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LONGTERM OPTIMIZATION MODEL FOR THE GAMBIA'S ENERGY TRANSITION

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Abstract. The energy sector in the Gambia is entirely dependent on imported petroleum products for electricity generation. The country is not only vulnerable to global oil market disruptions but also has an unstable electricity supply system. As of 2020, a huge portion of the country's electricity demand remains unsatisfied. Following recent government intervention to improve the energy system, this paper examined the optimal capacity expansion planning using the open-source energy modelling system (OSeMOSYS) on a time horizon of thirty years, (2020-2050). The three scenarios studied include the business as usual (BAU), which reflects the continuation with the existing power generation pattern, the second scenario (roadmap) aligns with the Gambia's strategic electricity roadmap (2021-2040) and the third scenario considered high renewable penetration in the energy mix. Contrary to policy makers expectations, renewables accounted for only 19.2% of electricity generation in the roadmap by 2030 and 11% by 2050. CO_2 emission in 2050 reduced by 31% in the roadmap scenario and 71% in the new scenario. The global cost of the new scenario is 29% more expensive than the roadmap scenario but becomes more competitive than the roadmap in terms of energy cost when the capital investment is fully subsidised in all scenarios.

Key words. The Gambia, Energy Transition, OSeMOSYS, Optimization, Sustainability

1. Introduction

Energy systems are transforming globally due to the challenges of Climate Change and the strive towards sustainable development and the need to transition to a low carbon economy is well-known. Since the Paris Agreement was reached in 2015, a series of plans have continued to emerge to tackle the climate crises. The European Green Deal[1] introduced in 2019 aims at reducing carbon emissions to 55% by 2030 and achieving carbon neutrality by 2050 through the increase of renewable energy in electricity generation, transport, buildings, including industry. To enable this vast shift, the green deal investment plan sets out €1trillion to be sustainably invested in supporting those impacted by the transition and the just transition mechanism allocates € 100 billion to be invested in, between 2021-2027[1]. In 2022, The United States under the Biden administration also enacted the Inflation Reduction Act[2], which has been seen as the greatest commitment of the country in combating climate change due to its allocation of $369 billion for energy and climate projects. It is hoped that through this initiative, the United States carbon emission levels will fall 40% akin to 2005 levels by 2030. Africa which accounts for less than 4% of the world's CO_2 emissions[3], is however more prone to the devastations caused by climate change impacts and as such cannot be left behind in the climate mitigation and energy transition crusade. Considering this reality, the climate change and resilient development strategy and action plan (2022-2023)[3] was also launched by the African Union in February 2022 with the vision of an Africa that is sustainable, prosperous, equitable and equally climate resilient. The strategy has four key objectives one of which is to "pursue equitable and transformative low emission, climate-resilient development pathways".

The trend of decarbonization is visibly evident in different regions of the globe and a unique feature among the major ambitious plans and strategies is that renewable energy is set to play a critical part in the transformation of the energy sector. The EU for example is committed to installing 1,236 GW of renewable capacity by 2030 to account for 45% of its total energy mix. In a similar move way back in 2015 with the backing and support of France, Germany, Canada and the USA, the Africa renewable energy initiative was launched with the core objective of providing the continent with renewable capacity of at least 10GW by 2020 and 300GW by 2030. While all these initiatives and plans are commendable, what remains clear as we briefly elaborate below is that a huge gap remains to be filled as far as the energy landscape particularly in Africa is concerned.

In Sub-Saharan Africa, 570 million people are still living without electricity access[4] and millions also depending on unclean cooking fuels. Despite Africa's huge renewable energy potential which can be harnessed to breach the energy access gap and move millions out of poverty, only 7% of electricity in Africa is generated from renewables and the continent as of 2020 had slightly above 50GW renewable energy installed capacity mainly from

Hydro (34GW), solar (10.4GW) and wind (6.5 GW)[4].The situation in the Gambia is even more revealing about Africa's low adoption of renewables as the country depends entirely on imported heavy fuel oil (HFO) for electricity generation[5] , a situation which have for the longest left the electricity sector in an unstable state with an enormous gap between supply and demand. Furthermore, about 40% of the Gambia's population is without access to electricity and 90% depends on biomass for cooking, a phenomenon associated with numerous deaths globally according to the World Health Organization[6].

In 2021, The Gambia updated its electricity sector road map (2021-2040)[7] in alignment with key policy objectives including universal electricity access by 2025, increasing domestic electricity generation, provision of low-cost electricity through energy imports and exports and the deployment of solar in the electricity generation mix. Similarly, the Gambia have also committed itself to achieving net zero emissions by 2050[8] while anticipating renewables to account for 30% of the power generation mix by 2030.

It is from this prospect that this research seeks to model the Gambia's long-term energy transition with the view of finding insights on whether the Gambia can meet its net zero emission target by 2050 as proposed in its long-term Climate Strategy, what set, or combination of technologies are suitable for the country's energy transition and at what cost will each of the electricity generation pathways be met by 2050.

While we acknowledge that answers to these questions are not straightforward given the complexity of energy policy and a wide range of uncertainties from techno-economic and social contexts, we recognise the fact that a good number of models[9] exist which can guide policy makers in taking optimal decisions in the energy sector. A point worthy of note is that despite this preponderance of energy system models, energy modelling efforts are still minimal in Africa due to capacity gaps in long-term energy system planning research thus leaving policy makers in some cases with the option of making decisions without sufficient scientific backing[10]. In the case of The Gambia, some of the previous energy modelling activities are highlighted below.

AF mercados EMI with funding from the European Union, prepared the Gambia electricity strategy and action plan[11] from 2013 to 2032 using their own ORDENA plus model. From their findings, they recommended three possible pathways for the Gambia which includes (i)continuation with the existing power generation pattern, (ii)widening opportunities for cross border electricity trade together with increased reliability and renewable capacity and the third being high penetration of renewables. [5] used the model for energy supply strategy alternatives and their general environmental impact (MESSAGE) on a fifteen years' time horizon (2015-2030) to assess the future electricity supply system of the Gambia. Out of the two scenarios modelled, they found the scenario which incorporates hydroelectricity imports by 2020 more desirable for the Gambia but also expressed concerns over energy independence and security.

Recently, in the planning of the Gambia's electricity sector roadmap (2021-2040)[7] with financial support from the World Bank, Waya Energy (WE) together with other organizations used the Reference Electrification Model (REM). Eleven scenarios were analysed and as part of the conclusion, electricity import from Senegal or Côte d'lvoire was found to be the least cost generation option for the Gambia and 70MW of solar capacity was regarded as "no-regret" investment for the country.

A unique feature among all the previous modelling exercises is that their model choices present a limitation in that they are not fully open source and attracts initial financial investment for their use. In our attempt to add to previous energy modelling efforts to promote sustainable planning of the Gambia's energy system, a distinctive feature of our approach is that we have used an open-source energy modelling tool[12] which curtails the shortcomings mentioned above. Furthermore, we have also adopted a longer time horizon in our model than the previous studies mentioned. This is important because 2050 is a period consistent with the Gambia's long term climate change strategy as well as the Gambia's long-term development vision (2050)[13], currently under development by the ministry of finance and economic affairs.

The purpose of this paper is therefore twofold. First, it seeks to utilise the open-source energy modelling systems (OSeMOSYS) using a time horizon of thirty years, 2020-2050 to provide insights on the long-term capacity expansion planning of the Gambia's energy system and net zero ambition to boost the transition. Secondly, it aims at contributing to energy systems modelling for Africa to boost evidence-based research for the continent. OSeMOSYS is a bottom-up optimization modelling approach applied for both medium and long-term energy systems planning and analysis[12]. With its objective function being cost minimization of the exogenously defined demand, it allows for the examination of various energy transition scenarios and provides least cost options including CO_2 emissions pathways.

OSeMOSYS has been used in modelling electrification pathways for Tanzania, assessing impacts of energy policies in Cyprus, as well as Ethiopia[14]. OSeMOSYS has a short learning curve and requires no upfront financial cost hence making it readily available for policy makers and academics particularly in developing countries where modelling exercises for the energy sector are mostly outsourced and at cost. To widen modelling capabilities of various stakeholders especially those from developing countries, OSeMOSYS is being used for both research and capacity building activities around the world. It is not only restricted to energy systems planning but can also be used for integrated modelling of climate, land-use, energy, and water systems[15]. The model management infrastructure (MoManI) is an open-source browser-based interface and one of the most popular interfaces used for operating OSeMOSYS. It is easily editable and allows scenario analysis and results visualisation. Through the google based discussion forum, new users of OSeMOSYS can ask questions and have them answered by experienced modellers and experts and in this way, a community of practice[16] is maintained which allows user problems to be solved and more improvement made on the model.

Country Background

Figure 1: Political map of The Gambia

The Gambia is Africa's smallest mainland country with a land area of eleven thousand square kilometres located in the Western region of Africa. It is enclosed by Senegal from the North, East and South and the Atlantic Ocean on the West as can be seen in *fig.1*. The country's capital city is located on the island of Banjul. English is the Gambia's official language and Dalasi its currency[17]. The Gambia is uniquely bisected by a river which occupies about 20% of the total land area. According to the last population and housing census conducted by the Gambia Bureau of Statistics (GBoS) in 2013, the country has a population of 1.8 million people comprising 55% urban and 45% rural settlers with an annual growth rate of 3.1%.

The climate of the Gambia is subtropical, and the country experiences a long dry season period between November and May during which dusty winds from the Sahara are normally felt, and a short-wet season from June to October. The Gambia has a tiny economy with about 40% unemployment rate[18] and the main contributors to GDP includes services 63%, Agriculture 19%, industry 15% and others 3%. The main products that are exported includes groundnut, fish and fish products, timber, and cashew nuts but recent statistics shows a decline as imports are seen to be taking the lead. The Gambia's dependency on external energy resources have been one of its major challenges since its independence from Britain in 1965 and unlike its neighbour Senegal which has recently made some significant discoveries in the hydrocarbon sector and working on its exploitation, the Gambia has not yet confirmed the existence of economically exploitable oil and gas reserves. Notwithstanding, solar radiation is high throughout the country measuring on average between 4.6-6.7 KWh/m2/day[19] and a slightly reasonable potential for harnessing wind energy exists along the coastal areas where studies have revealed speed of 4.3 m/s at a height of 30 meters[19]. The electricity sector is unstable and highly dependent on external energy resources.

According to the Gambia's Public Utilities Regulatory Authority (PURA), there was a total number of 249,678 electricity customers in the Gambia in 2020 with an energy demand of 1,096,275MWh[20] which grew by 3% in the same year. The country has a total installed capacity of 147.2 MW with only 108 MW available[7]. The unavailable capacity could be linked to several factors ranging from plant decommissioning or underutilisation due to high inefficiency or delay of spare parts delivery after engine breakdown. Added to the problem of the Gambia's power sector is a deficient generation, transmission, and distribution system and according to the ECOWAS Center for Renewable Energy and Energy Efficiency (ECREEE), the aggregate electricity losses of the Gambia is 22%[21] which is much more higher than the 10% regional target.

2. Methodology

We have used the open-source energy modelling system (OSeMOSYS) to model the Gambia's long term energy transition with 2020 as the base year given the availability of reference data from that period. We have analysed three scenarios for the Gambia's energy transition up to 2050 with key assumptions on both technical and economic parameters. The first step undertaken was a background assessment of the Gambia to understand its energy resource potential, power system composition and current realities and the reference energy system (RES) for The Gambia is shown in *fig.2*. A RES is a graphical representation which simplifies the real energy system under analysis and rather than limiting to the present configuration, it can also capture the likely development of the energy system.

It consists of primary, secondary, and tertiary levels. The primary comprises fuel supply technologies, the secondary is made up of energy conversion technologies including transmission and distribution network while the tertiary represents the final end-users which the exogenously defined demand is meant to satisfy. The lines represent the fuels while the boxes represent the technologies which produces or uses the fuels.

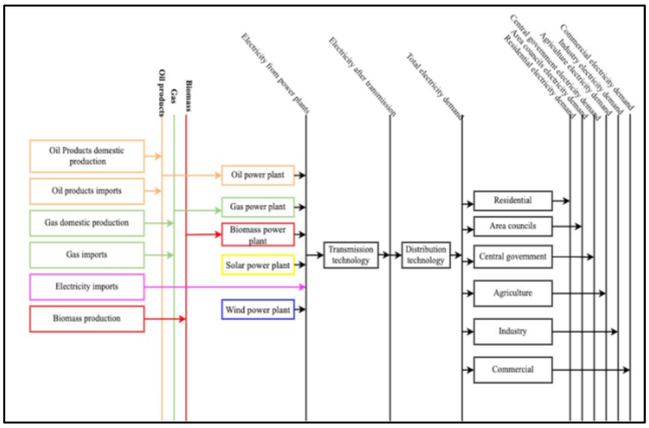

Figure 2: Reference Energy System

The exogenously defined energy demand (MWh)for the Gambia is assumed to grow at a rate of 3% annually consistent with the 2020 value reported by PURA [22].Technologies such as concentrated solar power (CSP), nuclear and coal were left out in this model primarily because they do not currently fall under the country's generation technologies and by extension, energy policy aspirations. Coal have been a potential option in the past but never materialized and recent activities by environmentalists in neighbouring Senegal which led to the abandonment of a proposed coal power plant could potentially affect a similar attempt in the Gambia from succeeding and for this reason, it has also been excluded from the model.

The recent U-turn made by certain European countries to reopen and commission new coal power plants in the wake of the Russian-Ukrainian crises might influence some policy shifts in Africa whose energy policy have for long been dominated by Europe. The three scenarios were constructed in view of current realities and the expected transition of the energy sector in the Gambia.

Data is an essential element for energy modelling and OSeMOSYS being one of the most detailed energy modelling frameworks, parameters and sets had to be selected carefully to suit the modelling purpose. All the Data regarding cost parameters was obtained from the Gambia strategic electricity sub-sector roadmap (2021-2040) document[7] and these were adjusted from kilowatt (KW) to megawatt (MW) or from kilowatt hour (kwh) to megawatt hour (MWh) values where necessary. The emission factors were obtained from[23]. A comparative analysis of techno-economic parameters and assumptions used in different energy modelling approaches can be found on [24].The model management infrastructure (MomanI) was used for inputting data and results visualization. Since models provide insights to aid decision making and planning, the final crucial step in this modelling exercise was results interpretation and analysis.

Scenario defination

BAU (Business as usual) This scenario reflects a continuation with the existing power generation pattern without accounting for any policy shifts. The trend of total dependence on external fossil fuels therefore continues unabated up to 2050. 15% of reserve margin was applied on the heavy fuel power plant (HFOP) to account for unexpected peak load.

Roadmap scenario

This scenario is consistent with the strategic electricity sub-sector roadmap (2021-2040) which aspires for universal electricity access by 2025, increased domestic electricity generation, low-cost electricity through electricity imports, deployment of solar in the generation mix. It also factors the Gambia's long-term climate strategy of achieving net zero emissions by 2050. To model this scenario, a mix of technologies were introduced in the model for electricity generation. Electricity import (ELCIMP) was limited to 40MW, and the maximum capacity of the combined cycle gas plant (CCGT) was set at 50MW throughout the model period in accordance with the government's capacity expansion plan. The capacity of the heavy fuel oil power plant was unrestricted while maximum renewable energy capacity for solar (20MW) and wind (3.6 MW) were gradually added starting from 2023. 150MW of solar was added in 2025 while the capacity of wind remained constant. Furthermore, a reserve margin was fixed to meet 15% of demand at any point during the model period.

A renewable energy target of 30% mainly from wind and solar was set from 2030 to 2050.

New Scenario

This scenario assumes a high penetration of renewable energy considering the country's renewable energy potential and recently launched solar projects with various capacities. No restriction was imposed on the solar capacity during the modelling period under this scenario.

3. Results

Based on the assumed 3% growth rate of the current energy demand, The Gambia's energy demand is expected to reach 54.81GWh by 2050 which implies a massive increase in installed capacity to provide the required generation capacity. In terms of energy production, the heavy fuel oil plant dominates in both the business-as-usual as depicted in *fig.3* and roadmap scenarios shown in *fig.4* but reduce drastically to only 13% in the new scenario as indicated in *fig.5*. Furthermore, the contribution of the gas power plant in the generation mix in the roadmap scenario decreased by 44.4% while electricity imports fell by 56% in the new scenario. As can be seen in *fig.5*. 60% of generation capacity in the new scenario was satisfied by solar in 2030 thus exceeding the 30% targeted in the country's energy mix in the same period and this trend is continued up to 2050. The biomass plant was not utilised in both the roadmap and new scenarios due to its associated high costs and that is not surprising since there is no such plant currently under operation in the Gambia.

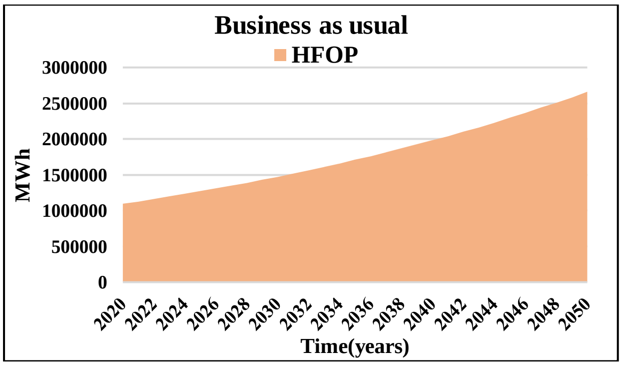

Figure 3: Business as usual scenario

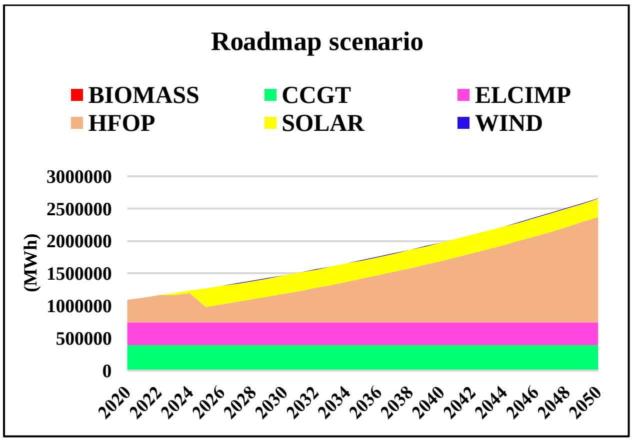

Figure 4: Roadmap scenario

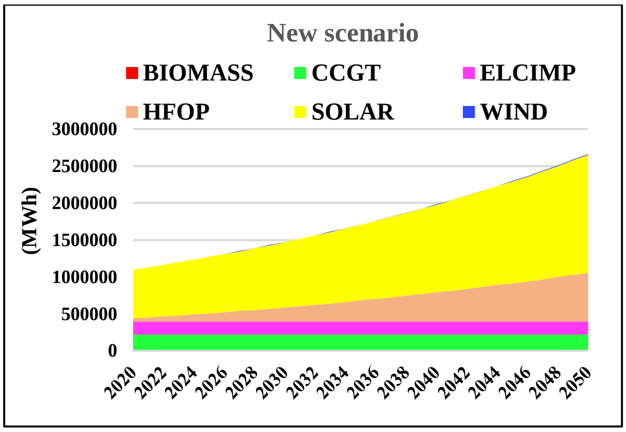

Figure 5: New scenario production by technology

395MW of solar was installed in the new scenario in 2020 as shown in *fig. 6.* with slight increases annually until 2045. New wind capacity of 3.6MW was only added in 2025, 2045 and 2050 respectively while new capacity for electricity import (40MW) and gas(50MW) were only added in 2020 and 2050 respectively. The heavy fuel plant in the new scenario started to add new capacity of 3MW in 2030 which increased to 14MW in 2031 before declining to 4MW in 2032 and thereafter increased and decreased along the years and with an eventual addition of 7MW in 2050.

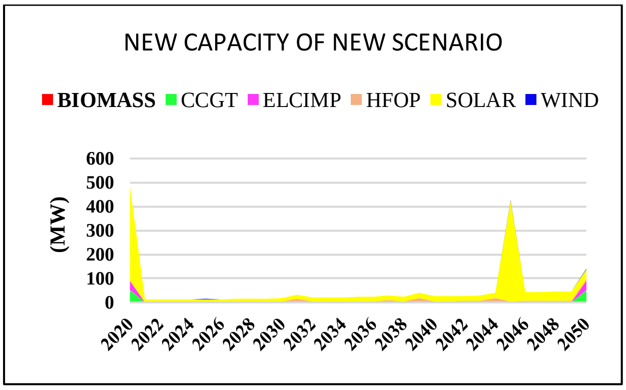

Figure 6: New capacity added by technology in new scenario

The annual CO_2 emissions in 2050 resulted to 1873 kilotons in the BAU scenario and decreased by 31% for the roadmap scenario. In the new scenario however, CO_2 emissions fell by 71% in 2050 which could be explained by the dominance of solar in the generation mix (see *fig. 7* for details). Cumulatively, emissions were 38578.2 kilotons for BAU, 21761.4 for the roadmap and 9397.9 in the new scenario.

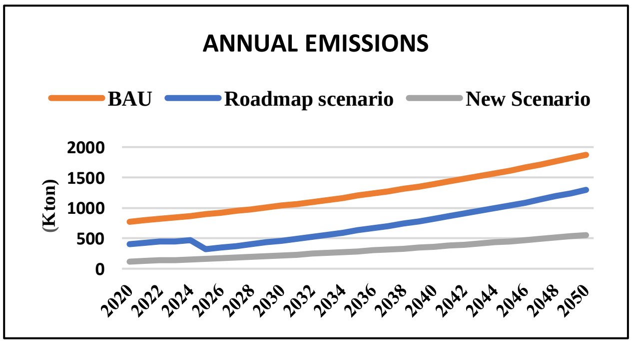

fig.7: Annual Emissions by scenario

Table 1: Global cost and Capital investments

Scenario	Global cost (M$)	Capital Investment (M$)
BAU	1141.5	571.4
Roadmap	2354.3	713.2
New	3039.7	1705.5

Table 1 presents the global costs and capital investments of each scenario up to 2050. The new scenario is the most expensive being 166.3% more than the business-as-usual scenario and 29% more than the roadmap. However, to make the scenarios easily comparable, table 2, shows the results per unit of energy (Kwh). The subsidised cost shows the costs attributable to the end customer considering an external financial support covering the required investment cost by 100% in all scenarios. In this case, the new scenario becomes more competitive than the roadmap scenario. This assumption was made in consideration of the fact that the Gambia receives international assistance for energy development through various projects.

Table 2: Energy costs

Scenario	Global cost (Kwh)	Subsidised cost (KWh)
BAU	0.020	0.010
Roadmap	0.042	0.0299
New	0.055	0.024

4. Conclusions

We have modelled the Gambia's energy transition from 2020 to 2050 and the energy system have been optimized following techno-economic parameters. We found that contrary to policy makers expectations, renewables accounted for only 19.2% of electricity generation in the roadmap by 2030 and 11% by 2050. The new scenario which presents more opportunities to decarbonise (71%) by 2050 is also associated with the highest cost (29% more than the roadmap) which suggests that sustainable means of financing the transition are required. As shown in our results, such transition will require various strategies stemming from the combination of various technologies as well as the utilisation of local resources particularly solar which is abundantly available in the country year-round but currently absent in the country's energy mix. The installed renewables capacity in the new scenario however contrasts with the Gambia climate mitigation strategy which plans to gradually add 250MW solar capacity by 2050 and 100MW wind by 2030. In addition, it also differs from the Gambia's strategic electricity sub-sector roadmap in which it is recommended that 70MW of solar capacity would be of "no-regret investment". Notwithstanding these differences in findings, we however contend that low solar capacity does not in any way reduce The Gambia's dependency on external energy resources but rather keeps the energy system fragile and as such it is more economically viable to increase reliance on locally available energy resources. Although the new scenario appeared to be the most expensive, it contains embedded benefits. Firstly, it will be more economically viable in the long run given the absence of fuel costs in the operation of renewable energy technologies. From a social standpoint, it has more job creation potential considering the new capacity needed. We however anticipate that the implementation of the new scenario may be affected by delays due to the unavailability of funds or potential renewable energy investors willing to play a role in transforming The Gambia's energy sector. Possible shortcomings from our findings could stem from our assumption of the demand growth rate which could be less or higher than the actual. We have also assumed the associated technology costs to remain constant throughout the model period which is unlikely especially given the unstable nature of oil prices and the declining rate of costs associated with renewable energy technologies. Further research will therefore be required on energy demand projection and financing mechanisms for the Gambia's sustainable energy transition.

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