UNIVERSITY OF PIRAEUS
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MSc in Energy: Strategy, Law and Economics

Master Thesis

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Athens, August 2021

Declaration

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Signed: Nikolaos A. Giannios

The Political Economy of Energy in Western Africa: Perspectives and Challenges.

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Finance, MSc / Economics, BSc

A Thesis submitted to the Department of International and European Studies of University of Piraeus in partial fulfillment of the requirements for the degree of Master of Science in Energy: Strategy, Law and Economics.

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Abstract:
Western Africa is at the crossroad of electrification in order to meet both the electricity needs that are coming from the fast population growth and the lack of access to electricity. Since the current situation of low access to electricity is a fact, we have to keep an optimistic view and see as an opportunity the fact that large proportion of additional MWh needed, may come from a sustainable renewable source like Solar, Wind and hydro. Based on the analysis of expected mean efficiency, Solar power dominates over Wind as the future electricity source, while CCG not justifiable to further increase its current share in the electricity production with the construction of new units. Further analysis with the incorporation of efficiency's range volatility turns balance in favor of CCG since as a well-establish technology has a more stable outcome. This last conclusion highlights on the one hand the importance of natural gas as a transition fuel and on the other makes future gas and emission prices fluctuation a crucial factor.

Lower than required macroeconomic development, combined with demographic growth, poor livability and ongoing conflicts, compose an extremely difficult and demanding landscape, the overcoming of which requires a fast-pace transformation of the regional economies' structure from rent-seeking into production oriented ones.

Contents

…to my Mother and Father

MASTER THESIS

The Political Economy of Energy in Western Africa: Perspectives and Challenges.

Introduction

1. The aim of the thesis is to strengthen the view that a large proportion of any additional MWh in Western Africa, may come from a sustainable renewable source.
2. Methodology: The concept of "Leverized Cost of Energy" (LCOE) will be used as this been introduced, defined and published by "Lazard Inc" while regression analysis, Monte Carlo simulation and portfolio theory concept are the main tools in order to analyze the data and predict the efficient mix of power sources.
3. The presentation of the countries that make up the West African region and their respective major Union (ECOWAS) is followed by an overview of economic and demographic analysis and trends in order to determine and identify the main driving forces of future electricity needs. Finally, the ultimate power generation combination is calculated so to meet the estimated needs by 2030.
4. The expected main contribution is to justify from a financial point of view the increased incorporation of renewables like "solar" and "wind" to the future power mix of ECOWAS countries.

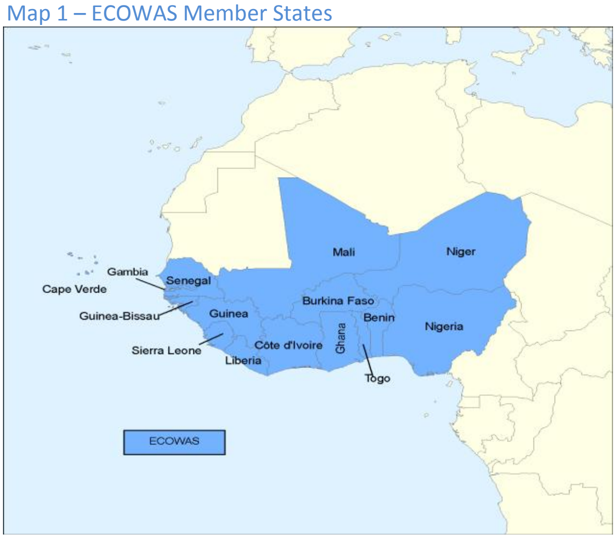
Global economy depends on energy for development since the undisrupted supply of energy sources and the universal power accessibility are beyond any doubt the cornerstone of energy security. In this context the fact that almost the 50% of population of the West African States lack access to electricity is a serious drawback mirroring in the poor development, the absence of structural transformation and consequently the ongoing dependence on commodity markets fluctuation as a result of the heavily dependence on mineral products' exports.

Indicative of the region's power poverty is that electricity consumption per capita is 156 kWh while the global average is 2400 kWh and that the population with access to electricity is 52%. Taking into account that during the last decade the increase of people that gained access to electricity didn't match the increase of the population is obvious that the call for an increased power capacity and expansion and modernization of the grid in a fast pace is urgent, in order to meet both the expected yearly population growth by 2.25% and to cover the present lack of power access.

Currently, West African States are on a crossroad of energy development since they have to cover both the increasing electricity demand and the very limited access to electricity. So, the question arising is which combination of power generation methods is the optimal one. Since the most suitable answer is dependent upon the combination of many variables (e.g. Geography, Financial, Institutions, Local energy resources etc), I will try to give an indication regarding the direction that ECOWAS countries must adopt, from a financial point of view, for the development of their electricity generation capacities and capabilities by comparing and combining three alternative technologies, Solar PV, Onshore Wind and Natural Gas fired power plants while taking into consideration the already planned development of hydro power plants.

The study area is the Sub Saharan African region of the fifteen member states (map 1) constituting the Economic Community of West African States (ECOWAS). These countries have both cultural and geopolitical ties and share common economic interest. “The Atlantic Ocean forms the western as well as the southern borders of the West African region. The northern border is the Sahara Desert, with the Ranishanu Bend generally considered the northernmost part of the region. The eastern border lies between the Benue Trough and a line running from Mount Cameroon to Lake Chad. Colonial boundaries are still reflected in the modern boundaries between contemporary West African states, cutting across ethnic and cultural lines, often dividing single ethnic groups between two or more states” (ECOWAS) . Geographically, two more states are included in the Western Africa region, Sao Tome and Principe and Mauritania.

Map 1 – ECOWAS Member States



Source: Archive: ECOWAS - EU

The ECOWAS Member states:

	Population (2019) mil	Land area ‘000 km^2	GDP (2019) bln constant $ 2010	GDP per capita USD
BENIN	11.8	112.6	14.9	1262
BURKINA FASO	20.32	274,2	16.7	822
CABO VERDE	0.55	4	2.15	3882
CÔTE D'IVOIRE	25.72	322.4	44.42	2276
GAMBIA, The	2.35	10.7	1.91	816
GHANA	30.42	238.5	57.32	1884
GUINEA	12.77	245.8	11.76	921
GUINEA BISSAU	1.92	36.1	1.22	635
LIBERIA	4.94	111.3	2.55	516
MALI	19.66	1240.2	15.56	792
NIGER	23.31	1267	13.13	563
NIGERIA	200.96	923.8	477.2	2374
SENEGAL	16.3	196.7	25.82	1584
SIERRA LEONE	7.81	71.7	3.82	488
TOGO	8.08	56.8	5.63	696
Total	**386.9**	**5111.8**	**694**	**1794**

About ECOWAS

*"*Established on May 28, 1975 via the treaty of Lagos, ECOWAS is a 15-member regional group with a mandate of promoting economic integration in all fields of activity of the constituting countries. Considered one of the pillars of the African Economic Community, ECOWAS was set up to foster the ideal of collective self-sufficiency for its member states. As a trading union, it is also meant to create a single, large trading bloc through economic cooperation" (ECOWAS) .

My point of view

It's common ground for many optimistic policy makers to highlight the key figure of GDP when referred to Western Africa in order to back their suggestions that this part of the world is likely to claim its position in the 21st century, like, for example, the Economic Commission for Africa (ECA) did back in 2012 by arguing that "Africa is likely to make the twenty-first century its own" (UN, ECA, 2012). Unfortunately, this is not the case so far, despite the progress that has been made; the West African countries still has a very long way to go, not towards becoming a growth pole but towards securing a sustainable development for their people.

It's not so realistic to talk about booming economies and prosperity in a region which still heavily suffers by poverty, poor governance, corruption and continued humanitarian crisis caused by insurgent groups, as the one started in Nigeria in 2015 and still goes on by Boko Haram and its faction known as Islamic State West Africa or the coups that broke out in Mali in August 2020 and June 2021.

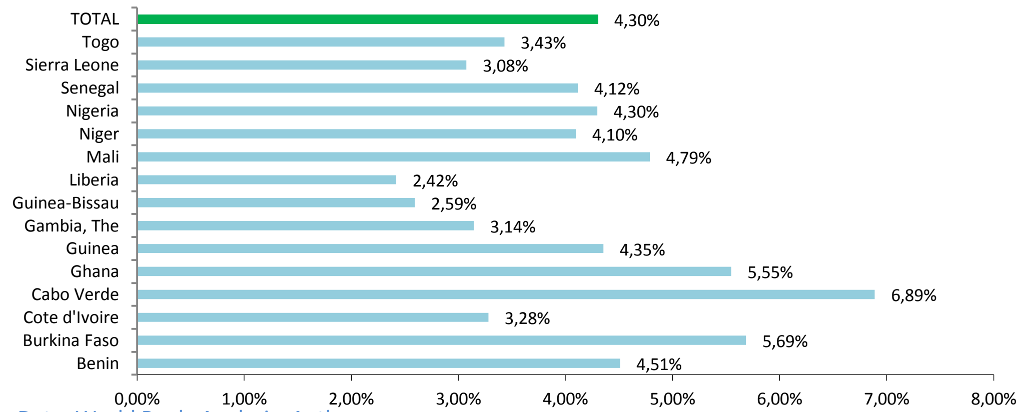
The outlook for the region remains challenging in many aspects since the high economic growth didn't decrease poverty in a substantial manner despite the clear positive linkage between growth and poverty reduction. In a great extend this may be attributed to high income inequality, whose starting point is crucial in determining the magnitude of poverty reduction due to the growth effect (OECD, DFID).

Since a deeper macroeconomic analysis is out of the scope of the current thesis I will highlight the key economic challenges, developments and dependences that the ECOWAS countries have to cope with focusing on the main objective which is an estimation of the direction that must be followed, by the countries of the region, regarding the future development of the vital electricity-generation parameter.

General Economic Outlook

Gross Domestic Product: In terms of GDP the Western African countries under consideration evidenced a high level of growth during the last 30 years (1990 to 2019) with an average total increase equal to 4.30%. The average increase for each country is presented below in Graph 1.

Graph 1 - GDP avg growth rate (1990 - 2019) constant 2010 $

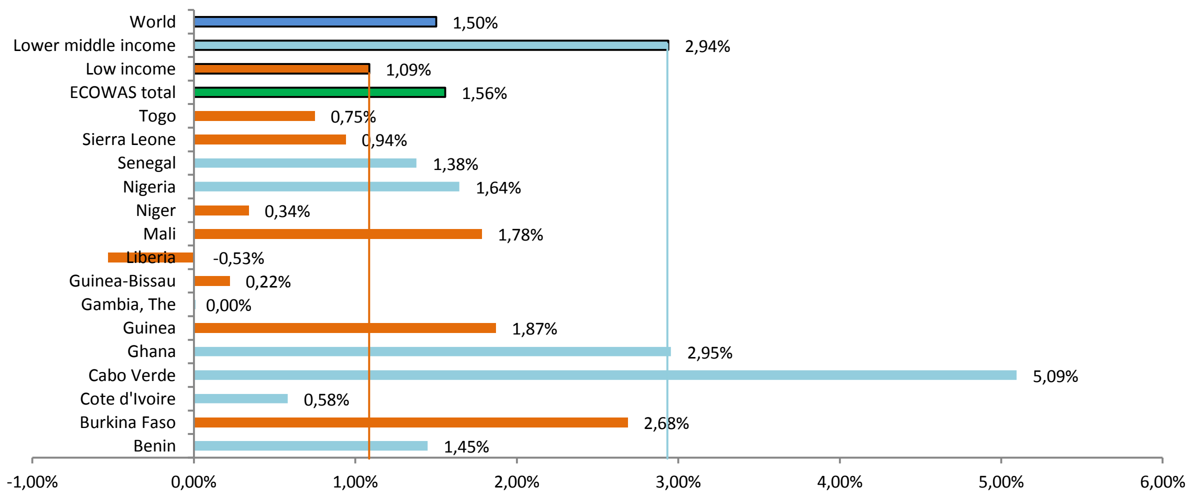


Data: World Bank, Analysis: Author

GDP per capita:

The aforementioned GDP growth is not enough to put this particular group of countries on track of sustainable development, not only because of structural problems, like poor institutionalization, corruption, decrease in manufacturing, limited access to electricity and heavy reliance on minerals rents, as we will analyze later, but also because this growth has been largely "erased" by the population growth which, as an average of the total, was 2, 70% for the period 1990 – 2019. The weighted to population yearly average growth of GDP per capita (WORLD BANK) for the same period, presented in Graph 2, is comparable to the total GDP growth. For comparison purposes, the average growth rate for the "world" as well as for the "low income" and "lower middle income" countries worldwide, based on the relevant classification by the UN, has been added.

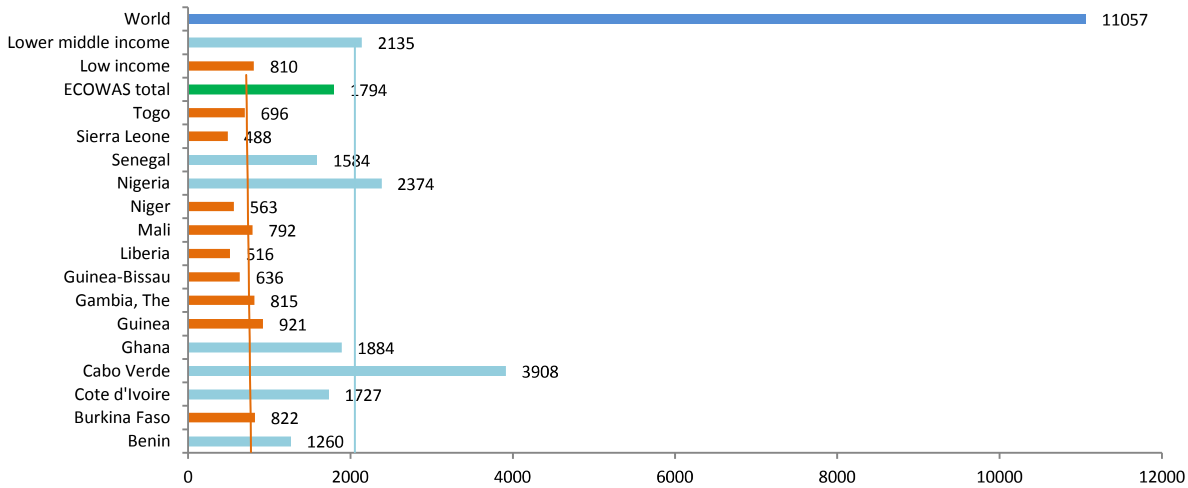
Graph 2 - GDP per capita avg growth rate (1990 - 2019) constant 2010 $



Data: World Bank, Analysis: Author

There are five out of the fifteen ECOWAS countries that outperform the average growth rate of their global "peers" in term of income. More specifically, the smallest economy of the region Cabo Verde exceeded by 2.15% the average growth of its class (lower middle) while Ghana's average growth equals the average of the same class. In the "low income" class, only three out of nine countries exceed their respective peers' average growth, namely, Mali, Guinea and Burkina Faso. Nigeria, which is the largest economy of the region in terms of GDP, falls short of its class average by 1.30%. The absolute values of GDP per capita in constant 2010 USD as of 2019, are presented in Graph 3.

Graph 3 - GDP per capita in constant 2010 USD



Data: World Bank, Analysis: Author

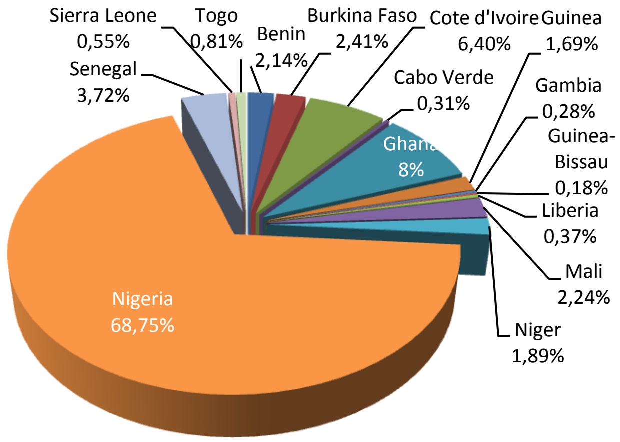
Sectoral breakdown of Economies:

In terms of absolute values Nigeria is by far the biggest economy in the area with a GDP that exceeds $477 bln thus representing the 68.75% of the total GDP in constant 2010 USD (Graph 4).

Country	bln $
Benin	14,87
Burkina Faso	16,71
Cote d'Ivoire	44,42
Cabo Verde	2,15
Ghana	57,32
Guinea	11,76
Gambia, The	1,91
Guinea-Bissau	1,22
Liberia	2,55
Mali	15,56
Niger	13,13
Nigeria	477,16
Senegal	25,82
Sierra Leone	3,82
Togo	5,63
TOTAL	694,02

World Bank GDP 2019 / constant 2010 $

Graph 4 – Percentage allocation of total GDP



Data: World Bank, Analysis: Author

The sectoral breakdown of GDP (UNITED NATIONS, 2021) (tables 1, 2) as well as the exports diversification based on United Nations “International Standard Industrial Classification of All Economic Activities” (ISIC) (UNITED NATIONS, 2008) reveals the heavy reliance of the Western African economies on agriculture and natural recourses and the fact that region’s economic model has changed very little, over the years, towards productive, added value and innovative activities like manufacturing. Agriculture and natural resources remain the main drivers, and Africa has diversified its economies in little meaningful way, while the absence of the production’s diversification is one of the major drawbacks for development, a common conclusion that comes up in almost every regional economic outlook made by international organizations during the past decades.

UN - 2019 Shares of breakdown of GDP/Value Added at current prices in % table 1[1]

Benin	(ISIC A-B)	29,4	Ghana	(ISIC A-B)	18,5	Niger	(ISIC A-B)	40,3
	(ISIC C-E)	12,2		(ISIC C-E)	27,8		(ISIC C-E)	15,9
	(ISIC D)	10,8		(ISIC D)	11,2		(ISIC D)	6,5
	(ISIC F)	5,6		(ISIC F)	6,4		(ISIC F)	3,6
	(ISIC G-H)	17,4		(ISIC G-H)	18,6		(ISIC G-H)	15,9
	(ISIC I)	11,7		(ISIC I)	10,1		(ISIC I)	5,1
	(ISIC J-P)	23,5		(ISIC J-P)	18,5		(ISIC J-P)	19,2
Burkina Faso	(ISIC A-B)	22,3	Guinea	(ISIC A-B)	22,6	Nigeria	(ISIC A-B)	22,1
	(ISIC C-E)	24,7		(ISIC C-E)	26,7		(ISIC C-E)	21,4
	(ISIC D)	11,2		(ISIC D)	11,4		(ISIC D)	11,6
	(ISIC F)	3,7		(ISIC F)	4,6		(ISIC F)	6,2
	(ISIC G-H)	11,8		(ISIC G-H)	20,7		(ISIC G-H)	16,6
	(ISIC I)	4,5		(ISIC I)	4,6		(ISIC I)	12,8
	(ISIC J-P)	33,0		(ISIC J-P)	20,7		(ISIC J-P)	20,8
Cabo Verde	(ISIC A-B)	5,4	Guinea-Bissau	(ISIC A-B)	51,0	Senegal	(ISIC A-B)	16,5
	(ISIC C-E)	11,2		(ISIC C-E)	11,7		(ISIC C-E)	22,8
	(ISIC D)	7,8		(ISIC D)	11,0		(ISIC D)	16,7
	(ISIC F)	11,7		(ISIC F)	1,2		(ISIC F)	3,4
	(ISIC G-H)	20,8		(ISIC G-H)	18,2		(ISIC G-H)	15,4
	(ISIC I)	14,8		(ISIC I)	4,5		(ISIC I)	8,8
	(ISIC J-P)	36,1		(ISIC J-P)	13,5		(ISIC J-P)	33,0
Côte d'Ivoire	(ISIC A-B)	22,1	Liberia	(ISIC A-B)	74,0	Sierra Leone	(ISIC A-B)	59,9
	(ISIC C-E)	18,7		(ISIC C-E)	6,8		(ISIC C-E)	5,0
	(ISIC D)	12,6		(ISIC D)	4,1		(ISIC D)	2,0
	(ISIC F)	4,0		(ISIC F)	1,9		(ISIC F)	0,8
	(ISIC G-H)	14,1		(ISIC G-H)	4,8		(ISIC G-H)	9,6
	(ISIC I)	10,1		(ISIC I)	5,3		(ISIC I)	3,5
	(ISIC J-P)	31,1		(ISIC J-P)	7,1		(ISIC J-P)	21,3
Gambia	(ISIC A-B)	20,1	Mali	(ISIC A-B)	39,8	Togo	(ISIC A-B)	22,0
	(ISIC C-E)	6,9		(ISIC C-E)	18,6		(ISIC C-E)	19,2
	(ISIC D)	4,7		(ISIC D)	17,7		(ISIC D)	15,5
	(ISIC F)	10,6		(ISIC F)	4,6		(ISIC F)	2,9
	(ISIC G-H)	39,3		(ISIC G-H)	11,1		(ISIC G-H)	8,6
	(ISIC I)	7,7		(ISIC I)	5,1		(ISIC I)	13,9
	(ISIC J-P)	15,3		(ISIC J-P)	20,8		(ISIC J-P)	33,4

Data: United Nations, Analysis: Author

[1] Percentages do not sum up to 1 because of some sectors overlapping.

UN - 1999 - 2019 % change of GDP/Value Added								table 2
Benin	(ISIC A-B)	12%	Ghana	(ISIC A-B)	-34%	Niger	(ISIC A-B)	3%
	(ISIC C-E)	-50%		(ISIC C-E)	-10%		(ISIC C-E)	31%
	(ISIC D)	-54%		(ISIC D)	-54%		(ISIC D)	-18%
	(ISIC F)	-25%		(ISIC F)	67%		(ISIC F)	41%
	(ISIC G-H)	13%		(ISIC G-H)	37%		(ISIC G-H)	-19%
	(ISIC I)	165%		(ISIC I)	24%		(ISIC I)	12%
	(ISIC J-P)	7%		(ISIC J-P)	22%		(ISIC J-P)	-12%
Burkina Faso	(ISIC A-B)	-23%	Guinea	(ISIC A-B)	-5%	Nigeria	(ISIC A-B)	-16%
	(ISIC C-E)	23%		(ISIC C-E)	20%		(ISIC C-E)	-23%
	(ISIC D)	-35%		(ISIC D)	156%		(ISIC D)	-29%
	(ISIC F)	-6%		(ISIC F)	-52%		(ISIC F)	233%
	(ISIC G-H)	-4%		(ISIC G-H)	-22%		(ISIC G-H)	-6%
	(ISIC I)	47%		(ISIC I)	-13%		(ISIC I)	152%
	(ISIC J-P)	4%		(ISIC J-P)	63%		(ISIC J-P)	-3%
Cabo Verde	(ISIC A-B)	-67%	Guinea-Bissau	(ISIC A-B)	15%	Senegal	(ISIC A-B)	-8%
	(ISIC C-E)	-33%		(ISIC C-E)	-30%		(ISIC C-E)	-8%
	(ISIC D)	-5%		(ISIC D)	-32%		(ISIC D)	-25%
	(ISIC F)	27%		(ISIC F)	313%		(ISIC F)	71%
	(ISIC G-H)	49%		(ISIC G-H)	-9%		(ISIC G-H)	-8%
	(ISIC I)	-4%		(ISIC I)	0%		(ISIC I)	38%
	(ISIC J-P)	27%		(ISIC J-P)	-5%		(ISIC J-P)	3%
Côte d'Ivoire	(ISIC A-B)	-5%	Liberia	(ISIC A-B)	4%	Sierra Leone	(ISIC A-B)	24%
	(ISIC C-E)	-23%		(ISIC C-E)	30%		(ISIC C-E)	-25%
	(ISIC D)	-43%		(ISIC D)	-14%		(ISIC D)	-42%
	(ISIC F)	12%		(ISIC F)	814%		(ISIC F)	-67%
	(ISIC G-H)	-36%		(ISIC G-H)	-73%		(ISIC G-H)	-2%
	(ISIC I)	78%		(ISIC I)	19%		(ISIC I)	-51%
	(ISIC J-P)	46%		(ISIC J-P)	16%		(ISIC J-P)	-18%
Gambia	(ISIC A-B)	-22%	Mali	(ISIC A-B)	5%	Togo	(ISIC A-B)	-34%
	(ISIC C-E)	-7%		(ISIC C-E)	27%		(ISIC C-E)	6%
	(ISIC D)	-25%		(ISIC D)	42%		(ISIC D)	58%
	(ISIC F)	80%		(ISIC F)	-20%		(ISIC F)	86%
	(ISIC G-H)	-9%		(ISIC G-H)	-17%		(ISIC G-H)	-39%
	(ISIC I)	184%		(ISIC I)	-31%		(ISIC I)	92%
	(ISIC J-P)	3%		(ISIC J-P)	-1%		(ISIC J-P)	31%

Data: United Nations, Analysis: Author

Classification
Agriculture, hunting, forestry, fishing (ISIC A-B)
Mining, Manufacturing, Utilities (ISIC C-E)
Manufacturing (ISIC D)
Construction (ISIC F)
Wholesale, retail trade, restaurants and hotels (ISIC G-H)
Transport, storage and communication (ISIC I)
Other Activities (ISIC J-P)

Dependence on Natural Resources

With the exception of the two tiny economies of Cabo Verde and The Gambia which have no significant reserves of mineral or other natural resources, the remaining thirteen countries are heavily reliant on agricultural and mining with the respective added values to GDP ranging from 40% (Senegal) to 80% (Liberia) in 2019. A similar conclusion can also be derived from the exports' data of the ECOWAS member States (table 3) where the four first exported products, as a percentage of total exports per country, are presented along with the value of the total exports of goods and services as a percentage of GDP based on the last available OECD data (OECD).

table 3

2018 OECD	Benin	Burkina Faso	Côte d'Ivoire	Cabo Verde	Ghana
1st	Coconuts, Brazil nuts 29,53%	Gold 78,50%	Cocoa beans 33,00%	Preserved fish; caviar 50,07%	Gold 37,34%
2nd	Gold 28,38%	Zinc 7,60%	Coconuts,Brazil nuts 9,43%	Fish, frozen, 21,13%	Petroleum oils 27,54%
3rd	Cotton, 10,07%	Cotton 3,77%	Natural rubber, balata 8,47%	Clothes 3,55%	Cocoa beans 11,22%
4th	Copper 6,56%	Coconuts,Brazil nuts 2,94%	Cocoa paste 7,53%	Parts of footwear 3,47%	Coconuts, Brazil nuts 3,10%
Exp/GDP	27,00%	27,85%	22,59%	48,95%	34,36%
	Guinea	Gambia	Guinea-Bissau	Liberia	Mali
1st	Aluminium ores 46,30%	Coconuts, Brazil nuts 31,16%	Coconuts, Brazil nuts 80,41%	Cruise ships 22,85%	Gold 88,76%
2nd	Gold 45,23%	Wood 12,73%	Fish, 13,24%	Gold 22,84%	Cotton, 3,55%
3rd	Petroleum gases 1,89%	Fish 8,79%	Wood 4,48%	Petroleum oils 21,69%	Wood 1,28%
4th	Artificial corundum 1,22%	Ferrous waste and scrap 5,97%	Ferrous waste and scrap 0,67%	Iron ores 11,10%	Mineral or chemical fertilisers 1,13%
Exp/GDP	32,85%	18,87%	25,76%	20,29%	24,67%
	Niger	Nigeria	Senegal	Sierra Leone	Togo
1st	Gold 51,58%	Petroleum oils 78,89%	Diphosphorus pentaoxide 24,06%	Titanium ores 22,48%	Petroleum oils No crude 43,03
2nd	Oil seeds 28,37%	Petroleum gases 11,87%	Gold 21,59%	Wood 14,34%	Gold 12,09
3rd	Petroleum oils No crude 1,44%	Petroleum oils No crude 1,44%	Fish 6,89%	Diamonds 12,60%	Electrical energy 4,66
4th	Vegetables 0,96%	Cocoa beans 0,96%	Crustaceans, molluscs 3,26%	Aluminium 12,22%	Petroleum oils 4,51
Exp/GDP	11,29%	16,59%	23,52%	18,06%	31,79%

Data: OECD, Analysis: Author

The first conclusion that may be derived is that the main structural imbalance of the Western African economies is the fact that they are mostly characterized by a continuing overdependence upon rents, rather than productive (manufacturing) growth. During the period 1999 – 2019, the manufacturing sector has shrunk in twelve of the block's States which account for the 89% of the region's total GDP. Capital intensive growth in labor surplus economies is a recurrent feature of underdevelopment whiles the failure to diversify economic growth away from hydrocarbons and other minerals, increases the vulnerability coming from the international markets and the value added that accrues outside of the region due to absence of downstream sector.

The quantification of the high degree of dependence on natural resources provides an even more clear view of the region's vulnerability in relation to the international market prices' volatility. To this end, the following regression model has been estimated for a period of 30 years (1999 – 2019), upon data of the two largest economies, those of Nigeria and Ghana, in order to evaluate the degree to which the variance of the GDP per capita is correlated to the price variances of the main exporting product of each country, Crude Oil and Gold respectively.

$Y_i = a + bX_i + e_i$

Where: Y = log GDP per capita

a = intercept

X = log average yearly price of Oil and Gold[2] (Nigeria, Ghana respectively)

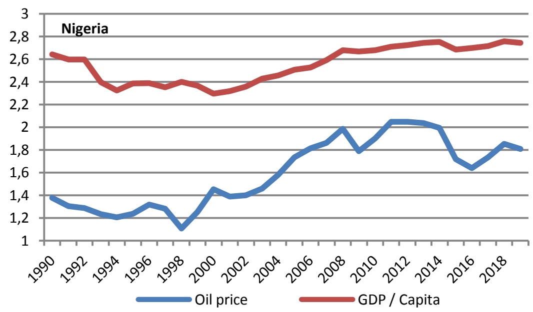
e = Standard error

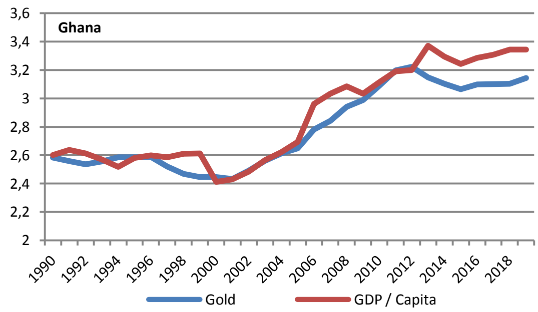
Nigeria

Regression Statistics		*Significance F*		*Coefficients*	*P-value*
Multiple R	0,8437	< 0,01	Intercept	1,36	< 0,01
R Square	0,7119		Oil	0,94	< 0,01

Ghana

Regression Statistics		*Significance F*		*Coefficients*	*P-value*
Multiple R	0,9701	< 0,01	Intercept	-0,36	0,02
R Square	0,9411		Gold	1,16	< 0,01





Data: World Bank, Bloomberg, Analysis: Author

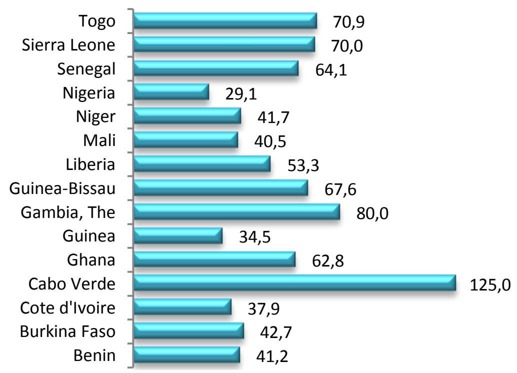
[2] Bloomberg terminal

The results of the regression analysis confirm the strong dependence of the sample countries on their primary exported goods, while similar findings also exist for the rest of the economies. In the case of Nigeria, the variance of the per capita GDP is by 71% explained by the variance of the Oil price; in the case of Ghana, the respective level is 94% compared to the gold price, while a strong correlation is also exists with the prices of crude oil, its second exporting product. The results present a strong significance level, as both "Significance F" and "P-value" are well below the critical value of 0.05 and the correlation between the data series "multiple R" is very high, 0.84 and 0.97 for Nigeria and Ghana respectively.

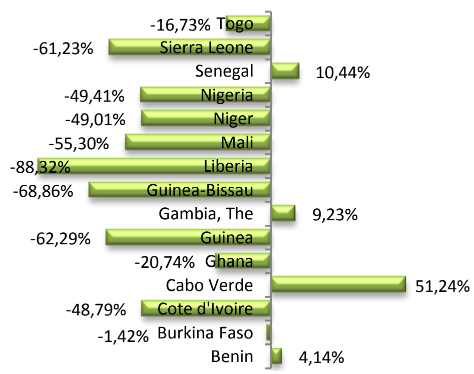
Debt: Based on the available data from the IMF for the period 2000 to 2019 (graph 5), most of the countries were heavily indebted until late 2000s and early 2010s, when a debt relief program of approximately $40 bln took place for the qualified countries of the region (excluding Nigeria and Cabo Verde) under IMF's "Heavily Indebted Poor Countries" (HIPC) Initiative, while Nigeria and the Paris Club announced, in 2005, a final agreement for debt relief worth $18 bln. Currently, additional programs for further debt relief of the Western African economies are on track by IMF, World Bank and the Paris Club.

According to the IMF: "Debt relief is one part of a much larger effort, which also includes aid flows, to address the development needs of low-income countries and make sure that debt sustainability is maintained over time. For debt reduction to have a tangible impact on poverty, the additional money needs to be spent on programs that benefit the poor […] but still long-term debt sustainability remains a concern for most of the African countries that have received debt relief. To mitigate debt-related vulnerabilities, they need to increase domestic revenue mobilization, diversify their production and export bases, and strengthen public institutions" (IMF, 2021).

Graph 5 - Debt to GDP % - 2019



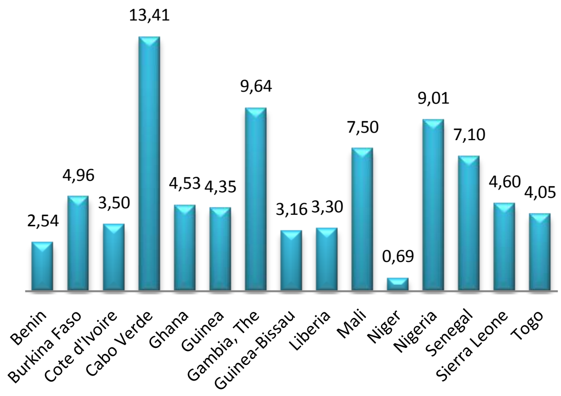
Debt to GDP change 2000 - 2019



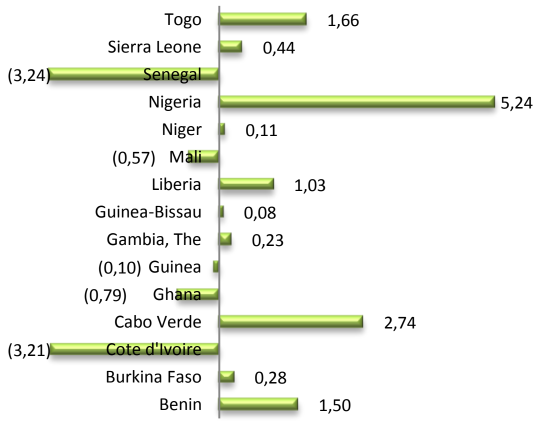
Data: IMF, Analysis: Author

Unemployment: The rate of unemployment in ECOWAS countries in 2020, according to the World Bank (WORLD BANK) ranged between 0.69% in Niger and 13.41% in Cabo Verde (graph 6). In the two largest economies, Nigeria and Ghana, the unemployment rates are 9.01% and 4.53% respectively. It is worth mentioning that "according to the National Bureau of Statistics' (NBS) Labour Force Survey, the unemployment rate was 27% in Q2 2020 - four percentage points higher than the 23% reported in Q3 2018" (PWC, 2020) . According to those data, one out of two of the country's labor force is either unemployed or underemployed while this is the first time in six quarters that the country's unemployment data have been published. The huge difference that appears is mainly attributed to the different methodologies followed by ILO and NBS.

Graph 6 - 2020 Uneployment rate %



Change of unempoyment rate 2010 - 2020



Data: World Bank, Analysis: Author

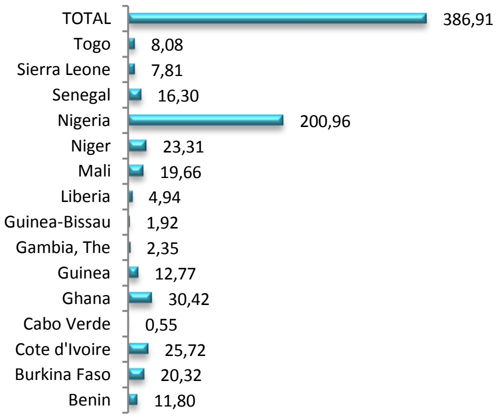
The most worry finding regarding the evolution of unemployment, is that Nigeria, the largest economy of the region with a total population exceeding 200 million people and a work force (15 – 64 years old) of 122 million, posses the highest increase (5.24%) in unemployment during the last decade, while in the last five years (2015 – 2020) the absolute change was 4.70%. Furthermore, according to the ILO, the underemployment (less than 20 hours per week) is above 8% while the unemployment is higher among the urban population and the young people between the ages 15 – 24 years old.

Population, the driving force:

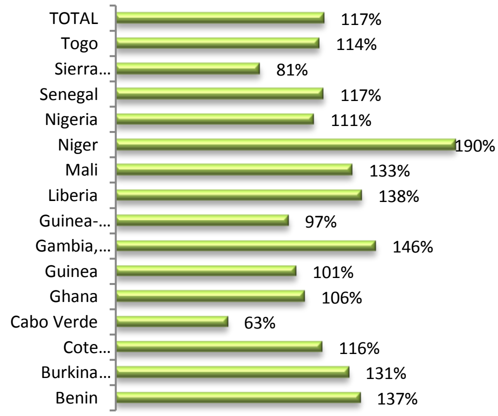
"Population dynamics and urbanization will continue to figure among the major transformations affecting West Africa. Between 2015 and 2040, the population of West Africa will double and cities will absorb most of this demographic growth" (UNIVERSITY OF FLORIDA, 2020).

The ongoing population boom and urbanization in the region, call for adequate policies to tackle with the problems of limited job creation, inadequate structural transformation, energy access and poor livability. During the last 30 years the total population (WORLD BANK) of the ECOWAS countries has more than doubled from 178mil to 387mil people (graph 7) with an average growth rate of 2,70%, while in absolute numbers Nigeria's population currently exceeds 200mil and Ghana's 30mil.

Graph 7 - Population 2019 in mil



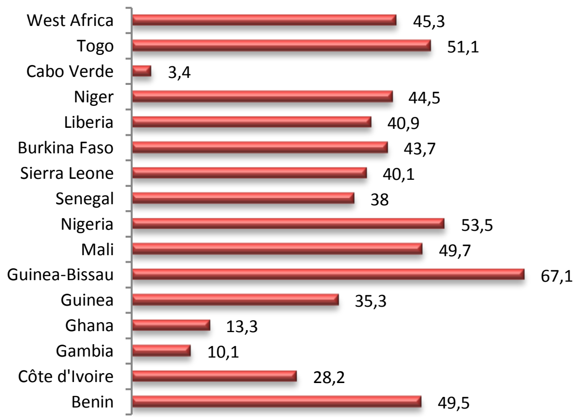
Population growth 1990 - 201



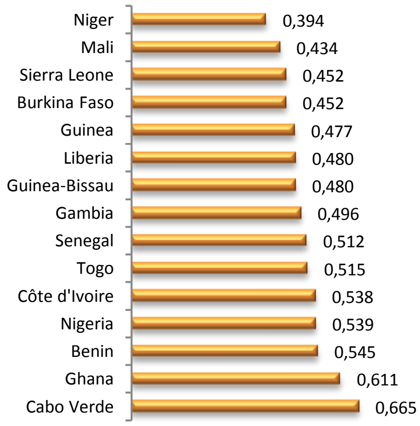
Data: World Bank, Analysis: Author

Apart from the population growth, states must also confront with poverty and low living standards and conditions, as in this part of the world the size of the population living below the poverty line accounts for almost half of the global extremely-poor population the size of which, despite the fact that the poverty rate has decreased compared to 1990, continues to rise. In other words, the poverty rate in Western Africa has not fallen fast enough so to keep up with the population's growth in the region. A total of 175 million people are living below the income poverty line, that is the equivalent of 1.90$ per day (PPP 2017$), with 107 mil living in Nigeria. This number represents the 45% of the total population (graph 8). Poverty data are also mirrored in the Human Development Index (UN DEVELOPMENT PROGRAM, 2020) which combines various data such as life expectancy, years of schooling and Gross National Income per capita. According to the HDI, only two countries, Ghana and Cabo Verde are included in the group of the "Medium Human Development" countries, while the rest thirteen belong to the "Low Human Development" group; it's worth mentioning that the total number of countries included in this last group is thirty-three.

Graph 8 - % population below income poverty line



HDI 2019



Data United Nations, Analysis: Author

Lower than required macroeconomic development, combined with demographic growth, poor livability and ongoing conflicts, compose an extremely difficult and demanding landscape, the overcoming of which requires a fast-pace transformation of the regional economies' structure from rent-seeking into production oriented ones, through the development of sectors like processing and manufacturing, the modernization of the agricultural production and the disengagement, as far as possible, from minerals' rents, in order to turn into advantage what currently seems as a drawback: the booming young population. The success of the above depends on the institutional improvement and elimination of the corruption, a common conclusion of almost every international organization.

Further analysis and suggestions regarding the macroeconomic environment is out of the scope of this thesis, the objective of which is to focus on energy matters and more specifically on the directions that the ECOWAS countries must go along, from a financial point of view, for the development of their electricity generation capabilities and capacities. Luckily, the technological improvements and the economic mature of the renewable energy sources, offer opportunities for modern power generation, independent from the prices fluctuations of the tradable commodities, like oil and gas. Currently the region with the lowest access to electricity globally is at the crossroad to choose its electrification future, since is out of doubt that energy and development are heavily interdependent.

The Energy Landscape

Energy production:

Based on the last available data (IEA) for seven out of the fifteen countries, the vast majority of energy production, with the exception of Ghana, comes from biofuels even in Nigeria which is the ninth country globally in terms of Natural Gas reserves and the fifteenth in terms of Crude Oil production. Biomass as a major source of energy is used in the form of charcoal and fuel wood for cooking and heating and by small industrial units. In any case this particular source of energy is been used in its traditional way and not as a modern derivative of organic materials also known as bioenergy.

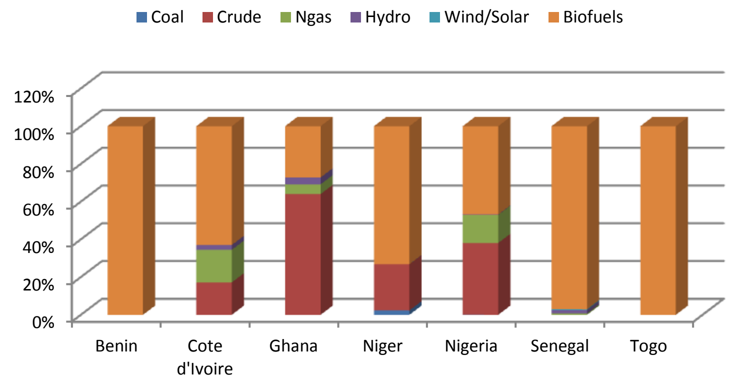
In table 4 below presented the energy production by source in ktoe for 2018 (IEA, 2021) while in graph 9 the percentages of each source to the total production are displayed.

table 4

Production (ktoe)	Coal	Crude	Ngas	Hydro	Wind/Solar	Biofuels	Total
Benin						2705	2705
Cote d'Ivoire		1707	1716	255		6257	9935
Ghana		9142	739	517	3	3881	14282
Niger	78	828			2	2470	3378
Nigeria	29	97547	38147	555	2	119983	256263
Senegal			11	31	7	1615	1664
Togo						2712	2712

Data: IEA, Analysis: Author

Graph 9 – Energy production by source



Data: IEA, Analysis: Author

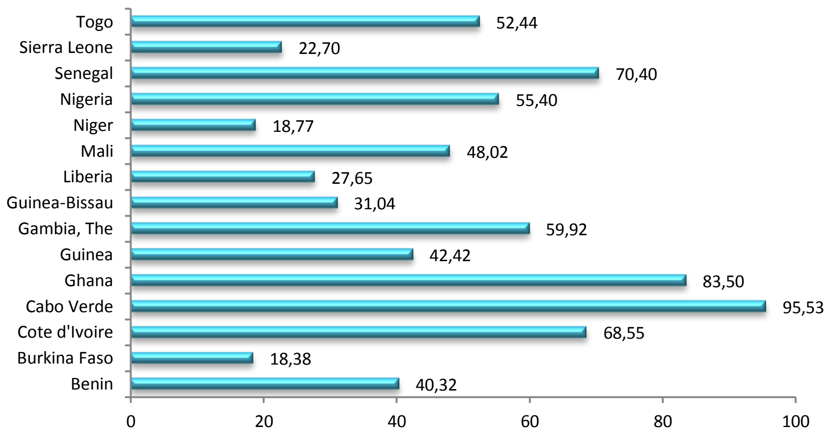
While detailed electricity data for each country will be presented in a following paragraph it is worth mentioning that renewables (including hydro), which along with Natural gas and Coal (mainly in Niger) are used for electricity generation, are at a very low level in this particular group of countries, which represent the 82% of the total population. This means that there is a lot of room for the development of green energy like Wind, Solar and Hydro in the years ahead taking into account that the percentage of population with access to electricity in the ECOWAS countries is 52%, the forth lowest regional level globally. The first three positions of this negative statistic are kept by Central, South (excluding South Africa) and East African countries with 24%, 39% and 47% respectively.

Access to electricity:

"While the number of people without access to electricity has steadily declined since 2013, it is now set to increase in 2020 due to the Covid-19 pandemic, pushing many countries further away from achieving the goal of universal access by 2030" (IEA).

Based on the analysis of data provided by the World Bank (WORLD BANK), in the region under consideration 183 out of 387 mil people are without access to electricity despite the progress that been made during the last decade (2009 to 2019) where the respective percentage of access to electricity increased from 43% to 52% meaning that 76 mil people have gained access to electricity. The big problem of electrification is found in rural territories where the access is below 30% while in urban is about 87%. This is due to the pure expansion of the main grid system, the rapid urbanization and the low penetration of off-grid systems. Access to electricity as a percentage of the total population per country is presented in graph 10

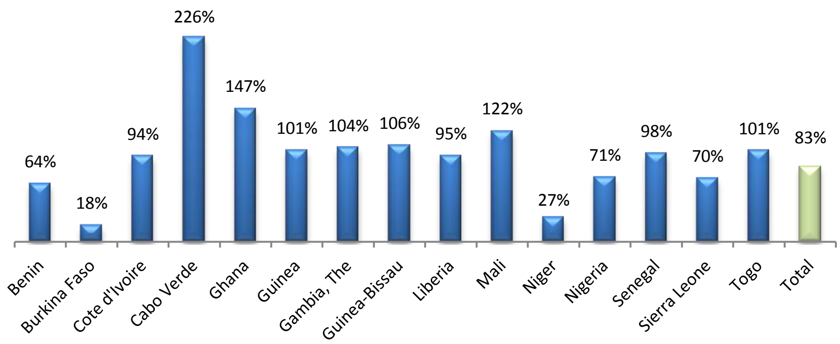
Graph 10 - % Access to electricity 2019



Data: World Bank, Analysis: Author

An interesting finding is that the absolute increase of the total population by 91mil was not coupled by a corresponding increase in the number of people who access to electricity (76mil) between 2009 and 2019, even if the percentage improved due to the lower increase of total the population (31%), compared to the people who gained access (60%). Graph 11 illustrates in what percentage the population growth matched the increase in the number of people with access to electricity. So, for example in Nigeria the population growth between 2009 and 2019 was 46mil while the number of people who gained access to electricity was 33mil, thus resulting in a 71% matching.

Graph 11



Data: World Bank, Analysis: Author

What is obvious from these data is that the two states, Ghana and Cabo Verde, with the higher matching rate (147%, 226%), has also the higher rate of electricity access among the ECOWAS countries with 83% and 95% respectively. In turn this finding directly questions, at least in the Western Africa, the realization of the goal that been set by IEA and the UN regarding the universal access to electricity by 2030, since the expansion rate of the access to electricity that must be achieved is stands well above the rates recorded so far in many countries. At this point it should be noted that statistics regarding the access to electricity per household, would be even more enlightening as to the actual situation.

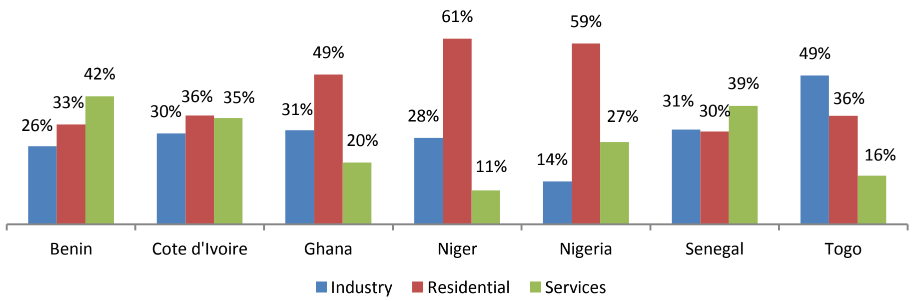
Electricity consumption:

The driving force of electricity consumption in Western Africa is beyond doubt the growing population and the needs for electric power that are directly or indirectly associated to the population growth, such as the needs coming from the residential, the commercial or the public services respectively. The contribution of the industrial sector to energy consumption, based on the last detailed data from IEA for 2018, vary from 42% in Benin to 11% in Niger, while in Nigeria and Ghana, the two biggest countries in terms of GDP and population, the electricity consumption coming from industry is 27% and 20% respectively (graph 12). Furthermore, by comparing data for the period between 2009 and 2018 (table 5) we find that the total consumption has increased in the industrial, the residential and the commercial and public services sectors by 49%, 70% and 72% respectively.

table 5

electricity consumption ktoe	Benin		Cote d'Ivoire		Ghana		Niger		Nigeria		Senegal		Togo	
	2009	2018	2009	2018	2009	2018	2009	2018	2009	2018	2009	2018	2009	2018
Industry	11	25	83	171	254	349	14	33	267	317	49	92	21	52
Residential	29	32	131	205	196	555	29	71	874	1337	73	90	36	38
Services	28	41	110	200	92	229	6	13	399	609	67	115	9	17

Graph 12 Electricity consumption by category as a % of total / 2018



Data: IEA, Analysis: Author

Analyzing further the data provided by IEA for the period from 2004 to 2018, we conclude that the total final electricity consumption in Nigeria and Ghana is explained, by 96% and 82% respectively, by the increase in the residential consumption, while similar high and statistically important findings were also found for the other states. The regressions findings for Nigeria and Ghana are summarized below.

Nigeria

Regression Statistics		*Significance F*		*Coefficients*	*P-value*
Multiple R	0.98	< 0,01	Intercept	0.60	< 0,01
R Square	**0.96**		Residential	0,88	< 0,01

Ghana

Regression Statistics		*Significance F*		*Coefficients*	*P-value*
Multiple R	0,90	< 0,01	Intercept	1.22	< 0.01
R Square	**0,82**		Residential	0.67	< 0,01

Data: IEA, Analysis: Author

Currently, the population that has access to electricity, pays one of the most expensive prices in the world (0.21 €/kWh), more than double the price paid by the consumers in East Africa. In addition, operational deficiencies result in unreliable electricity services, with an average of 80 hours of outages per month (WORLD BANK, 2020) while the average final consumption per capita is 156 kWh.

"Over the past decade, member countries of the Economic Commission of West African States (ECOWAS) have been working - through the West Africa Power Pool (WAPP) - towards a fully integrated power market. Within a few years, they will have completed the primary interconnectors that will link them together. The West Africa Energy Development Policy Financing Program supports a policy reform program, being implemented by Burkina Faso, Côte d'Ivoire, Guinea, Liberia, Mali and Sierra Leone, to facilitate trade in cleaner, low-cost electricity generated from gas, hydropower and renewable energy resources across borders. This will replace the more expensive electricity generation from inefficient small-scale oil-fired power plants, as well as diesel-fueled power generators and will improve the reliability of the electricity services" (WORLD BANK, 2020) ; it's worth mentioning, however, that the aging and low-quality grid infrastructure is responsible for power losses which account, at an average, to 19% of the production, according to metrics from the West African States.

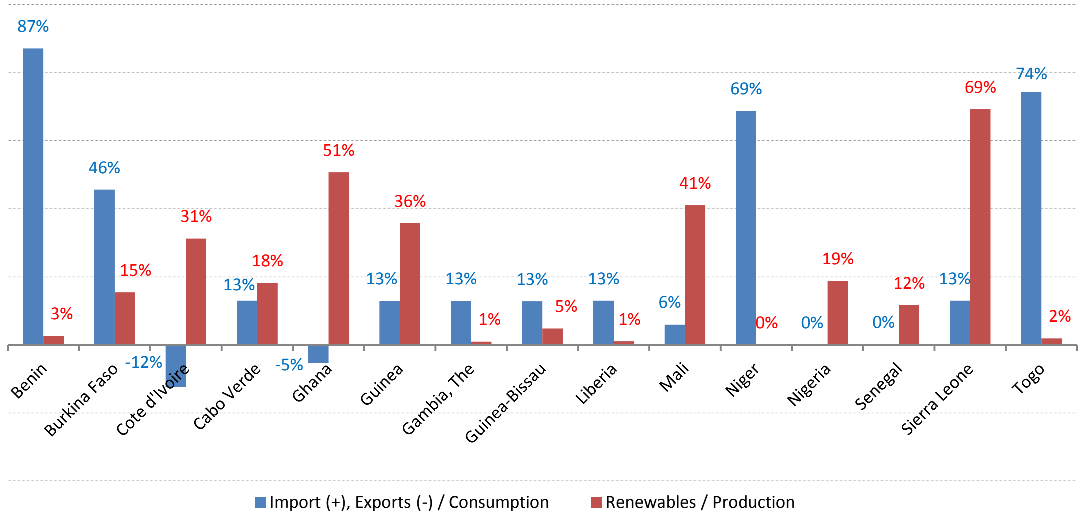
The total production of electricity for the fifteen States including renewables, Imports / Exports, Losses and final consumption are presented in table 6. Available data (COUNTRYECONOMY.COM) from 2008 to 2018 show that, as a percentage of the total electricity production, renewables (including hydro) have declined from 38% to 27% despite their absolute increase from 15524 GWh to 18663 GWh. This is attributed to the higher penetration of Gas from the producing countries due to the relatively higher costs for the development of renewable energy sources, like on-shore wind farms and solar PV, at least until the middle of the past decade. The steps taken towards the power markets' integration and interconnection between the states led to an increase in power imports and exports, as a percentage of the production, from 3.5% to 5.3% or, in absolute values, from 1435 to 3725 GWh.

table 6

GWh	**Production**	**Renewables**	**Imp / Exp**	**Losses**	**Cosumption**
2018	69882	18663	3726	13044	60564
2017	68122	19363	2600	11949	58773
2016	63323	18984	3239	11990	54572
2015	61342	15872	2643	11736	52249
2014	60681	18347	2665	11513	51833
2013	55874	17538	2059	11023	46910
2012	54055	18017	2229	10276	46008
2011	50252	17507	1851	9947	42156
2010	48059	17261	1419	9223	40255
2009	40071	15327	1573	8113	33531
2008	40451	15524	1435	8430	33456

Data: countryeconomy.com, Analysis: Author

Graph 13



Data: countryeconomy.com, Analysis: Author

Sierra Leone, Ghana, Mali, Guinea and Cote d'Ivoire lead the power generation from renewables (graph 13), with more than 30% of their total electricity production coming from renewables, mainly hydro (table 1) which is also the case in Nigeria with 19% renewables. Another interest finding is that due to the significant under-capacity in electricity generation, some countries in the region such as Benin, Burkina Faso, Niger and Togo rely on electricity imports for a substantial share of their supplies.

Estimation of electricity needs up to 2030

In order to estimate the electricity needs for each country, the above presented data regarding the population's access to electricity, the consumption and the population growth are combined with the average increase in consumption per capita and the average increase in the population's access to electricity for the period from 2008 to 2018, into the following formula (1), under the constrain of 100% access. As mentioned before the driving force of electricity consumption in Western Africa is beyond doubt the growing population, which is expected to reach 517mil by 2030. Based on a regression analysis of *log total population* upon *log total consumption* for the aforementioned period, the electricity needs are explained by 96% (table 7) by the population growth, directly and indirectly.

$Y_i = a + bX_i + e_i$

Where: Y = log electricity consumption

a = intercept

X = log population

e = Standard error

table 7

Regression Statistics		*Significance F*		*Coefficients*	*P-value*
Multiple R	0.98	< 0,01	Intercept	-0.97	> 0,02
R Square	**0.96**		Population	2.24	< 0,01

Also, important factors in the formula are the percentage by which the access to electricity may overrun the increase of the population and the average increase in consumption per capita. The last is explained by the fact that, as years pass, consumers add new appliances and the commercial and public services (schools, hospitals etc) are increased.

$$E = [A * (1 + I)^t] * [P * (1 + G)^t] * [C * (1 + N)^t] \quad (1)$$

Where:

E = Total electricity consumption in 2030
A = Current population access %
I = Average Access increase %
P = Current population
G = Average population growth %
C = Current Consumption per capita (kWh)
N = Average consumption increase per capita (kWh)
t = 12

table 8

	Benin	**Burkina Faso**	**Cote d'Ivoire**	**Cabo Verde**	**Ghana**	**Guinea**	**Gambia**	**Guinea Bissau**	**Liberia**	**Mali**	**Niger**	**Nigeria**	**Senegal**	**Sierra Leone**	**Togo**
(A)	39,2%	14,40%	67,17%	93,43%	80,40%	44,00%	60,30%	28,51%	24,82%	50,90%	17,60%	56,50%	66,00%	26,10%	50,00%
(P)'18 mil	11,5	19,75	25,07	0,54	29,77	12,41	2,28	1,87	4,82	19,08	22,44	195,9	15,85	7,65	7,89
(G)	2,99%	2,88%	2,65%	1,70%	2,50%	2,39%	3,11%	2,33%	3,01%	2,91%	3,67%	2,58%	2,66%	2,04%	2,63%
(C)	103	89	266	836	297	159	127	20	72	159	70	148	242	31	158
(N)	1,98%	6,49%	3,76%	4,72%	1,57%	5,48%	0,12%	0,73%	1,12%	10,5%	6,16%	2,71%	5,16%	4,32%	4,18%
(I)	3,00%	1,33%	1,08%	2,47%	2,84%	5,59%	3,83%	5,65%	9,29%	7,75%	3,95%	1,16%	2,78%	7,69%	4,50%
(E) GWh	**2139**	**5264**	**14257**	**1212**	**16142**	**4998**	**426**	**56**	**567**	**17842**	**5010**	**54249**	**9626**	**512**	**2794**
Access Increase	56%	17%	76%	100%	100%	85%	95%	55%	72%	100%	28%	65%	92%	63%	85%
Cons. Increase	80%	199%	113%	166%	83%	152%	46%	44%	63%	487%	216%	87%	151%	112%	123%

Analysis: Author

In table 8 all inputs are presented along with the projected increase in both access to electricity and consumption by 2030. The total consumption in all fifteen States is expected to increase by 123% (or 74532 GWh) reaching 135096 GWh compared to 60564 GWh in 2018. Based on this estimation, only seven countries will succeed in achieving access to electricity for 80% or more of their population, while three of them will achieve a universal access, Cabo Verde, Ghana and Mali. Another interest finding is that three out of four States that heavily rely on electricity imports, Benin, Burkina Faso and Niger are expected to have in 2030 the lower access, meaning that apart from the increase of the domestic production capabilities they have also to expand the grid which is the case for most of the countries especially in rural areas. To what extend those estimates will be verified are also subject to the pace of urbanization, the construction of off-grid units in order to cover remote areas, the political stability and the availability of funds. What's certain, is that under the current pace of expansion, many States will lack full access in 2030 and huge investments will be channeled towards electricity production in the years ahead. In the following chapter, an analysis and estimates about the best energy portfolio mix will be made, from a financial point of view, comprised of Solar PV, on-shore wind farms and Gas, given that the current plans for hydro projects by each State, will cover a substantial proportion of the future needs.

The Hydro giant and the crucial role of WAPP

"West Africa accounts for over 23,000 Megawatt (MW) of technically exploitable hydropower capacity. However, a key challenge has been the distribution capabilities: the major sources of electricity supply are located far away from the main centers of consumption.

The West Africa Power Pool (WAPP) was conceived to help address this problem. Doing so, is a critical part of improving access to energy in a region where much of the population has relied for years on firewood and charcoal to meet their energy needs" (WORLD BANK, 2021).

Map 2

Source: World Bank

Taking advantage of the huge renewable energy resources potentials of the region, WAPP whose mission is "to promote and develop power generation and transmission infrastructures, as well as to coordinate power exchange among the ECOWAS Member States" (WAPP) promotes the cooperation between countries regarding not only the electricity transmission among them, but also the cross-border power development and trade (Map 2), like for example the 200MW Manatali (Mali) hydro plant, which was a result of a partnership between Senegal, Mali and Mauritania. Co-funding of large-scale project is a crucial parameter for the region, since their completion is becoming more affordable for the countries and more sustainable, with cleaner sources of electricity. Cross border trade could lead to cost savings of $5 – 8 billion per year by allowing expensive power in one country to be replaced by cheaper power imports from neighbors. Trading power could also bring electricity costs down by 50% in many countries. It's obvious that WAPP's role is crucial regarding affordability, reliability and sustainability of electricity.

Currently, Ghana, Nigeria and Cote d'Ivoire cover their electricity production by 50%, 17% and 29% respectively from hydro plants, while the states of the region with the collaboration of the WAPP are promoting hydro plants as the major future source of power. Based on data provided by the International Renewable Energy Agency (IRENA) (IRENA, 2018) and WAPP (WAPP, 2020) the planned projects for the development of hydro plants that will be completed until 2030, account for 9075 MW capacity which is translated into a 32990 GWh production, with an efficiency rate of 41,5% (U.S. DEPARTMENT OF ENERGY, 2021). From table 3 we may calculate the rate of total consumption to production to 86% for the last four available years which means that, given the expected improvement of the grid and the consequently decrease of losses, an assumption of 90% rate deemed reasonable, meaning that hydro plants will cover 29692 GWh of the consumption or the 39.8% of the estimated increase in consumption by 2030 (table 8). Planned hydro plants capacity, until 2030, per country are provided in table 9 below.

table 9

Benin	147	Liberia	900,5	Ghana	307	Sierra Leone	748,3
Burkina Faso	106,9	Niger	228,5	Guinea	2425,6	Togo	104
Cote d'Ivoire	909	Nigeria	3050	Guinea Bissau	20	Senegal	128

Data: IRENA, WAPP. Analysis: Author

The question

As findings suggest, West Africa is currently at the crossroad of electrification sources and the states have to choose their electricity supply mix under the constraints of both emission targets set by the UN and cost-effective funding. The "answer" that I will try to give is an indication of the direction that the ECOWAS countries, apart from the already planned hydro plants, may adopt for the development of their electricity generation capacities, by comparing and combining three alternative technologies, Utility scale Solar PV, Onshore Wind farms and Combined Cycle Gas Turbine (CCG).

Methodology

In order to find the efficient mix, the concept of "Leverized Cost of Energy" (LCOE) will be used as this been introduced, defined and published by "Lazard Inc" and also used as a methodology by World Organizations such as World Bank and IEA. First, I inverse LCOE in order to represent MWh per $1000 (efficiency), instead of dollars per MWh, since this form serves better the purpose of the analysis. Furthermore, by using Monte Carlo simulation the range of inverse LCOE is predicted up to 2023 and finally the mean-variance approach is being used upon Monte Carlo distribution data sets (up to 2023) in order to maximize the energy production mix.

"The LCOE is similar to the concept of the payback for energy systems. However, instead of measuring how much is needed to recoup the initial investment, the LCOE determines how much money must be made per unit of electricity (kWh, MWh etc. or even other type of energy like home heating) to recoup the lifetime costs of the system. This includes the initial capital investment, maintenance costs, the cost of fuel for the system (if any), any operational costs and the discount rate.

The LCOE is one way of determining whether or not a firm will build a project because if the project will not break-even, then it will not be built. The LCOE is a useful tool because it can combine both the fixed costs and variable costs into a single measurement to simplify analysis. To determine the LCOE, one must determine the necessary parameters such as the lifetime of the system, how much electricity it will produce and the input costs. All those factors will be used to form the following equation:

$$\text{Total Lifetime Cost} = \sum_{t=1}^{n} \frac{I_t + \mathrm{M}_t + F_t}{(1+r)^t}$$

$$\text{Total Lifetime Output} = \sum_{t=1}^{n} \frac{\mathrm{E}_t}{(1+r)^t}$$

$$\text{LCOE} = \frac{\text{Total Lifetime Cost}}{\text{Total Lifetime Output}}$$

- I_t = Investment and expenditures for the year (t)
- M_t = Operational and maintenance expenditures for the year (t)
- F_t = Fuel expenditures for the year (t)
- E_t = Electrical output for the year (t)
- r = The discount Rate
- n = The (expected) lifetime of the power system

LCOE analysis can help firms and states determine the benefits and drawbacks of various energy systems. When comparing conventional fossil fuels systems, such as coal-fired power plants and natural gas power plants, with renewables systems such as solar, wind or nuclear, a LCOE analysis can tell which the most viable system to implement is" (ENERGY EDUCATION) .

In the current analysis unsubsidized LCOEs data (table 10), as these have been calculated and published, by "Lazard Inc" from 2011 to 2020 (LAZARD INC, 2020) about the three under examination technologies, are used. At a first glance the most important and promising finding is that the cost of renewable energy systems such as the onshore wind and utility-scale solar, which directly challenges in a new-build basis the conventional technologies several years ago, continues to decline. Technology's costs that declined most in the last 10 years is are the utility scale PV ones (whose mean LCOE value declined by 77%), while Wind and CCG declined by 44% and 56% respectively, with an average price volatility, an important parameter affecting future investment decisions, is of 6.4%, 5.9%, and 5.4% for solar, wind and CCG respectively.

table 10

USD / MWh		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Solar PV	Hi	166	149	104	86	70	61	53	46	44	42
	Low	148	101	91	72	58	49	46	40	36	31
	Mean	157	125	98	79	64	55	50	43	40	37
Onshore WIND	Hi	92	95	95	81	77	62	60	56	54	54
	Low	50	48	45	37	32	32	30	29	28	26
	Mean	71	72	70	59	55	47	45	43	41	40
CCG	Hi	97	88	87	87	78	78	78	74	68	73
	Low	69	62	61	61	52	48	42	41	44	44
	Mean	83	75	74	74	64	55	50	43	40	37

Data: Lazard Inc, Analysis: Author

As mentioned above, for the determination of the ultimate mix the inverse LCOE per 1000$ is used, since the presentation of the improved competitiveness of each technology as an increasing value, is suitable for maximization under the mean-variance approach. At this point it's worth noting that the upper limit of costs in most cases refers to Far East countries, and especially Japan, which have one of the highest initial investment costs in all of the three technologies, as well as the highest fuel expenditure as regards CCG due to high importing prices of LNG. So, in order to avoid biases towards irrelevant high prices the entire range between high and low values is divided into four percentiles and proceed by excluding the 4th percentile for each technology. The relevant data are presented in table 11.

table 11 – Inverse LCOE

MWh per $1000		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Solar PV	**Hi**	**6,76**	**9,90**	**10,99**	**13,89**	**17,24**	**20,41**	**21,74**	**25,00**	**27,78**	**32,26**
	Low	**6,19**	**7,30**	**9,93**	**12,12**	**14,93**	**17,24**	**19,51**	**22,47**	**23,81**	**25,48**
	Mean	6,47	8,60	10,46	13,01	16,08	18,82	20,63	23,74	25,79	28,87
WIND	**Hi**	**20,00**	**20,83**	**22,22**	**27,03**	**31,25**	**31,25**	**33,33**	**34,48**	**35,71**	**38,46**
	Low	12,27	12,01	12,12	14,29	15,21	18,35	19,05	20,30	21,05	21,28
	Mean	16,13	16,42	17,17	20,66	23,23	24,80	26,19	27,39	28,38	29,87
CCG	**Hi**	**14,49**	**16,13**	**16,39**	**16,39**	**19,23**	**20,83**	**23,81**	**24,39**	**22,73**	**22,73**
	Low	**11,11**	**12,27**	**12,42**	**12,42**	**13,99**	**14,18**	**14,49**	**15,21**	**16,13**	**15,21**
	Mean	12,80	14,20	14,41	14,41	16,61	17,51	19,15	19,80	19,43	18,97

Analysis: Author

Estimation of future efficiency (MWh per $1000)

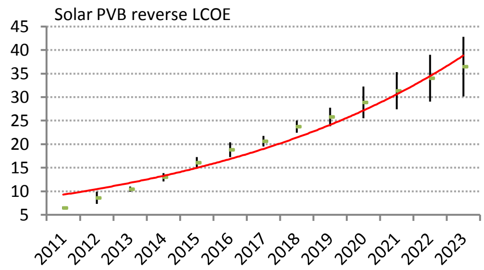
Since LCOE is very sensitive to various factors such as future discount rates, technological developments and cost of materials, the analysis and projections of inverse LCOE is limited to three years ahead, considering that any further estimation will be subject to serious errors and biases. Furthermore, three years ahead is enough time so to give an indication regarding the direction that the states should adopt regarding the development of their electricity production capabilities so to both meets the growing needs and cover the access gap. A Monte Carlo simulation with one thousand iterations per year is performed for the estimation of Hi, Low, range and mean values until 2023, while the average (best estimator) of the simulation's distribution is used as a forecasted value. For the first year (2021) data from the previous five years (2016 – 2020) have been used. For the rest of the years the relevant 5 years rolling period is implemented. Maybe five years could be considered a relatively short period of time for estimations in general, however in this case it captures effectively the market trends, competitiveness and technological developments, parameters that are actually considered as critical ones for large-scale projects. In table 12 and the following graphs, estimations for the 3rd percentile (75% of inverse LCOE's range) are displayed.

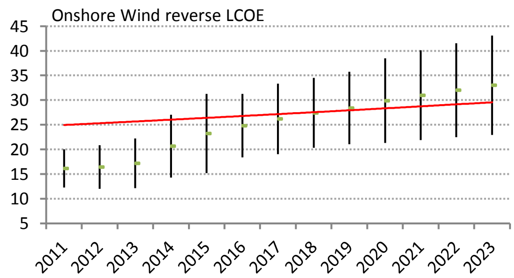
Monte Carlo parameters: $M_{t+1} = \frac{1}{n} + ln\frac{M_t}{M_{t-n}}$, $V = \sqrt{\sum_{i=1}^{n} \frac{\left(\ln\left(\frac{M_i}{M_{i-1}}\right) - \frac{\sum_{i=1}^{n}\left(\ln\left(\frac{M_i}{M_{i-1}}\right)\right)}{n}\right)}{n}}$, $D = M - \frac{V^2}{2}$

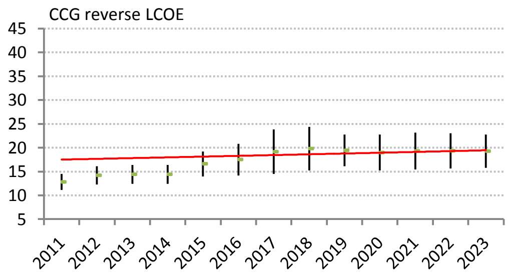
Where: M = mean, V = Standard deviation, D = drift, n = 5

table 12		2016	2017	2018	2019	2020	2021	2022	2023
Solar PV	Hi	20,41	21,74	25,00	27,78	32,26	35,20	38,77	42,57
	Low	17,24	19,51	22,47	23,81	25,48	27,43	29,22	30,42
	Range	3,17	2,23	2,53	3,97	6,78	7,77	9,55	12,15
	Mean	**18,82**	**20,63**	**23,74**	**25,79**	**28,87**	**31,31**	**34,00**	**36,50**
Onshore Wind	Hi	31,25	33,33	34,48	35,71	38,46	40,07	41,49	43,03
	Low	18,35	19,05	20,30	21,05	21,28	21,90	22,54	22,93
	Range	12,90	14,29	14,18	14,66	17,18	18,17	18,95	20,10
	Mean	**24,80**	**26,19**	**27,39**	**28,38**	**29,87**	**30,99**	**32,01**	**32,98**
CCG	Hi	20,83	23,81	24,39	22,73	22,73	23,11	23,33	23,07
	Low	14,18	14,49	15,21	16,13	15,21	15,45	20,68	20,45
	Range	6,65	9,32	9,18	6,60	7,52	7,67	2,65	2,62
	Mean	**17,51**	**19,15**	**19,80**	**19,43**	**18,97**	**19,28**	**19.31**	**19.13**

Analysis: Author

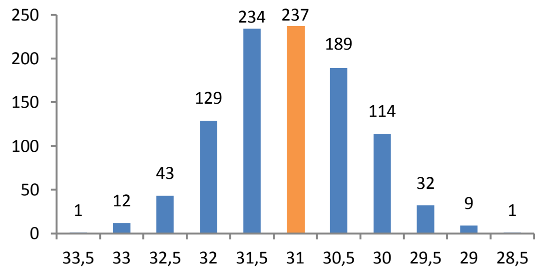




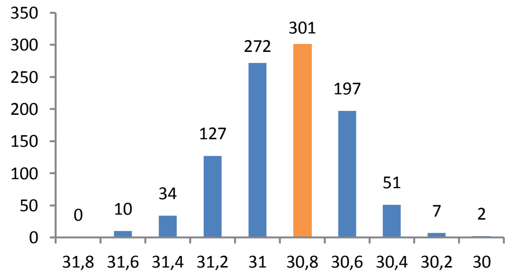


Indicatively in graphs 14, 15 MC simulation's distributions of Solar PV and Onshore Wind mean values estimations for the first year (2021) are presented.

Graph 14 – Monte Carlo simulation mean value (Solar PV)



Graph 15 - Monte Carlo simulation mean value (Onshor Wind)

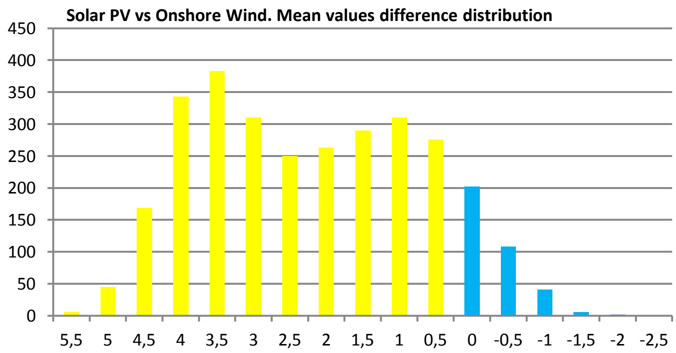


Analysis: Author

Based on the analysis, the clear winner is the utility scale solar PV which along with the onshore wind are expected to offer even more competitive, from a financial point of view, alternatives to the power generation mix. This trend can also be justified by the fact that PV is a relative new technology meaning that efficiency may increase even further in the years ahead and also its penetration is lower than Wind and CCG, resulting in an increasing competition between manufacturers to win market shares with a clear positive effect in cost. CCG on the other hand, as a well-established technology seems to have already reached its efficiency potentials, since the range of cost is actually determined by the fluctuation of Natural Gas prices which represent above 50% of total LCOE.

In order to further deepen into the simulations' results, a comparison between their values is made so to quantify the extension to which the technologies are expected to overcome each other. To do so, the three thousands iterations (2021 to 2023) of MC simulations from each technology are compared to the other two. The results showed that PV is expected by 88% to give a greater mean value than Onshore Wind (graph 16) whiles the probability of CCG overcoming the other two technologies is zero.

Graph 16



Analysis: Author

The question that has risen so far, also being set previously as an objective of the current thesis, is: what is the ultimate mix of future electricity production between those three technologies, given that hydro will cover about 40% of consumption? In order to answer this question, the concept of Markowitz's Portfolio theory (MARKOWITZ, H.M., 1952) is borrowed. More specifically, a mean variance approach upon simulation results over the next three years (2021 – 2023) was adopted in order to maximize a similar to Sharpe ratio (SHARPE, William F., 1994); since there is no "risk free return" benchmark and absolute values instead of returns are used.

The current approach is: Expected efficiency in MWh (per $1000) per unit of efficiency range.

Where,
Expected efficiency: $E_r = \frac{1}{n}\sum_{i=1}^{n}(M)_i$
Volatility: $V = \frac{1}{n}\sum_{i=1}^{n}(R)_i$
Covariance: $Cov(x,y) = \frac{1}{n}\sum_{i=1}^{n}(M_{xi} - \overline{M_x})\left(M_{yi} - \overline{M_y}\right)$
M = mean, R = range (see table 12)

Finally, the index subject to maximization is: $\mathrm{EM} = \frac{E_r}{V}$ which is interpreted as the expected MWh per unit of range.

The allocation of technologies as a result of EM's maximization is presented below (table 13) along with the variance covariance matrix and the expected efficiency.

table 13

	SOLAR	WIND	CCG	EM = 3.58	
SOLAR	9,8	5,3	-0,2	Solar PV	40%
WIND		19.2	-0,08	Onshore Wind	16%
CCG			7.4	CCG	44%
Er	34	32	19		

Analysis: Auhtor

While Solar PV technology dominates (see graph 14) due to its higher expected mean efficiency in terms of MWh / $1000 the lower volatility of CCG's expected range brings this particular technology in the top of the electricity mix along with solar PV. The positive covariance between PV and wind is attributed to the manufacturers' effort to further develop the efficiency of the renewables technology, while the close to zero covariance between renewables and CCG reflects the independence among them. What is remarkable is while based on the expected mean efficiency CCG no longer poses an attractive solution, for the newly established electricity production units; if the volatility of the expected range of efficiency be incorporated the CCG becomes the top alternative, because of its outcome certainty, thus highlighting both, the importance of natural gas as a transition fuel and the importance of future Natural gas and emission prices estimation.

The results of the above maximization, combined with the estimation of electricity consumption in 2030 and the planned projects for the construction of hydro plants, give the following allocation of electricity production capacity (GWh)[3] in order to cover the increase in the consumption (74532 GWh)[4]: Wind 7972 GWh, Solar 19929 GWh, CCG 21922 GWh and Hydro 32990 GWh, while the total allocation of renewables, including the current established production becomes: Hydro 51591 GWh (34%), Solar 19929 GWh (13%), Wind 7972 GWh (5%).

Currently, 1309 GWh of Solar PV, 93 GWh of onshore Wind and 7503 GWh of CCG are under planning in the region.

As previously pointed out the range of efficiency for CCG units depend largely on Natural Gas global prices while for renewables on industry's maturity and the development of technology. Under any approach, the answer for the future mix is that renewables and especially Solar PV should promoted further and covers a larger proportion of electricity generation while CCG due to its well-established technology (lower volatility) will continue to poses a key position in the transition era.

Conclusions

Western Africa is at the crossroad of electrification in order to meet both the electricity needs that are coming from the fast population growth and the lack of access to electricity. Since the current situation of low access to electricity is a fact, we have to keep an optimistic view and see as an opportunity the fact that a large proportion of any additional MWh needed, may come from a sustainable renewable source like Solar, Wind and hydro.

The planned power generation units suggests that states exploit at a high degree the vast hydro potentials of the region, while so far, they do not take advantage of the other renewables sources, especially Solar. Based on Monte Carlo analysis of expected efficiency, Solar power dominates over Wind as a future electricity source, while the development of CCG is not justifiable to further increase its current share in the electricity production with the construction of new units, a fact that is also true even for Natural Gas producing countries (e.g. Nigeria, Ghana). The incorporation of efficiency's range volatility turns balance in favor of CCG thus highlighting both, the importance of natural gas as a transition fuel and the importance of future Natural gas and emission prices fluctuation, since 50% of its lifetime cost comes from fuel. A further conclusion is that the well-established technology of natural gas serves as the low carbon alternative allows States to control the pace of transition into the zero emission era by giving time to battery storage industry to maturing and thus be directly competitive in order to support larger amounts of electricity produced by Solar and Wind.

I strongly believe that as the integration of the electricity markets evolves and the interconnection between countries is expanded, thus resulting in a more competitive

[3] Efficiency factors: Hydro 41.5%, Solar 24.9%, Wind 35.4%
[4] Under the assumption of 10% losses

environment which encourages more private investments, the development of renewables alternatives, other than hydro, will expand especially in rural regions of non gas producing countries. At this point and under the assumption that Solar and Wind facilities will expand, as projected by the mean value expected efficiency, in the coming decade I would like to point out the need for electricity storage facilities, something that will raise substantially the associated cost. Since the percentage of renewables in the overall electricity production, which makes the development of storage capacity necessary, is not fixed but rather depends on each State's unique characteristics, in this thesis the demand for storage facilities is assumed to be zero, because the evident promotion of the hydro plants, by the West African States, also serves as an alternative to the storage needs. On the other hand if the estimate that incorporates volatility turn out to be correct, Solar and Wind will account for 18% of the total production by 2030, which means that the region may meet its needs without the need for battery storage facilities, at least in the foreseeable future, provided that sufficient pumped hydroelectric energy storages for load-balancing purposes will also be constructed. It is worth mentioning that in 2012 a 48% share of renewable energy sources in the power generation mix by 2030 was set by the ECOWAS Member States as a target for the total electricity generation mix so to meet the objectives of the Paris Agreement and the UN's Sustainable Development Goal seven (SDG7) (UNITED NATIONS). As showed in the current thesis things have changed since then and a higher goal of at least 52% of renewables is now financially feasible to be achieved.

The region must take full advantage of its rich energy sources, both renewables and fossil, so to meet its electricity needs with sustainable management of solar, wind and hydro plants, on the one hand, and on the other to fund, via exports of fossil fuels, the transformation of the economy towards value added activities in order to improve its people's wellbeing. Taking into account that electricity accounts for just 18% of the total final energy consumption globally and that manufacturing, at least for the time being, is almost solely powered by fossil fuels (like gas and oil) some of the ECOWAS countries hold a comparative advantage so to proceed to the necessary structural transformations and furthermore to strengthen the regional trade at a first place, while keeping an eye on the global trends.

All of the above are under the condition of the institutional development, the elimination of the corruption and the deepening of democracy, objectives which ECOWAS embraces and promotes, while at the same time it tries to enhance the regional co-ordination and cross-border power transmission in order to achieve the optimal power mix. This co-operation must further expanded in other economic activities, as well, such as trade of goods and food processing, so to reduce its dependence upon natural resources and, consequently the high exposure to the global markets' prices fluctuations.

While development is what ECOWAS members are asks for is of high importance to remember that any expansion and development, either structural or regarding electricity production, must take into account and protect the unique natural environment of Western Africa, from tropical savannas and shrublands to tropical forests.

As a last sentence I would like to quote the phrase of Mr. Koffi Annan "….there is also a long way to go — and Africa's governments must as a matter of urgency turn their attention to those who are being left behind." (THE WORLD, 2012)

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