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Thermoeconomics and Energy Modelling

Project Work Report
Electricity planning for Sub-Saharan countries

Course of Thermoeconomics and Energy Modelling
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Group 23

Ghana

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Outline

INTRODUCTION

Ghana is a country in West Africa that has the city of Accra as capital. It borders with the Gulf of Guinea, Ivory Coast and Togo. Its population was 30.8 million in 2021[1], making the country the second-most populous in the Region after Nigeria. Ghana also covers an area of 238,535 km^2 (92,099 sq mi) that is politically and demographically divided into regions as illustrated in figure 1.

FIGURE 1

The climate in Ghana is characterized by warm and tropical conditions. The eastern coastal region experiences warm and relatively dry weather, while the southwest corner is hot and humid. In the northern part of the country, the climate is hot and dry. Ghana is also home to Lake Volta, which is the largest man-made lake in the world and stretches across the eastern part of the country.

The southern region of Ghana receives the highest amount of rainfall, with precipitation exceeding 1,500 millimeters (60 inches) annually. The small west coast area receives even more rainfall, with approximately 2,000 mm (80 inches) per year. On the other hand, the driest areas are the north, where rainfall amounts to around 1,000 mm (40 inches) per year, and the eastern coast, including the capital city of Accra, where it drops below 800 mm (31.5 inches).

1.1. History and Political Aspects

Ghana, previously known as the Gold Coast, was discovered by Portuguese explorers who, when arrived in the 15th Century, were astonished by the abundant gold reserves between

[1] The population and housing census results has officially been declared by Ghana Statistical Service.

the Ankobra and Volta rivers, leading them to name the region "Mina," meaning mine. Nowadays, the country operates under a Parliamentary Democracy system, with English as its official language.
Upon gaining independence from the British in 1957, Ghana faced considerable challenges, much like other newly-formed nations during the Cold War era. Military rulers governed Ghana for a considerable period, with varying impacts on the country's economy. However, in 1992, Ghana successfully transitioned back to democratic rule, establishing itself as a stable and progressive economy.
The shift towards democracy resulted in increased aid from Western nations, further contributing to Ghana's economic recovery. Since 1992, the country has held competitive multiparty elections and achieved peaceful transfers of power between the two main political parties. Over the past two decades, Ghana has made significant strides towards democracy, adopting a multi-party system and fostering public trust in its independent judiciary. Notably, Ghana consistently ranks among the top three African countries for freedom of speech and press.

1.2 Economy

Ghana has one of the strongest economies in Africa. Its rapid growth (7% in 2017-19) was halted by the COVID-19 pandemic, the March 2020 lockdown, and a sharp decline in commodity exports with an overall GDP as low as 0.4%[i]. Ghana's economy is projected to remain relatively strong over the medium term, supported by higher prices for key exports and strong domestic demand. It's worth highlighting the richness of the country in terms of primary resources. Moreover having a position that secures lots of sun irradiation and water access, Ghana is also an exporter of oil and a great producer of natural gas.

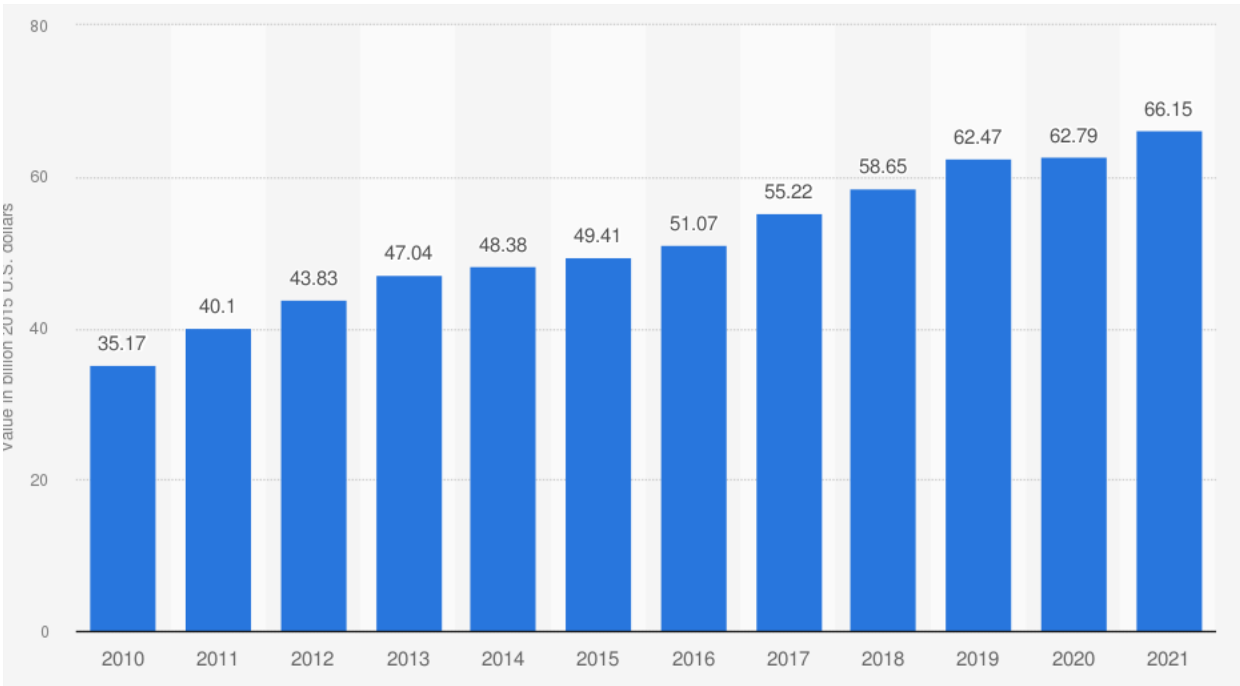

FIGURE 2- GROSS DOMESTIC PRODUCT (GDP) IN GHANA FROM 2010 TO 2021

PROBLEM DEFINITION AND DATA GATHERING

Ghana, the pioneer of independence in Sub-Saharan Africa (SSA) in 1957, is widely recognized as a shining example of democracy's success on the African continent. It serves as a testament that achieving growth beyond the norm is feasible also in terms of energy access. Over the past two decades, Ghana has made steady progress in expanding access to electricity, with electrification rates reaching nearly 85% in 2017, thanks to the implementation of a successful electrification strategy. The country depends on a varied energy mix and is home to the largest hydropower project in West Africa[ii].

Despite these shining characteristics, over the last thirty years, Ghana has faced multiple instances of power crises, primarily attributed to fluctuations in rainfall that affects the country's heavy dependence on hydro-Dam technology. The most recent and potentially longest drought occurred between 2012 and 2015, resulting in the implementation of electricity rationing. At the height of the crisis, electricity consumers were guaranteed approximately 12 to 13 hours of power supply within every 36-hour period. However, in some cases, the actual duration of electricity received by consumers was even shorter due to unforeseen disruptions in the network. The consequences of this crisis had a significant negative impact on the economy's performance.
Considering residential demand and consumption as the biggest portion of energy use in Ghana, it is somewhat evident from the figure 3 that energy usage in this country is spread out through different regions so that in our model we can assume the whole nation as one single region.

FIGURE 3

Along with choosing the number of regions to implement in our model, other data are required such as the electric consumption profile and the distribution of power plants. All the following information were taken from technical papers[iii] or official document[iv] such as the National Energy Commission of Ghana[v].

REFERENCE ENERGY SYSTEM DEFINITION AND POLICY IMPLEMENTATION IN HYPATIA

Energy reference system

To set up the files needed for Hypatia, the software used for analysis, to run, the electricity sector reference system is represented. The system does not consider any import or export from other countries neither transmission lines between macro regions since it represents a single node model. For the study of the Power Sector, refinery technologies are neglected, and only resources and supply technologies are considered accounting to produce electricity.

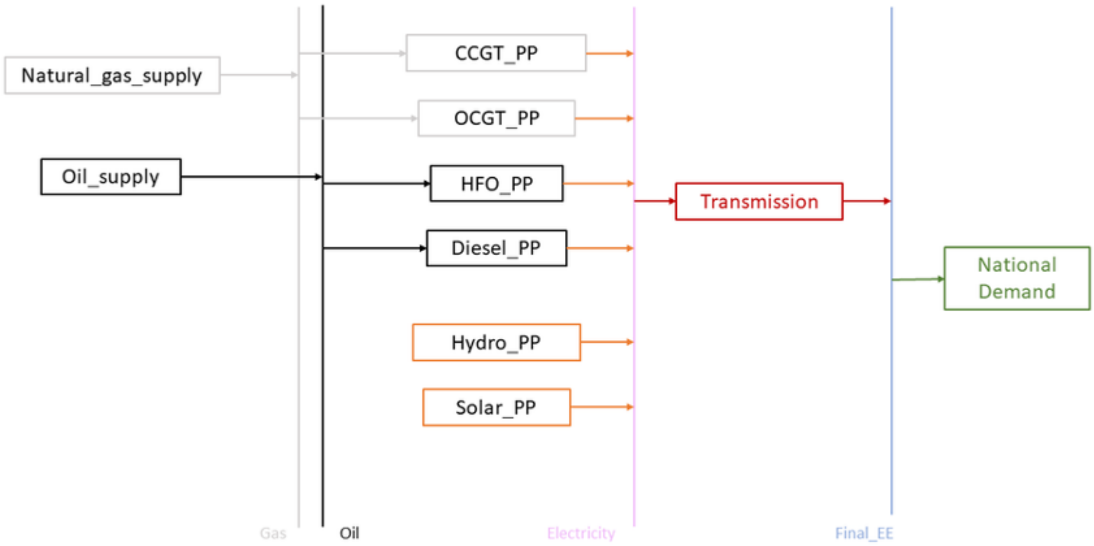

FIGURE 4

Policy implementation Hypatia: Operation Mode

Operation mode reflects the situation of the year taken as a reference, in our case 2019. The technologies adopted are Hydroelectric power plants (both from dam or run of the river plants), Heavy Fuel Oil power plant, Diesel, PV power plant and Gas Turbines (Combined and open cycles). The table below shows the power plants with their nominal capacities considered in our study.

Name	Technology	MW	Year
CENPower Kpone	CCGT	340	2019
Sunon Asogli 2	CCGT	340	2017
Takoradi 1	CCGT	300	1998
Takoradi 2	CCGT	320	2000
Amandi Limited	CCGT	192	2020
Sunon Asogli 1	CCGT	180	2011
Bridge Power	CCGT	400	2019
MV Karadeniz Powership Osman Khan	CCGT	470	2016
Ameri	OCGT	230	2016
Kpone	OCGT	200	2015
Tema CENIT	OCGT	100	2013
Tema	OCGT	100	2009
Tema	Diesel	45	2010, 2015 Expansion
AKSA Energy	HFO	350	2017
Akosombo	Dam	1020	2005
Bui	Dam	400	2013
Kpong	Ror	160	1982
Mienergy Onyadze	PV	20	2018
BXC Oyandze	PV	20	2016
VRA Navrongo	PV	2.5	2013
Bui Phase I	PV	51	2021

TABLE 1

Capital investment, fixed operational costs, fuel prices, lifetimes and efficiencies for each technology are taken from literature[vi] -Below in figure 5 can be seen a table with all the values implemented-. For some of missing values, we have made assumptions, such as the ones of specific emissions in which we have assumed that the specific emissions of the thermal power plants are the world's average[vii].

Table 8
Techno-economic parameters of electricity generation technologies in Africa (sources F, G, P).

Technology	Capital Cost ($/kW in 2020)	Fixed Cost ($/kW/yr in 2020)	Operational Life (years)	Efficiency (%)	Average Capacity Factor (%)
Biomass Power Plant	2500	75	30	35	50
Coal Power Plant	2500	78	35	37	85
Geothermal Power Plant	4000	120	25	80	79
Light Fuel Oil Power Plant	1200	35	25	35	80
Oil Fired Gas Turbine (SCGT)	1450	45	25	35	80
Gas Power Plant (CCGT)	1200	35	30	48	85
Gas Power Plant (SCGT)	700	20	25	30	85
Solar PV (Utility)	1378	18	24	100	Varies by country
Concentrating Solar Power without Storage	4058	41	30	100	23
Concentrating Solar Power with Storage	5797	58	30	100	26
Large Hydropower Plant (Dam) (>100MW)	3000	90	50	100	Varies by country
Medium Hydropower Plant (10-100MW)	2500	75	50	100	Varies by country
Small Hydropower Plant (<10MW)	3000	90	50	100	Varies by country
Onshore Wind	1489	60	25	100	Varies by country
Offshore Wind	3972	159	25	100	Varies by country
Nuclear Power Plant	6137	184	50	33	85
Light Fuel Oil Standalone Generator (1kW)	750	23	10	16	30
Solar PV (Distributed with Storage)	4320	86	24	100	Varies by country

FIGURE 5

The resource availability for each hydro power plants is taken, in terms of monthly capacity factors, from the African Hydropower Atlas, and converted into energy by the means of the installed capacity of each plant. The resources availability of PV for country is taken from web tool developed by Imperial College London and ETH Zürich (Renewables Ninja). Regarding other technologies, the resource reservoir is assumed to be infinite.

Policy implementation Hypatia: Planning Mode

Looking at the next ten years, Ghana will be facing a significant increase in annual electricity demand, estimated at around 74% by 2030[viii]. To meet this growing demand, the Energy Commission of Ghana has stipulated a detailed plan to ensure also a more sustainable future for its community, planning to build up to 1100 MW of new renewable power plants (figure 6) and scaling up the RES penetration to 25% in the electricity mix.

Table E1: REMP Implementation Schedule 2019 to 2030

REMP IMPLEMENTATION PLAN - RE TARGETS UP TO 2030										
Renewable Energy Technologies	Reference 2015		Cycle I (2019-2020)		Cycle II (2021-2025)		Cycle III (2026-2030)		Cumulative in 2030	
	No. of units	MWp	No. of Units	MWp	No. of Units	MWp	No. of Units	MWp	No. of Units	MWp
Solar Energy										
Solar Utility Scale	-	22.5	-	130	-	195	-	100	-	447.5
Distributed Solar PV		2		18		80		100		200
Standalone Solar PV	-	2	-	8	-	5	-	5	-	20
Solar Street/Community lighting	-	3	-	4	-	4	-	14	-	25
Solar Traffic signals (% of total traffic signals installed in the country)	14	3	11	-	15	-	20	-	60	-
Solar Lanterns	72,000	-	128000	-	300000	-	500000	-	1000000	-
Solar irrigation	150	2.8	6000	6	20000	20	20000	20	46150	48.8
Solar Crop Dryers	70	-	80	-	250	-	300	-	700	-
Solar Water Heaters	4,700	-	15300	-	50000	-	65000	-	135000	-
Wind Energy										
Wind Utility Scale	-	0	-	0	-	275	-	50	-	325
Standalone Wind Systems	-	0.01	-	0.1	-	0.9	-	1	-	2
Wind Irrigation/Water Pumping	10	-	25	-	30	-	35	-	100	-
Biomass / Waste-to-Energy										
Biomass Utility-Scale	-	0	-	0	-	72	-	0	-	72
Waste-to-Energy Utility Scale	-	0.1	-	0	-	30	-	20	-	50.1
Biogas (Agricultural/Industrial Organic Waste)	10	-	20	-	70	-	100	-	200	-
Biogas (Institutional)	100	-	80	-	140	-	180	-	500	-
Biogas (Domestic)	50	-	30	-	50	-	70	-	200	-
Woodlot Cultivation (ha)	190,000	-	60000	-	100000	-	78000	-	428000	-
Charcoal (Local Demand)	1,551,282	-	94017	-	93947	-	100877	-	1840123	-
Charcoal (Export)	190,450	-	59550	-	100000	-	78000	-	428000	-
Briquetting/Pelleting	19,700	-	20300	-	25000	-	35000	-	100000	-
Biofuel (tonnes)	0	-	100	-	4900	-	15000	-	20000	-
Hydro / Wave Power										
Small/Medium Hydro Plants	-	0	-	0.03	-	80	-	70	-	150.03
Wave Power	-	0	-	5	-	0	-	45	-	50
Hybrid Mini-Grids										
Mini/Micro-grids	13	-	73	-	114	-	100	-	300	12
End User Technologies										
Improved Biomass Cookstove (Domestic)	800,000	-	500000	-	500000	-	1200000	-	3000000	-
Improved Biomass Cookstove (Institutional/Commercial)	1,800	-	1200	-	7000	-	8000	-	18000	-
Total Installed RE Electricity Capacity										***1353.63***

FIGURE 6

Despite the immense solar energy potential in Ghana, the sector has faced various challenges over the years that include lack of political will, limited technical expertise, difficulties in accessing components, financing constraints and land availability issues. However, its implementation is crucial to ensuring a constant rise in the electricity access by rural communities and to achieving the goals set by the government.

Furthermore, hydropower generation in Ghana has declined due to low reservoir levels. In 2018, the Akosombo hydropower plant had to operate only three out of its six turbines during off-peak periods and up to four turbines during peak periods. Currently, only about half of the country's installed hydropower capacity is available. The government aims to have 10% of the country's power supplied by non-hydro renewable energy sources by 2030, with solar and wind energy being the primary contributors.

Our planning work is divided into two main scenarios. The first one is without any political constrains and it aims to show a pure economic analysis of the technologies available. While the second considers the political goals set by the government in terms of new capacity installed and minimum renewable share in the electric mix. An additional sensitivity analysis was made over this latter scenario to highlight some critical issues and possible solutions to them.

CRITICAL ANALYSIS OF THE RESULTS

Setting the input from reliable data enables us to produce good quality results used either to mirror the current situation or to plan a more solid future.
The year taken as reference is 2019 and its study was made possible through the "Operation" mode in the Hypatia software. The figure 7 shows the annual production that minimizes NPC by each technology.

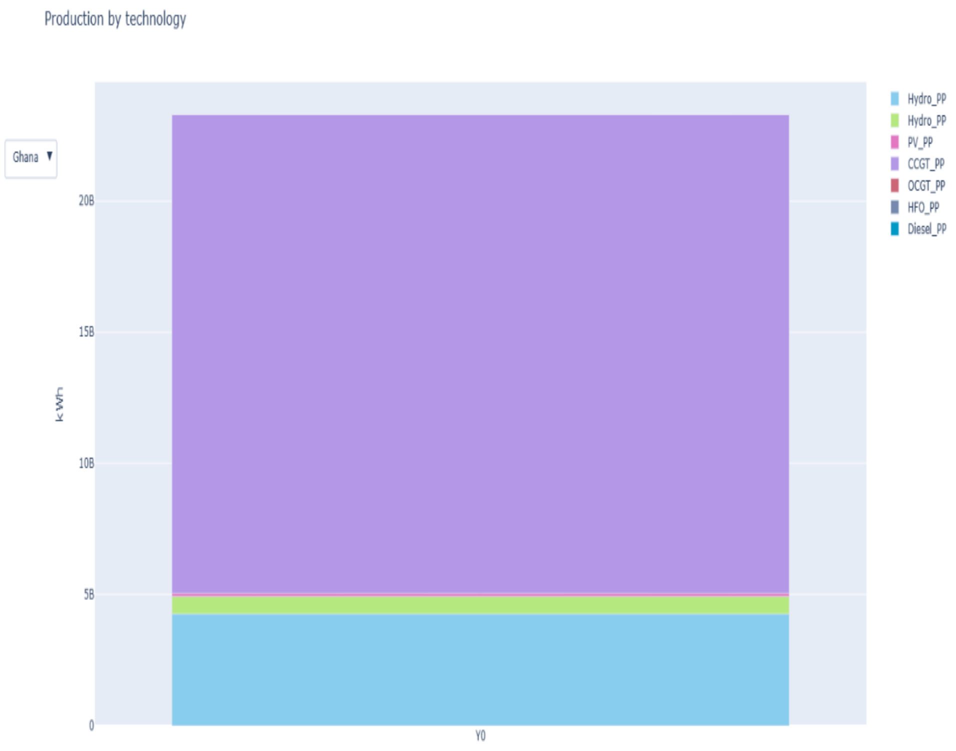

FIGURE 7

It is worth noticing the heavy dependence on CCGT power plants due to the higher technological efficiency compared to others options and the great amount of capacity installed. This later aspect can be explained by the great potential that the country has in

terms of gas deposits. It's possible also to highlight the production from hydro power plants, on of the country's greater resource, that represents almost the 22% of the total share.
There are not present oil plants due to their low efficiency -compared to CCGT- and OCGT for the same reason. Moreover, the PV share is really low due to the lack of an appreciable generation capacity.

The current situation analyzed can represent a solid case for future prevision. Indeed, the planning structure of our work was divided into two main scenarios, each of them with the corresponding sensitivity analysis.
The first scenario considered is without any political or economical constraints, leaving the scene to a pure economical analysis.

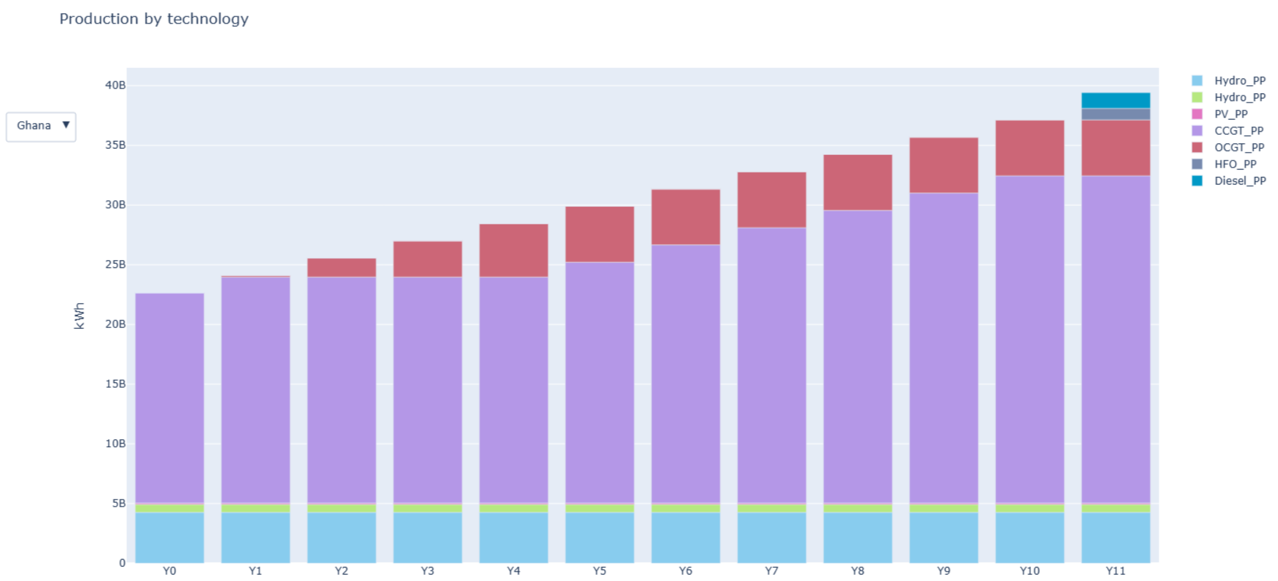

Figure 8

Many things and trends can be pointed out.
Firstly, the already existing generation capacity can compensate all the rising demand; therefore, in a scenario with no carbon emission constrains this capacity would be enough. In second place, the increasing demand is met by the rise of CCGT power plants for the reason explained in the previous section. In 2030, since gas power plants have reached the maximum production, oil plants are used. Moreover, as seen in the operation mode, the hydro power generation is saturated, already giving the maximum possible contribution to the energy mix.

To address a more accurate analysis, Ghana policies were taken into account. The policies guidelines, stated by the government for the time horizon considered, consist in the construction of new renewables plants -for a utility scale total of 1094 MW- and a minimum renewable electric share of 25%.
After implementing them in the software the result was the following.

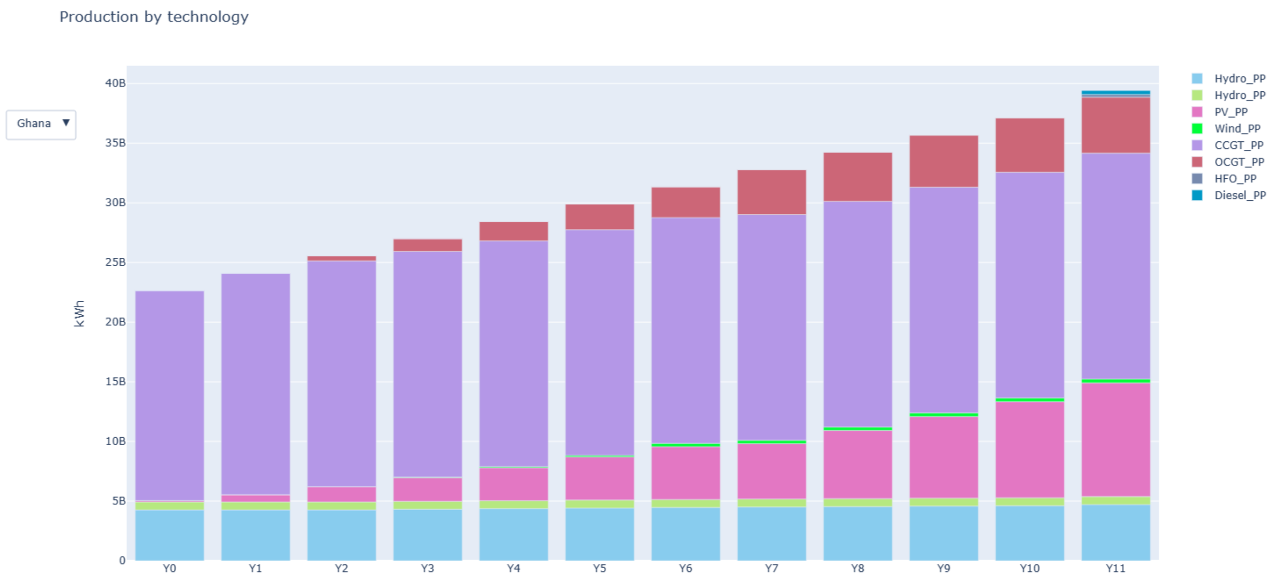

FIGURE 9

It's possible to note that all renewables technologies are used, even though in different proportions.
PV, due to its low cost of investment, is the most used technology, evincing that their economical life can be lower than 10 years. Not the same can be said about wind and hydro. Even though their share increases in time, the high cost of investment are relevant limiting their implementation. Most of the rise is compensated, once more, by CCGT power plants.
It's relevant to highlight that without any limitation, even with a higher renewable production capacity, the NPC is optimized with only the use of CCGT. Additional constrains to this model are analyzed such as the effect of carbon taxes to naturally making renewable the best economical solution.

Nowadays Ghana is not putting any tax on the natural gas supply[2], while the average of the OECD country is of 27.7 €/tons of CO2 equivalent.
Implementing this value leads to the following result.

[2] https://www.oecd.org/tax/tax-policy/taxing-energy-use-ghana.pdf

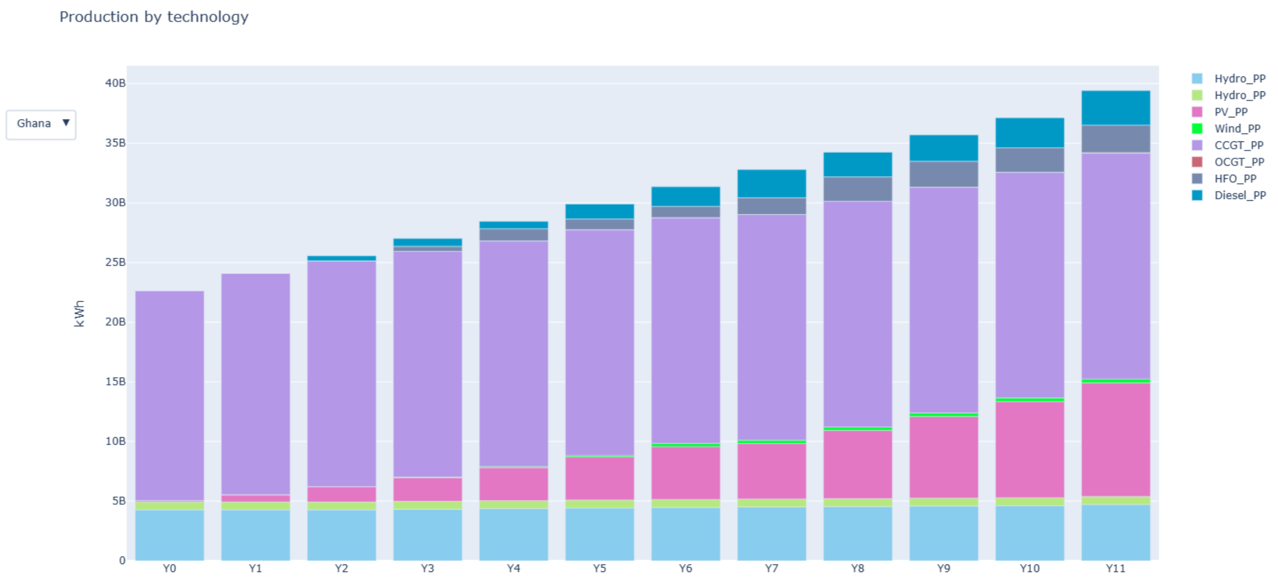

FIGURA 10

The renewable share is not modified while the OCGT plants are replaced by oil power plants. This latter plants are, therefore, more economically feasible than renewables. The reason for that is the limited time horizon considered. Making an investment in renewables will not lead to an economic saving before 10 years, while running already existing oil plants is the cheapest option.
This observation is justified by looking at the figure 10 in which we can see that the increasing variable costs of oil supply are still way lower than the PV investment required.

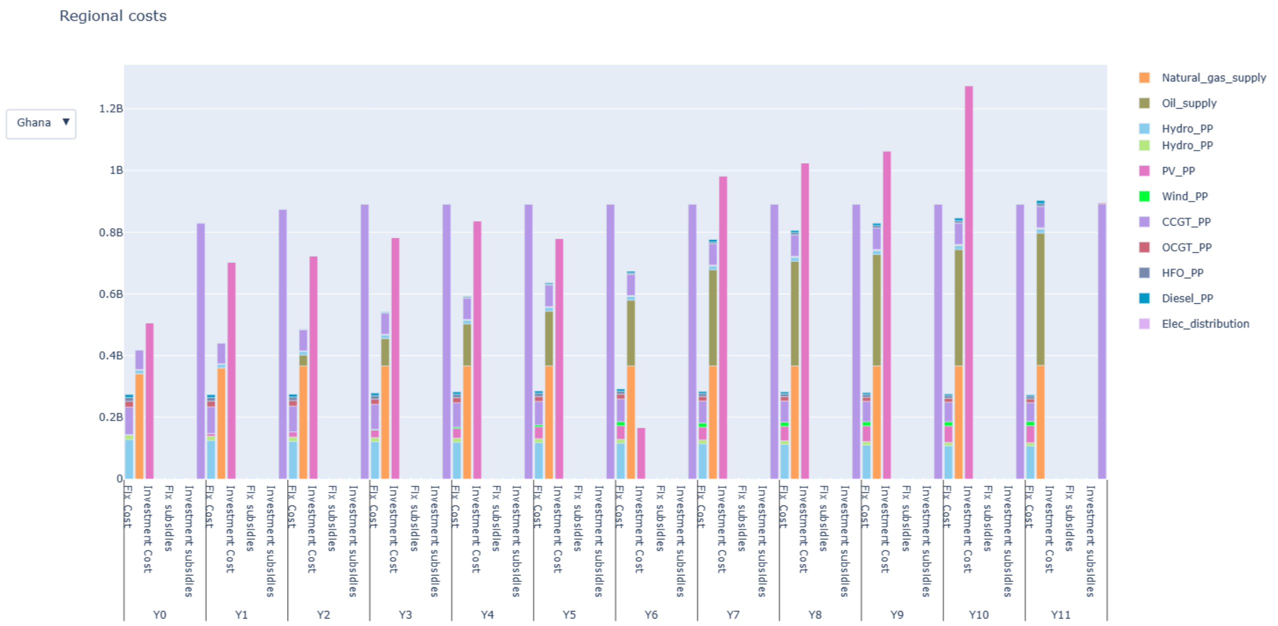

FIGURE 10

POLICY RELEVANT CONCLUSION

As said in the introduction, the work aims at producing useful guidelines for the government of Ghana, helping them to take the best decisions possible for the future of the country.
Before addressing any suggestions, it's rightful to remember that Ghana is still a developing country that needs a surprisingly fast consumption of energy to bring it at the average levels of the world. It would be simple to exploit all the fossil fuel resource that this country has, but it's even more important to ensure a rightful and sustainable development in the long-term run.
To achieve government's goals lots of work needs to be done but the analysis made has pointed out some important results.
The first is that the generation capacity of 2019 would be enough to cover all the rising demand up to 2030 as seen in the base case. The new power plants constructed are not, therefore, running if they are not economically sustainable. Renewables present high investment costs with respect to thermal power plants, but they are feasible in the long term. Sot he suggestion that we would like to address is to put these policies for 2030 into a greater scenario -maybe up to 2050- in order to analyze the real benefit of such technology.
Focusing more on the time horizon set, we can see that the most efficient and cheap way to produce electricity is CCGT. To reduce its use, carbon taxes are not enough -in fact to have an appreciable effect we have to impose taxes ten times higher than the average of the OECD countries-.
Seen this, carbon taxes need to be coupled with heavy subsidies on the investment of renewables.
Among them, PV plays the major role and has a double advantage.
Firstly, has a lower investment cost than the others and so it's easier to address subsidies.
Secondly, PV can not be used only at the utility scale level but also in distributed and stand-alone applications, vital for the rural access of countries to electricity.
In 2021 Ghana government has also imposed heavy subsidies on the use of oil.

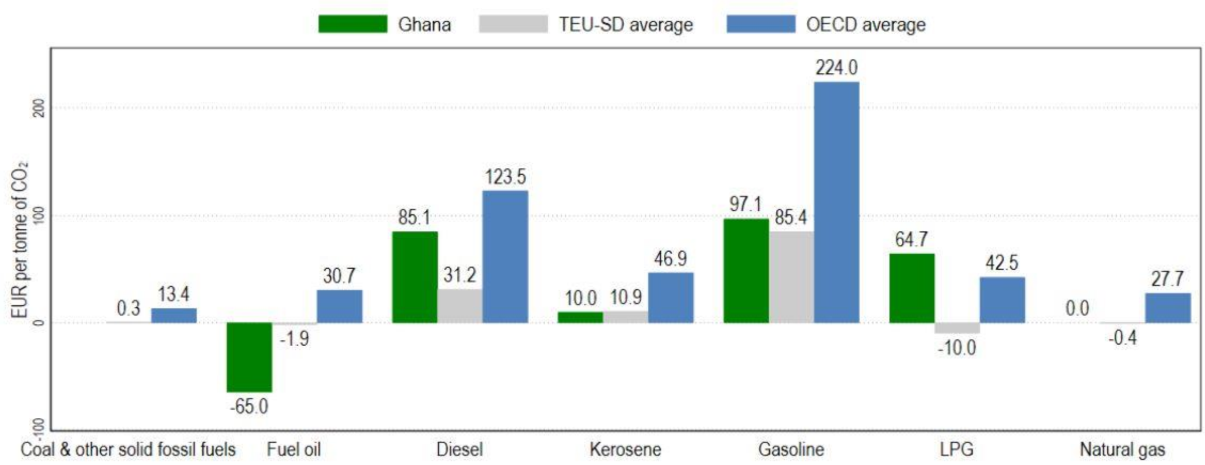

FIGURE 11

This is why the country is a large exporter of this resource but, in order to ensure the long-term energy stability, the il power plants needs to be replaced by renewables.
If all these subsidies were taken off, oil plants still represent a cheaper solution to renewables but, on the contrast, need lighter taxes on emissions, compared to the gas ones, to make them more expensive than green energy sources.
To summarize, we got some important results such as:

- Generation capacity is enough to cover the countries future needs but not in a sustainable way.
- The new power plants need to be economically feasible to have an impact on the short-term energy mix and this can be achieved by putting carbon taxes and subsidies on renewables, especially on PV to enable their fully exploitation.
- Oil power plants and OCGT are more sensible to carbon taxes than CCGT, due to their efficiency difference.

These suggestions can not be implemented without looking at the history and potential of this country. We believe that Ghana, for its geographical position and resources, can play a very important role in the next future that has to be planned in the wiser way possible to ensure the brightness its potential.

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