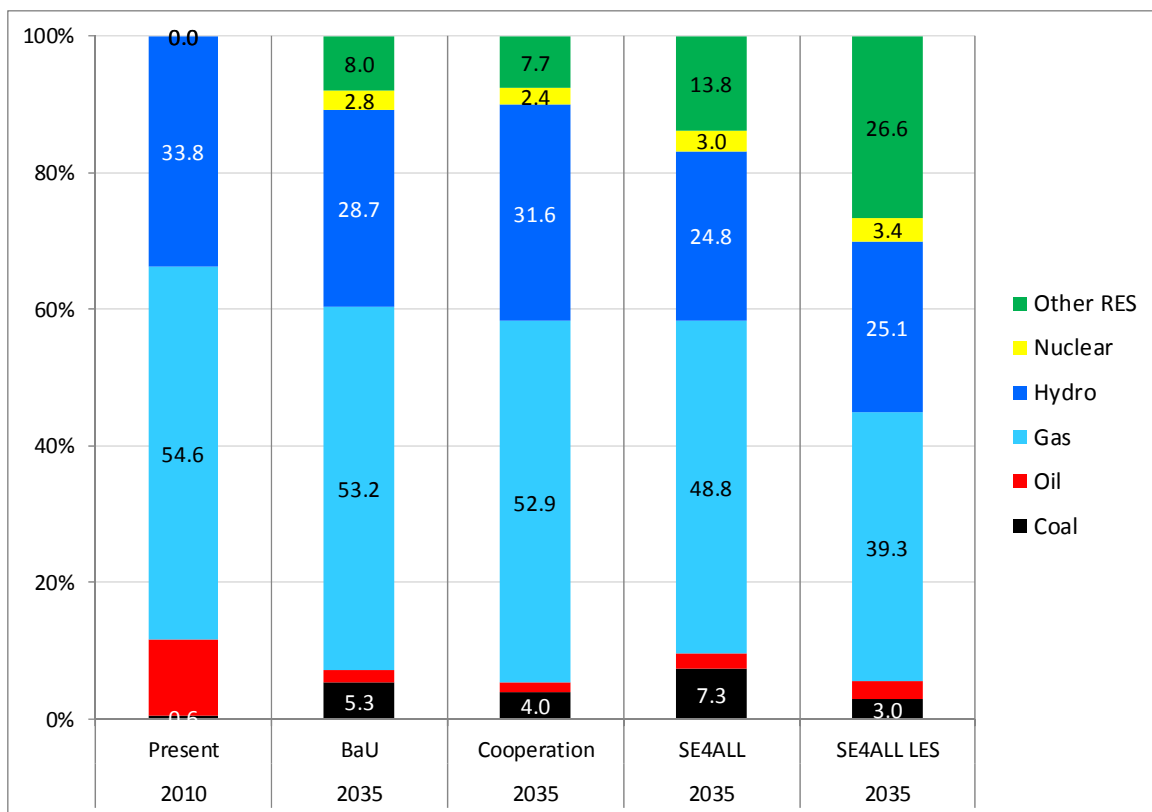
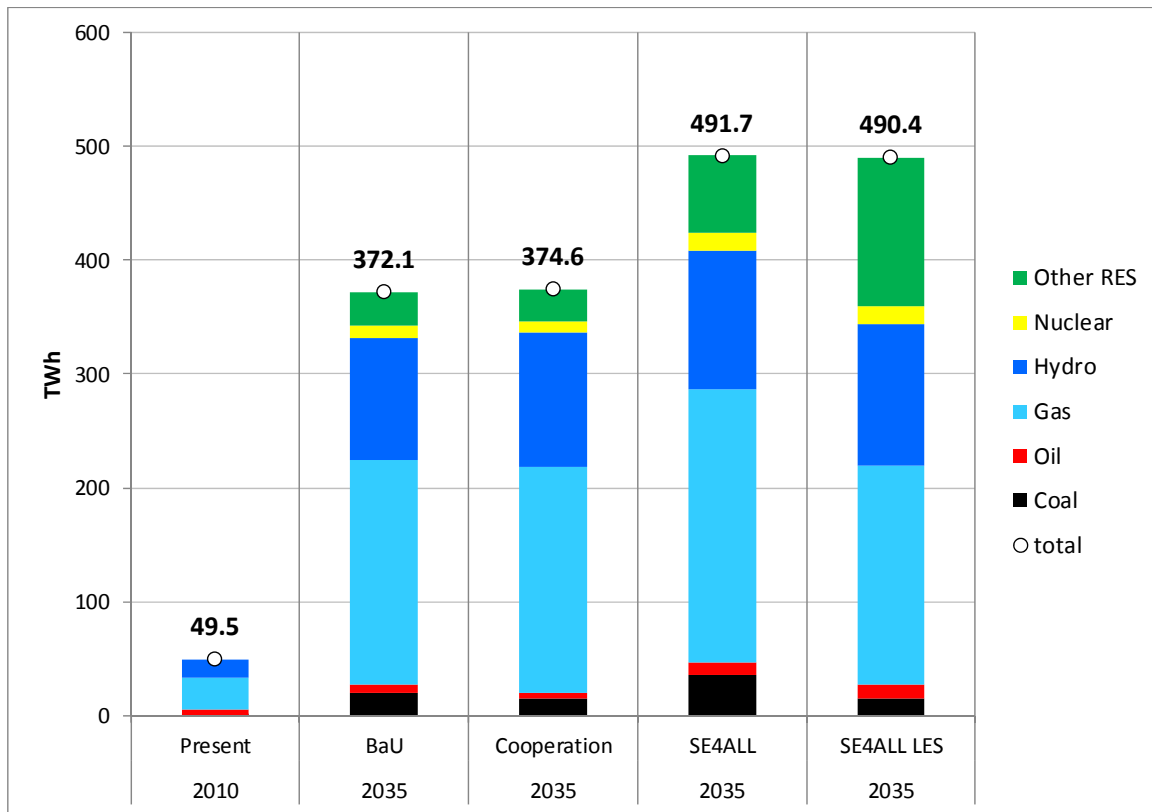


FIG. 44. Comparison of electricity generation structure across supply scenarios.

Direct carbon dioxide emission (from the combustion of fossil fuels) is presented in Table 24 and Figure 45. The cumulative CO₂ emission in the period 2010-2035 is expected to reach between 1.02 Gton (scenario Cooperation) and 1.24 Gton (scenario SE4ALL). This indicates

that reaching the objectives defined under the universal electricity access scenario will cause additional environmental burden, i.e. a cumulative increase of CO₂ emission by up to 21.7%.

The SE4ALL LES scenario seeks to limit environmental stress to the same level as under the Cooperation scenario. In all cases the contribution of nuclear power to this target was evident, i.e. without nuclear power, carbon dioxide emissions were even higher.

TABLE 24. COMPARISON OF CO₂ EMISSION ACROSS SUPPLY SCENARIOS

CO ₂ emission, Mton				
Scenario	Business as usual	Cooperation	SE4ALL	SE4ALL LES
2010	23.61	23.61	23.61	23.61
2015	27.06	25.88	27.41	25.64
2020	27.10	24.54	27.46	24.36
2025	37.61	31.51	41.21	32.53
2030	66.87	60.12	75.45	62.38
2035	112.40	104.82	148.93	110.60
Cumulative Emission 2010-2035, Mton	1124.9	1022.1	1244.0	1052.8
<i>Difference to Business as usual, Mton</i>		+102.8	+119.1	+72.0
<i>Difference to Business as usual, %</i>		+9.1	+10.6	+6.4

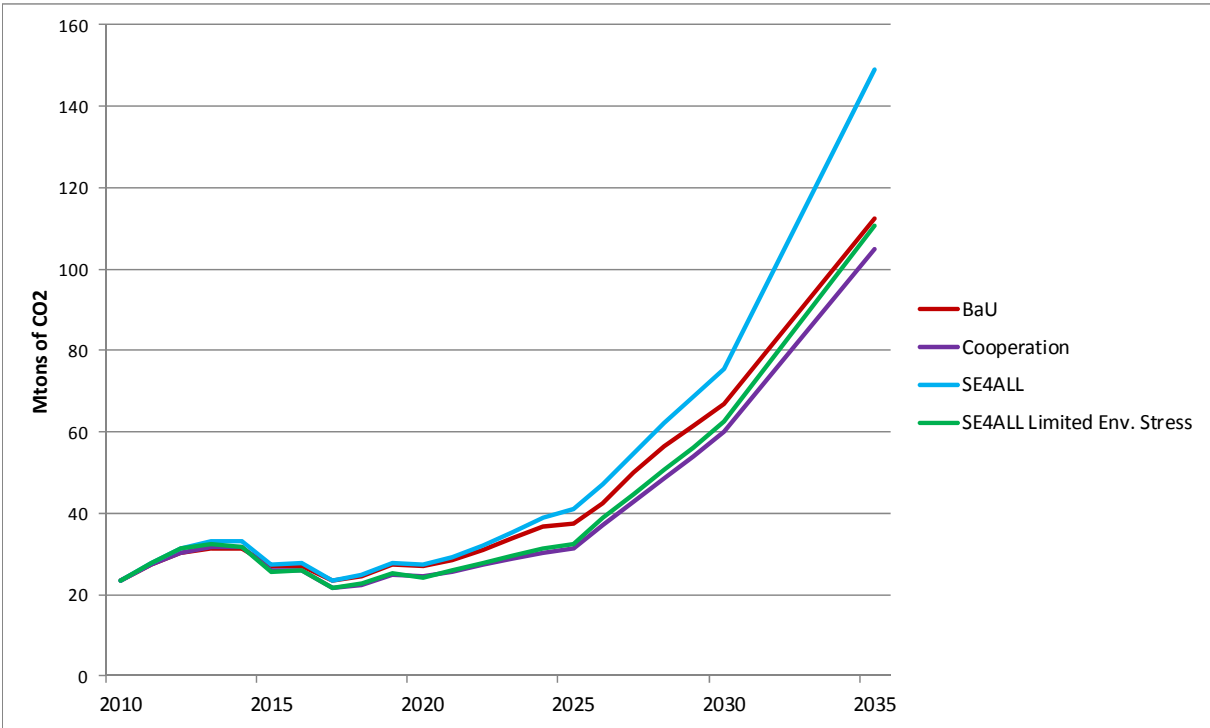


FIG. 45. Comparison of CO₂ emission across supply scenarios.

The increased electricity consumption under the Universal access scenario (i.e. for SE4ALL and SE4ALL LES scenarios), means that more investments into generation and transmission/distribution assets are needed. The additional investment requirements range from 45% to 58% for the 2010-2035 period as presented in Table 25 and Figure 46.

TABLE 25. COMPARISON OF INVESTMENTS ACROSS SUPPLY SCENARIOS

Investment into generation and transmission, billion USD				
For the 2010-2035 period	Business as usual	Cooperation	SE4ALL	SE4ALL LES
Generation	134.3	136.5	214.5	259.9
Transmission	119.8	124.8	164.6	154.2
Total	254.1	261.4	379.1	414.1
<i>Difference from Business as usual, billion USD</i>		+7.2	+124.9	+160.0
<i>Difference from Business as usual, %</i>		+2.8	+49.2	+63.0

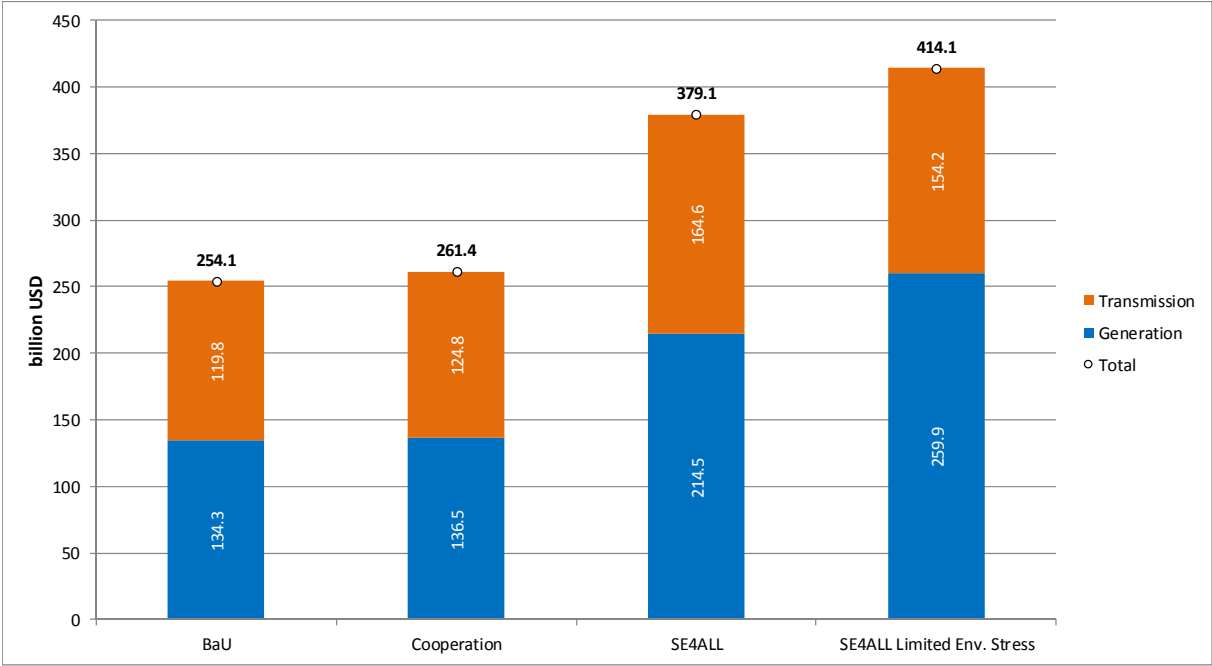


FIG. 46. Comparison of investments in period 2010-2035 across supply scenarios.

The average supply cost at sub regional level is expected to decrease over the planning period as presented in Table 26 and Figure 47. Changes in average supply costs are influenced by several factors: undeveloped hydro potential, increases in fossil fuel prices, assumed decrease in specific investment costs of renewable technologies and expected changes in the consumption structure, which will influence dynamics of investments into transmission and distribution networks.

TABLE 26. COMPARISON OF AVERAGE GENERATION COST ACROSS SUPPLY SCENARIOS

Average generation cost, USD/MW·h				
Scenario	Business as usual	Cooperation	SE4ALL	SE4ALL LES
2010	102.7	102.6	102.6	102.7
2015	108.4	104.6	104.6	105.9
2020	95.9	92.6	92.6	94.5
2025	95.7	91.4	91.4	94.7
2030	102.2	97.1	97.1	104.1
2035	96.0	92.0	92.9	96.6

At the beginning of the planning period, the average generation cost increases due to an increase in demand and a need to use more expensive oil based generation units (only oil based generation can be developed in a short time frame). After an initial increase, the generation cost is expected to decrease in all cases, as local hydro projects are developed and completed.

The trend of declining generation costs lasts until 2022, when most of the cheap hydroelectric power sites have been developed and more expensive options must be deployed to meet a still increasing demand (combined with an increase in fuel prices). After 2022, the average generation cost increases until 2030. Beyond 2030, costs are expected to decrease slightly due to a combination of several factors: increased use of other RES options with decreasing specific investment costs (due to technological learning), and changes in the structure of consumption which will influence the need to invest in domestic transmission and distribution systems (i.e. change of shares of different categories of consumption).

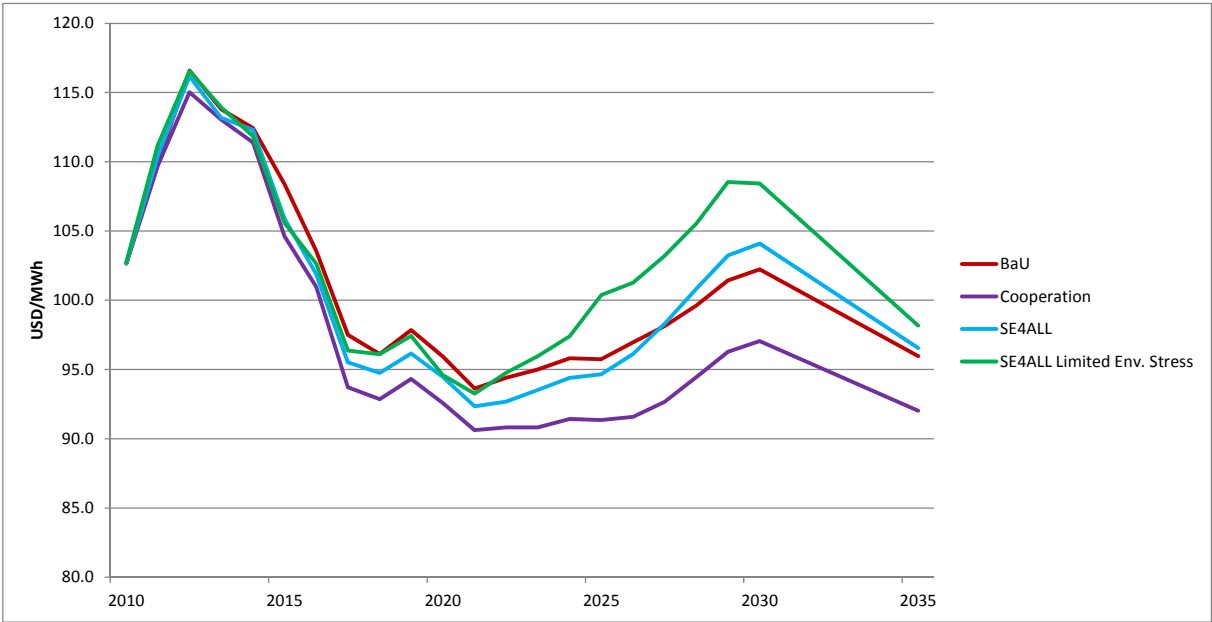


FIG. 47. Comparison of average supply cost across all supply scenarios.

The lowest average generation cost is achieved under the Cooperation scenario, which clearly demonstrates benefits of joint development. Achieving universal electricity access will require investment in more expensive options, which in turn will result in an increase of average

generation costs. However, cooperation between countries would allow to keep cost at the same level that countries would have when pursuing separate national strategies (i.e. under the Business as usual scenario). In other words, at approximately the same level of cost for final users, it would be possible to substantially increase electricity access and affordability as presented by Figure 48.

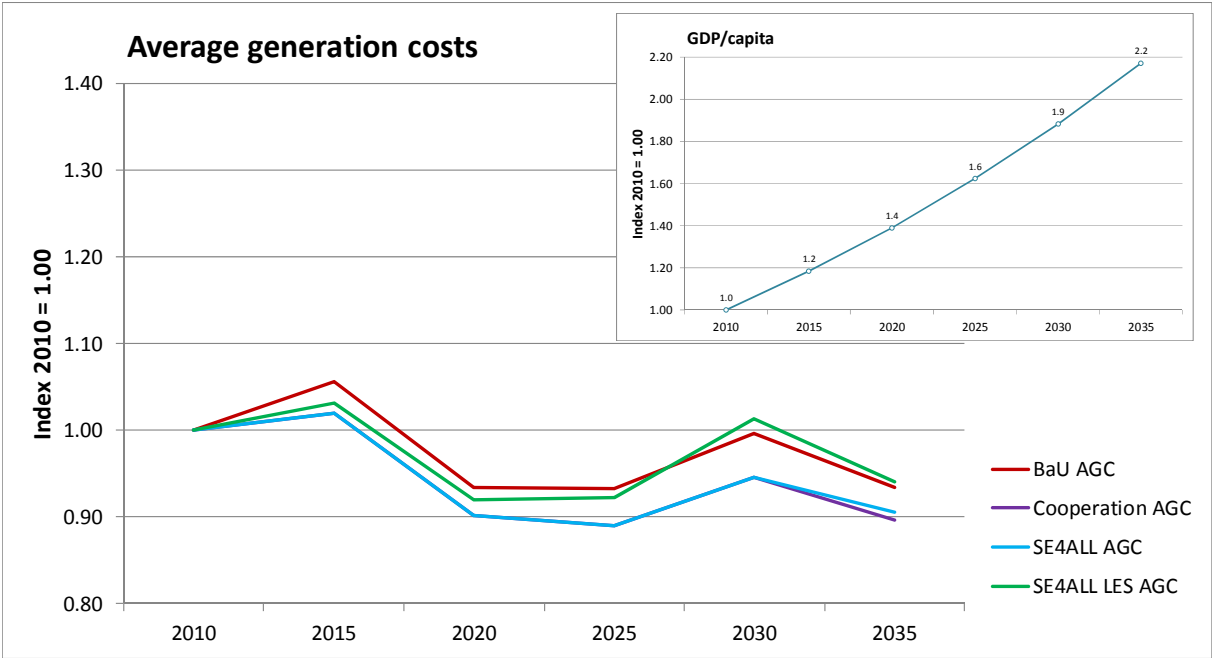


FIG. 48. Trend of average generation cost across supply scenarios and GDP/capita change.

Increasing electricity access and electricity supply and at the same time avoiding additional environmental burden will result in increased generation costs. Still, the overall decrease of average generation costs in the 2010-2035 period will contribute to increased affordability of electricity.

While the GDP per capita is expected to double by 2035, average generation costs are expected to decrease by 610% (in real terms), which should help make electricity more affordable. Further development of local renewable energy supply industries and services could additionally increase personal income and thereby increase the affordability of electricity.

5. CONCLUSIONS

This report presents the outcome of a study carried out by IAEA Member States in West Africa in the years 2012 to 2013 on future options for sustainable electricity supply in the region.

The study was supported by the IAEA's Technical Cooperation (TC) Project *RAF2009 Planning for Sustainable Energy Development*, in particular through training of experts in participating Member States in the use of the IAEA's energy assessment tools, which was then used to conduct the study, through the provision of expert support for conducting the national and sub regional studies, and through the provision of overall coordination and support for the preparation of this report.

The West African sub region is richly endowed with diverse energy and mineral resources. Although these resources can support meaningful industrial activity, and thus promote sustainable socio economic development, the region lags behind many developing regions of the world in human development. For instance, 13 out of the 15 member countries are classified as Least Developed Countries and 60% of the total population of 300 million live on less than one dollar per day. Against this background, access to energy and in particular to electricity is of prime importance for continued and sustainable socio economic development in the sub region.

The main objective of this study was to understand and assess future options for electricity supply at the lowest costs in the West African sub region. The study also examines energy resources and investment requirements for achieving universal access to electricity in the region by 2030/2035.

This study was conceived based on the idea of providing a coherent sub regional platform for the development of a robust sub regional policy framework for an enhanced and sustainable provision of electricity services to support socio economic growth.

The principal approach used in the study is scenario analysis supported by a mathematical model of the national and sub regional electricity systems. According to the Intergovernmental Panel on Climate Change (IPCC) [1], "Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future outcomes and to assess the associated uncertainties. Any scenario necessarily includes subjective elements and is open to various interpretations". A scenario is not a prediction of the future, but an internally consistent description of a future state or trajectory that is as comprehensive as needed for the purposes of the analysis.

A scenario based approach was chosen because the future is inherently uncertain. It was considered preferable to analyse and understand the implications of different potential development paths, rather than to try to predict the future, with a risk to irrevocably stick to solutions that are less robust, less flexible and more sensitive to uncertainties.

1. As first step, basic assumptions were made regarding demography and economic growth, based on available UN and national information.
2. As second step, two electricity *demand* scenarios were developed (Reference scenario and Universal access scenario). These scenarios contain detailed information on the demand side for electricity, until 2030, at country level.

3. As third step, possible *supply* scenarios to *meet this demand* were modelled by applying IAEA's energy system assessment tool and modelling framework MESSAGE, a flexible and versatile tool specifically designed for complex energy system analyses.
4. In a fourth step, these electricity supply scenarios were analysed as basis for the overall final conclusions.

Two electricity demand scenarios were defined and analysed:

- Under the Reference scenario, sub regional electricity access by 2030 will reach 67%, but large disparities between and within countries will remain. In many countries, a significant part of their population will not have access to electricity (e.g. in many countries electricity access in 2030 will range between 42% and 60%), and many rural areas will continue to rely on biomass.
- The Universal access scenario demand scenario seeks to bring electricity to all and reduce disparities within and among countries, bringing the whole sub region to a common development path. The Universal access scenario assumes additional policy efforts and field actions to speed up the electrification programs, both in urban and rural areas, so that by 2030/2035 all population in West Africa enjoys affordable, reliable and sustainable electricity supply. Reaching universal electricity access requires substantial policy and field actions. Electricity systems will have to develop more rapidly so that the current deficiencies in electricity supply are eliminated.

In order to meet the demand defined in the above electricity demand scenarios, three supply scenarios were defined: Business as usual (BaU), Cooperation and SE4ALL. In all three electricity supply scenarios, all technological options were considered in line with the availability of resources in each country. The first two (Business as usual and Cooperation) are based on the demand from the Reference scenario. The third electricity supply scenario SE4ALL, is based on the demand from the Universal access scenario.

The time horizon covered by the study is from 2010 until 2030.

The final analysis of both the demand and the supply scenarios yield the following findings and conclusions:

- A substantial effort is needed to increase generation capacity in order to meet the rapidly increasing demand.
 - Under the Cooperation scenario the installed electricity generation capacity has to be increased from 14.2 GW in 2010 to 63.1 GW in 2030 (a four times increase) and further to 76.4 GW in by 2035 (a more than five times increase).
 - Reaching the target of universal electricity access by 2030/2035 would require the construction of additional generation capacities. The required installed capacity in 2030 is 20% higher in the SE4ALL scenario than in the Cooperation scenario. This difference increases to 34% by 2035. If the same target of universal access is to be reached by keeping use of fossil fuels at the Cooperation scenario level, the difference increases further, showing the magnitude of additional actions and efforts needed to get onto a sustainable energy development path.
- A shift from predominantly fossil fuel based generation portfolio in 2010 (76% of installed capacity) to a more balanced and diversified supply by 2035 is expected.

- Due to the rapid development of local hydropower and the use of other renewable energy options, primarily solar thermal and solar photovoltaic, the share of renewable energy is expected to almost double, from 24% in 2010 to 44-47% in 2035 (for Business as usual, Cooperation and SE4ALL scenarios), while in the case of SE4ALL LES (Less Environmental Stress), the total RES share increase to 60%.
- Fossil fuel based electricity generation remains important, with a share in total electricity generation between 40 and 54%, depending on the scenario. Natural gas based electricity generation makes up the majority of the additional fossil fuel based generation. Oil fired units are still present as both centralized, and decentralized options. In many instances, these units are used as back-up power sources or to provide supply when intermittent sources are not available. Coal based electricity generation is increased, but their share remains relatively low.
- Nuclear power proves to be competitive from 2030 (estimated as the earliest year of the first installation) onwards. By 2035, nuclear power reaches 1.2 to 2.4% of the total installed electricity generation capacity.
- The structure of electricity generation is expected to change and become more diversified:
 - The share of fossil fuels is expected to decrease (66% in 2010). The largest drop is expected under the SE4ALL and SE4ALL LES scenarios, when penetration of other RES options (i.e. without hydro) is expected to increase significantly;
 - In all cases the contribution of all RES options to electricity generation is expected to increase from 34% in 2010 to at least 37% (Business as usual) and up to 52% (SE4ALL LES);
 - Natural gas will remain the most important fossil fuel resource under all scenarios. Its contribution to the overall supply is estimated between 39% and 54%. Oil based generation will still be present, but its share will drop to 13% of total supply. Coal could be deployed in several coastal countries (import) and in Niger;
 - Nuclear generated electricity contributes 23% to total generation.
- The electricity exchange across national borders is expected to increase over the study period:
 - The capacity of interconnecting electricity grids is expected to increase (based on economic incentives and differences among countries regarding energy resources), setting the stage for an increase in electricity trade between countries. Increased trade in turn allows an additional decrease of the average electricity generation cost in the sub region.
- The environmental burden estimated in terms of the direct carbon dioxide emission (from combustion of fossil fuels) will increase:
 - The cumulative CO₂ emission in the period 2010-2035 is expected to reach between 1.02 Gton (scenario Cooperation) and 1.24 Gton (scenario SE4ALL), indicating that providing universal electricity access may lead to increased environmental stress (i.e. cumulative increase of CO₂ emission by up to 22%);

- The SE4ALL LES scenario seeks to lower carbon emissions to the levels achieved under the Cooperation scenario (i.e. cumulative increase of CO₂ emission is only 3% compared to Cooperation scenario);
- The carbon intensity of electricity supply is expected to increase from 78.6 kg/capita in 2010 to 200272 kg/capita in 2035, but the sub region will remain among the less carbon emitting regions of the world;
- In all cases, the contribution of nuclear power to lowering carbon emissions was evident. Sensitivity analysis showed that if nuclear power is excluded, carbon dioxide emissions and average generation cost will increase.
- Increased electricity access requires increased investments into generation, transmission and distribution assets.
 - In order to reach the SE4ALL objective of universal electricity access, between 45% and 58% more investments are needed in the period 2010-2035.
- The average electricity generation costs is expected to decrease:
 - Securing universal electricity access while at the same time avoiding additional carbon emissions (i.e. scenario SE4ALL LES) will result in slightly increased generation costs (relative to the Business as usual scenario). However, there is an overall decrease in average electricity generation cost between 2010 and 2035 that will contribute to increased electricity affordability.
 - The GDP per capita is expected to more than double by 2035, while average generation costs are expected to decrease by 610% (in real terms), which should lead to higher affordability. The development of local renewable energy supply industries and services could additionally increase personal income and increase affordability of electricity.

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ABBREVIATIONS

ABN	l'Autorité du Bassin du Niger
AFD	Agence Française de Développement
AfDB	The African Development Bank
AIE	Agence Internationale de l'Energie (in English IEA)
AMADER	Agence Malienne pour le Développement de l'Energie Domestique et de l'Electrification Rurale
ANADEB	Agence Nationale de Développement des Biocarburants, Mali
BID	Banque Islamique de Développement
BM	Banque Mondiale
BOAD	Banque Ouest Africaine de Développement
BPSD	Barrels Per Stream Day
CCGT	Combined cycle gas turbine
CDM	Clean Development Mechanisms
CEB	Communauté Electrique du Benin
CEDEAO	Communauté économique des États de l'Afrique de l'Ouest
CEP	Common Energy Policy (of the WAEMU)
GHG	Greenhouse Gas Emission
CIA	Central Intelligence Agency
CIE	Compagnie Ivoirienne d'Electricité
CNESOLER	Centre National de l'Energie Solaire et des Energies Renouvelables, Mali
CSLP	Cadre Stratégique de Lutte contre la Pauvreté
CSP	Concentrated Solar Power
DDO	Distillate Diesel Oil
DISCO	Electricity Distribution Company, Nigeria
DNE	Direction Nationale de l'Energie, Mali
DNI	Direct Normal Irradiance
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States (in French CEDEAO)
ECOWREX	ECOWAS Observatory for Renewable Energy and Energy Efficiency (in French: L'Observatoire de la CEDEAO pour les Energies Renouvelables et l'Efficacité Energétique)
ECREEE	The ECOWAS Regional Centre for Renewable Energy and Energy Efficiency
EE	Energy Efficiency
EIB	European Investment Bank
EICVM	L'Enquête Intégrale sur les Conditions de Vie des Ménages
EPRS	Electric Power Sector Reform, Nigeria
ERERA	ECOWAS Regional Regulatory Authority
FCFA	Franc CFA
FDE	Fonds de Développement de l'Electrification (Burkina Faso)
GDP	Gross Domestic Product (in French PIB)
GENCO	Electricity Generation Company, Nigeria

GHI	Global Horizontal Irradiance
GNL	Gaz Naturel Liquéfié
GRIDCo	Ghana Grid Company Ltd.
GSGDA	Ghana Shared Growth and Development Agenda
HFO	Heavy Fuel Oil
HDI	United Nations' Human Development Index
IDB	Islamic Development Bank
IEA	International Energy Agency (in French AIE)
IMF	International Monetary Fund
INS	National statistics institute
INSD	National statistics and demography institute
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
ISO	Independent System Operator
LCO	Light Condensate Oil
LDC	Least Developed Countries
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MAFS	Ministry of Agriculture and Food Security (in Sierra Leone)
MDG	Millennium Development Goals
ME	Ministry of Energy (in Sierra Leone)
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MF	Ministry of Finance (in Sierra Leone)
MMR	Ministry of Mineral Resources (in Sierra Leone)
MTI	Ministry of Trade and Industry (in Sierra Leone)
MVA	Mega Volt Ampere
MYTO	Multi Year Tariff Order, Nigeria
NEDCo	Northern Electricity Distribution Company Ltd., Ghana
NELMCO	National Electricity Liability Management Company Ltd., Nigeria
NEP	Nigerian Energy Policy
NERC	Nigerian Electricity Regulatory Commission
NIGAL	Trans Saharan Gas Pipeline, also known as TSGP or Trans African Gas Pipeline
NIGELEC	Niger Electricity Company
NPA	National Power Authority (in Sierra Leone)
OMVG	Gambia River Basin Development Authority (in French: Organisation pour la mise en valeur du fleuve Gambie)
OMVS	Senegal River Basin Development Authority (in French: Organisation pour la Mise en Valeur du fleuve Sénégal)
OPEC	Organization of the Petroleum Exporting Countries
PEA	Perspective Economiques en Afrique
PHCN	Power Holding Company of Nigeria
PIB	Produit Interne Brut (in English GDP)

PPER	Programmes Prioritaires d'Electrification Rurale (en Sénégal)
PPP	Power Purchase Parity
PRRSE	Plan de Restructuration et de Redressement du Secteur de l'Energie
PV	Photovoltaic; Photovoltaïque
RE	Renewable energy
REA	Rural Electrification Agency (Nigeria)
RES	Renewable Energy Sources
SCADD	Stratégie de Croissance Accélérée et de Développement Durable
SE4ALL	UN Secretary General's global initiative Sustainable Energy for All
SENELEC	Senegal Electricity Company
SLNPC	Sierra Leone National Petroleum Company
SONABEL	Société Nationale d'électricité du Burkina
SONICHAR	Niger Coal Corporation of Anu Araren
SORAZ	Société de raffinage de Zinder, Niger Oil Company
TCN	Transmission Company of Nigeria
TPES	Total Primary Energy Supply
TSGP	Trans Saharan Gas Pipeline, also known as NIGAL or Trans African Gas Pipeline
UEMOA	l'Union Économique et Monétaire Ouest Africaine (in English WAEMU)
UN	United Nations
UNECA	United Nations Economic Commission for Africa
UNIDO	United Nations Industrial Development Organisation
UPDEA	Union of Producers and Distributers of Electricity in Africa
USAID	United States Agency for International Development
USD	US dollars
VRA	Volta River Authority
WAEMU	West African Economic and Monetary Union
WAGP	West African Gas Pipeline
WAPCo	West African Gas Pipeline Company
WAPP	West African Power Pool

ANNEX I

THE MESSAGE MODEL

I-1. MODEL OF ENERGY SUPPLY STRATEGY ALTERNATIVES AND THEIR GENERAL ENVIRONMENTAL IMPACTS (MESSAGE)

"MESSAGE is a systems engineering optimization model which can be used for medium to long term energy system planning, energy policy analysis, and scenario development (IIASA 2001)" [I-1] – see Figure I-1. The model provides a framework for representing an energy system with all its interdependencies. Scenarios are developed by MESSAGE through "minimizing the total systems costs under the constraints imposed on the energy system using mathematical techniques such as linear programming, mixed integer programming and nonlinear programming. The degree of technological detail in the representation of an energy system is flexible and depends on the geographical and temporal scope of the problem being analysed" [I-1], but could be anything from a global, multiregional, national or municipal energy system. MESSAGE can account for environmental (and other) effects of meeting the energy service need. "It can also include the environmental costs or taxes within its optimization, to help quantify the most sustainable energy scenarios in a given context and under various constraints. MESSAGE, originally developed at the International Institute for Applied Systems Analysis (IIASA), belongs to the same family of models as MARKAL and MERGE and has been widely used both by international organizations, such as the United Nations and World Energy Council, by utility companies" [I-1], as well as by numerous IAEA Member States.

The backbone of MESSAGE is the technical description of the modelled system. This includes the definition of the categories of energy forms considered (e.g. primary energy, final energy, energy service), the energy forms and other commodities actually used (e.g. electricity, coal etc.), as well as the energy service demands required (heating, lighting etc.) by the system. Technologies are defined by their inputs and outputs, their efficiency, and the degree of variability if more than one input or output exists. (Consider for example the co firing of a power plant on both oil and gas.)

These energy carriers, commodities and technologies are combined to construct so called energy/commodity chains, where the energy/commodity flows from supply to the use of energy services. The technical system provides the basic set of constraints to the model, together with demand, that is exogenous to the model. Demand must be met by domestic resources and from imports through the modelled energy chain(s).

The model takes into account existing installations of energy supply (e.g. power station) and using (e.g. boiler) technologies, their vintage and their retirement at the end of their useful life. During the optimization process, together with rising demands, this determines the need to construct new capacity of various technologies. The investment requirements are calculated from the new capacity needs. The levels of operation, investment choice as well as fuel choices are made so as to minimize the overall cost of the system. The system cost can be loosely summarized as the fuel costs entering the system, the cost of investing and operating the chain of technologies required to meet the demand and other cost penalties minus the salvage value of the technologies at the end of the modelling period as well as revenue from exports.

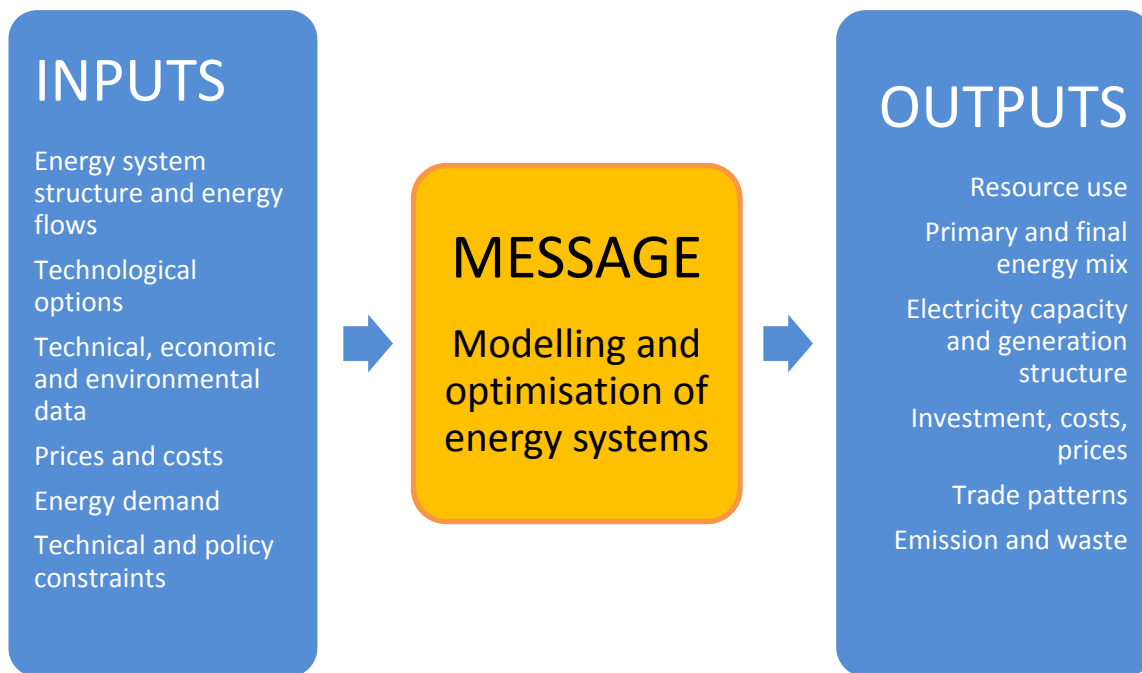


FIG. I-1 Schematic presentation of MESSAGE modelling framework.

For some energy carriers, assuring timely availability entails considerable cost and management effort. Electricity has to be provided by the utility at exactly the same time it is consumed. MESSAGE simulates this situation by subdividing each year into an optional number of so called "load regions." The parts of the year can be aggregated into one load region according to different criteria, for example, sorted according to power requirements or aggregation of typical "demand patterns (summer/winter, day/night). The latter (semi ordered) load representation creates the opportunity to model energy storage as the transfer of energy (e.g. from night to day, or from summer to winter)" [I-1]. Including a load curve further improves the representation of power requirements and the utilization of different types of power plants.

Environmental aspects can be analysed by accounting, penalizing and if necessary limiting, the amounts of pollutants emitted by various technologies at each step of the energy chains. This helps to evaluate the impact of environmental regulations on energy system development. In this application a penalty is associated with CO₂ for certain scenarios.

[I-1] INTERNATIONAL ATOMIC ENERGY AGENCY, MESSAGE – Model for Energy Supply Strategy Alternatives and their General Environmental Impacts, User Manual, IAEA, Vienna (2007).

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